Indonesian Journal of Educational Development (IJED)
Volume 7, Issue 1, 2026, pp. 30-48
ISSN: 2722-1059 (Online); ISSN: 2722-3671 (Print)
DOI: https://doi.org/10.59672/ijed.v7i1.5955

# Development of multimedia based on augmented reality to improve students' critical thinking skills

**Predian Yudha Prasetya[1], Sukarmin[*)2]**
[1]Universitas Negeri Surabaya, Surabaya, Indonesia; predianyudha.22003@mhs.unesa.ac.id
[2]Universitas Negeri Surabaya, Surabaya, Indonesia; sukarmin@unesa.ac.id
[*)]Corresponding author: Sukarmin; E-mail addresses: sukarmin@unesa.ac.id

**Article Info**

**Article history:**
Received December 22, 2025
Revised February 03, 2026
Accepted March 06, 2026
Available online May 20, 2026

**Keywords:** Augmented reality, Critical thinking, Multimedia, Reaction rate



**Abstract.** Limitations in students' critical thinking skills make it difficult to understand abstract concepts in the chemistry topic of reaction rates, even though critical thinking skills are essential in the twenty-first century. This study aims to develop an Augmented Reality (AR)-based Multimedia that is feasible to use to enhance students' critical thinking skills in the context of the reaction rate topic. Employing a Research & Development (R&D) approach based on the 4D model, the study involved 34 purposively selected twelfth-grade students from State Senior High School 1 Driyorejo. This study used questionnaires, observations, and tests, including validation sheets, student response questionnaires, pre-tests and post-tests, and observation sheets. AR multimedia obtained a mode of 5 in content validity, and construct validity is considered valid. Practicality was confirmed through a student response questionnaire, which scored 91.4%, categorised as practical, and supported by a 99.4% observation score of student activities. Effectiveness was demonstrated by a significant improvement in critical thinking skills, with an overall N-gain score of 0.73 (in the high category) and a Paired Sample T-test p-value of 0.001. Consequently, the developed AR-based multimedia is considered feasible, and teachers are recommended to use it, as it is practical and effective for improving students' critical thinking skills.

## Introduction

Critical thinking is an important skill for every individual to have in order to meet the challenges of the twenty-first century. There are six types of skills in the twenty-first century called 6C, and critical thinking is one of them. The current curriculum, namely the independent curriculum, aims to improve learning, one of which is through critical thinking learning activities (Kemdikbud, 2022). In facing various challenges in the twenty-first century, according to A. Y. Mulyani (2022). It is important for teachers to teach students critical thinking skills at school. Critical thinking skills are useful when students receive lesson material, as they will have a deeper understanding of it (Widana et al., 2024).

Facione & Gittens (2016) states that critical thinking is the process of evaluating something based on evidence, concepts, and context. The six components of critical thinking abilities are as follows: (1) interpretation; (2) analysis; (3) evaluation; (4) inference; (5) explanation; and (6) self-regulation (Facione & Gittens, 2016; Evi Yupani & Widana, 2023). Critical thinking skills can stimulate students' thinking, help them acquire knowledge, and apply that knowledge in the learning process.

This usefulness makes critical thinking skills essential for work life and effective in all other aspects of life.

Likewise, good chemistry learning can also develop students' critical thinking skills, which are essential. Despite the importance of this talent, students' critical thinking skills are still lacking in the real world, especially in the area of reaction rates. This is evidenced by research conducted by Ramadhanti & Agustini (2021) at a high school in Sidoarjo Regency, which shows that the average pretest results for the interpretation indicator were 50.8%, inference 46.1%, analysis 48.2%, and explanation 35.2%. Accordingly, research at a Surabaya high school by Karima et al. (2025) revealed that the average percentage of pretest results for critical thinking abilities on the subject of reaction rates tended to be poor, namely interpretation at 82.21%, analysis at 12.99%, evaluation at 3.85%, inference at 9.13%, and explanation at 9.61%. The findings of this study show that students with low critical thinking skills struggle to identify difficulties because they cannot understand, evaluate, and extrapolate data.

The six aspects or activities in critical thinking skills are often found in the topic of reaction rates, so reaction rates can be used as a vehicle or content to train these skills. Chemical reaction rates are taught in eleventh-grade high school, but many students still do not understand them well. Based on preliminary research conducted at SMAN 1 Driyorejo, 78.6% of respondents also agreed that reaction rate is one of the hardest concepts in chemistry to understand. Most students believe that the difficulty in learning about reaction rates stems from their abstract nature. The results of teacher interviews also revealed that this difficulty arose because students considered the material on reaction rates abstract, and they found it difficult to visualise microscopic particles, factors that influence reaction rates, collision theory, and activation energy. One of the chemistry topics with a lot of complex ideas is reaction rate, particularly when it comes to collision theory and the variables that influence reaction rate (Nisa & Sudrajat, 2023). This happened because the learning media used relied only on conventional media. 85.7% of students said that learning only through blackboard media meant they could not visualise abstract concepts in chemistry. Learning media is a component in the form of tools, methods, and strategies used in the learning process to support effective learning (Hasanah Lubis et al., 2023). The reaction rate has three levels of representation (Safitri et al., 2022). Johnstone (1982) divides chemical knowledge into three domains, namely macroscopic, submicroscopic, and symbolic, and emphasises that understanding chemical concepts requires the formation of internal relationships between these three levels of representation. This triplet framework is widely regarded as a key manifestation of conceptual understanding in chemistry (Yaman, 2020).

Previous research by Sudiyono & Sukarmin (2024) showed that learning media that can connect the three levels of representation can improve understanding of chemical reaction rates, as well as improve critical thinking (Musyadi et al., 2025; Retnaningtiyas et al., 2021). The application of AR media in chemistry learning enhances understanding of abstract concepts. AR can also visualise abstract concepts in chemistry, making them more real and improving students' critical thinking skills. Macariu et al. (2020) stated that AR applications that attract more students' attention in class support learning in class. Previous research by Octaviani et al. (2022) also showed that AR multimedia for reaction rate learning has good potential as a chemistry learning media. However, their research only examined concentration and catalyst factors that influence reaction rate.

The results of this finding clearly show a significant gap between the expected learning conditions and the actual classroom situation. Students should be expected to understand the concept of chemical reaction rates well and have good critical thinking skills, but the data shows that many of the students have difficulty understanding the abstract concept of reaction rates and cannot interpret, analyse, evaluate, infer, and explain the relationship between multiple representations in the topic of chemical reaction rates. This gap emphasises the urgent need for practical, accessible learning media that bridge the gap between abstract chemical concepts and students' critical thinking skills.

To overcome this problem, it is important to link these three levels of representation in learning chemistry, especially in the topic of reaction rate, with learning media, because they can be used as a way to help students relate what they already know to what they are learning with the help of their teachers (Ramadani et al., 2020). Augmented Reality (AR) that can link the three levels of chemical representation. AR allows the three chemical representations to be displayed virtually to students. Supriadi et al. (2023) mention that AR is useful for connecting the three levels of representation by simulating a substance's submicroscopic level. Augmented Reality (AR) is one kind of multimedia. Multimedia is defined as a combination of more than one type of media used to convey information contained in digital form (Wulandari et al., 2022).

With AR multimedia to visualise the three levels of chemical representation, students are encouraged to observe during the learning process (Dermawan et al., 2025; Agustian et al., 2025). S. D. Mulyani & Rudibyani (2018) explain that students are trained to connect representations from one form to another, which then trains students' ability to analyse, compare, and evaluate information, which is the core of critical thinking. It can be concluded that connecting chemical representations is also related to critical thinking skills. These three levels of representation are related to constructivist theory. Piaget's constructivist learning theory explains that knowledge cannot simply be transferred from teacher to student (Slavin, 2014). Learning is the process of constructing knowledge by abstracting experiences resulting from interactions between students and reality, whether personal, natural, or social (Wahab et al., 2021). Through activities that connect these three levels of representation and align them with the six critical thinking activities, students can construct their knowledge. Learning media that can visualise the three chemical representations is an effective solution to overcome the abstract nature of the reaction rate topic, while also improving critical thinking skills (Sudiyono & Sukarmin, 2024). So there is a close relationship between the three chemical representations and critical thinking. Activities that connect the third-level representations are also related to the six activities in critical thinking, so if AR-based multimedia is developed with activities that train critical thinking, its use can improve critical thinking skills.

With the current development of digital technology, software such as Unity, 3D Blender, and Canva can be used to develop AR-based learning media. Android smartphones can be used to run AR technology, and Android can support teachers' learning processes. Android-based media is now often developed for learning purposes. Macariu et al. (2020) stated that AR attracts more attention and reduces student stress in the classroom. AR presents multiple media, such as images, 3D objects, text, video, and sound, thus making it multimedia. This aligns with dual coding theory, which states that information encoded in both verbal and visual formats is more easily remembered than information stored in a single format (Slavin, 2014).

Based on this background, AR-based multimedia is needed that can display and connect three representations to improve critical thinking skills and facilitate chemistry learning, especially on the topic of reaction rates. The novelty of this research is the AR-based multimedia featuring a 3D model of the reaction rate lab experiment, in contrast to Sudiyono, who produced multimedia based on animation. Then, the four factors that influence the reaction rate are discussed: concentration, temperature, surface area, and catalyst. Then, this multimedia is packaged as an Android package kit (APK) and installed directly on an Android device. The APK is called Kinetic AR and can be used offline, making it more practical for students. In contrast to Octaviani, who developed only two factors, namely concentration and catalyst, and is based on Assemblr Edu, which must be run online.

Based on the background and literature review, the problem formulated in this study is: How feasible is AR-based multimedia for improving critical thinking skills on the topic of reaction rates? Multimedia feasibility criteria include validity, practicality, and effectiveness. The validity of the product as assessed by experts, the practicality of its use as perceived by students, and the effectiveness of the media in improving students' critical thinking skills. More specifically, this study investigates whether the use of AR-based multimedia can significantly improve students' critical thinking skills, which are essential in the twenty-first century. Thus, the objectives of this study are (1) to determine the validity of the AR-based multimedia developed, (2) to test its practicality in classroom learning, and (3) to evaluate its effectiveness in improving students' critical thinking skills. The hypothesis in this study is that the use of AR-based multimedia is feasible in terms of validity, practicality, and effectiveness to significantly improve students' critical thinking skills on the topic of reaction rates. It is anticipated that the findings of this study will help educators in their instruction and function as a guide for engaging educational materials that might enhance students' critical thinking abilities in chemistry classes on reaction rates.

## Method

### *Research Method and Design*

The 4D development model created by Thiagarajan et al. (1974) is used in this study in conjunction with the Research and Development (R&D) approach.

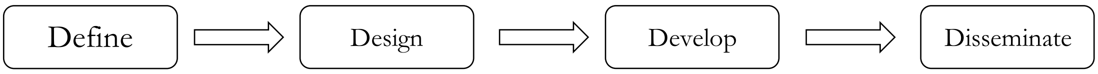


**Image 1.** 4D model development

The 4D Research and Development begins with the Define stage. (1) This Define stage is used to identify and define needs during the learning process. Researchers gather initial information on topics relevant to multimedia research and development. The stage of defining the parts consists of five activities, namely front-end analysis, student analysis, task analysis, concept analysis, and specification of learning objectives (Waruwu, 2024). (2) Once several problems and alternative solutions have been identified in the Define stage, the next stage is the Design stage, which aims to design the AR-based multimedia to be developed. The design phase will produce an initial AR-based multimedia design, which will then be developed into an APK. The design phase consists of four stages: criterion-test construction, media selection, format selection, and initial design (Waruwu, 2024). (3) Next comes the development stage, which produces AR-based multimedia that has been revised based on expert input and suggestions. Limited trials can then be conducted with students (Waruwu, 2024). This research is limited to the development stage, and only limited trials are carried out, because at this stage, it can only address the specified problem formulation.

### *Research Setting and Timeline*

The define and design stages were carried out at Surabaya State University in the first semester of the 2025/2026 academic year. Limited trials were conducted at Driyorejo Gresik State High School 1 on November 17 and 19, 2025.

### *Participants and Sampling Technique*

This study was conducted on 34 grade XII MIPA students enrolled in the science program at SMA Negeri 1 Driyorejo Gresik. The selection of participants was done purposively, with the criteria that they have received previous learning on the topic of chemical reaction rates, so that they are suitable to test the products developed.

### *Data Collection Techniques and Research Instruments*

This study used questionnaires, observation, and testing methods. (1) The questionnaire methods included: (a) a review questionnaire, completed by a chemistry lecturer, to collect review data on the product. This method used a review questionnaire sheet as an instrument; (b) a validation questionnaire, completed by a construct validity and content validity data. This method used a construct validation and content validation sheet as an instrument; (c) a student response questionnaire, derived from student assessments of the product. This method used a student response questionnaire sheet as an instrument. (2) Furthermore, the observation method, completed by observers during AR-based multimedia learning, used a student activity observation sheet as an instrument. (3) Finally, the testing method used in the limited trial provided quantitative data, namely scores on improvements in students' critical thinking skills before and after using the product. This method used pretest and posttest sheets, consisting of essay questions to measure improvements in critical thinking skills of the topic of reaction rates. A limited trial was conducted using a One-Group Pretest-Posttest design to determine changes in students' critical thinking skills. Differences in pretest and posttest scores were then compared and considered as the effects of the treatment (Sugiyono, 2019). The treatment used AR-based multimedia learning.

**Table 1.** One group Pretest-Posttest design

| Pretest | Treatment | Posttest |
|---|---|---|
| $O_1$ | X | $O_2$ |

**Table 2.** Instrument of Research

| Instrument | Purpose | Indicators | Scale |
|---|---|---|---|
| Validation sheet | To assess the AR-based multimedia's content and construct validity | truth and suitability of the media | Likert 1–5 |
| Student response questionnaire sheet | To understand the practicality and ease of using AR-based multimedia | Media ease of use and usefulness | Guttman (Yes/No) |
| Observation sheet | To evaluate student activities in supporting practical data. | Media ease of use and usefulness | Guttman (Yes/No) |
| Pre-test & Post-test | To find out the improvement in critical thinking skills and learning outcomes | (1) interpretation; (2) analysis; (3) evaluation; (4) inference; (5) explanation | Score 0–100 |

### *Instrument Validity and Reliability Tests*

There is data on the validity, practicality, and effectiveness of the product as a feasibility criterion (Plomp & Nieveen, 2007). The information gathered during the evaluation came in the form of remarks, critiques, or recommendations for enhancements to the product under development. Afterwards, quantitative descriptive methods were used to assess the data's validity. The product's validity was assessed using the findings. A Likert scale was used to assign scores, and a product was deemed valid if its mode score was at least 4, indicating "Good". Expert judgment verified the instruments' validity, and Cronbach's Alpha was used to assess their reliability; coefficients of 0.70 or greater were deemed reliable (Akpoghol et al., 2025).

**Table 3.** Likert Scale Score

| Score | Criteria |
|---|---|
| 5 | Very good |

| Score | Criteria |
|---|---|
| 4 | Good |
| 3 | Good enough |
| 2 | Less good |
| 1 | Not good |

Student response data were used to assess students' reactions to the product and, supported by observer observations, to determine the product's practicality. Both types of data were analysed using descriptive quantitative methods. Scores were given based on the Guttman scale and analysed using percentages.

**Table 4.** Guttman Scale Score

| Respons | Answer | Score |
|---|---|---|
| Negative | Yes | 0 |
| | No | 1 |
| Positive | Yes | 1 |
| | No | 0 |

$$\text{Practicality Percentage} = \frac{\text{total score for each statement}}{\text{number of respondents}} \times 100\%$$

Based on student responses and observations, a product is deemed practical if it receives a percentage> 61% in the "Good" category.

**Table 5.** Practicality Criteria Percentage

| Percentage (%) | Criteria |
|---|---|
| 81-100 | Very good |
| 61-80 | Good |
| 41-60 | Good enough |
| 21-40 | Less good |
| 0-20 | Not good |

The pretest and posttest results from the critical thinking test were used to assess product efficacy. The results were then evaluated using normalised gain (N-gain), as follows.

$$g = \frac{\text{Spost-Spre}}{\text{Smax-Spre}} \times 100\%$$

Table 5 below provides an interpretation of the N-gain scores (De Cock, 2012; Hake, 1998). If the N-gain score ($< g >$) $\geqslant$ 0.3 with a minimal category of medium-g, then critical thinking abilities have increased (Jannah & Ismaniati, 2019).

**Table 6.** N-gain Scoring Criteria

| N-gain Score | Criteria |
|---|---|
| $(< g >) \geq 0.7$ | High-g |
| $0.7 > (< g >) \geq 0.3$ | Medium-g |
| $(< g >) < 0.3$ | Low-g |

Then, a paired-samples t-test (two-tailed) was used to assess the statistical significance of the boost in students' critical thinking abilities. Decision-making was based on: 1) The pretest and posttest scores differ significantly if the p-value is less than 0.05, 2) p-value > 0.05 indicates that the pretest and posttest results do not differ significantly.

The product is deemed successful if the p-value is less than 0.05, indicating a significant difference between the pretest and posttest results. Normality is a prerequisite that this test must pass. If the significance value (sig > 0.05) is greater than 0.05, the data are considered normally distributed.

### *Product Specifications*

The product developed in this research is AR-based multimedia, consisting of the Kinetic AR APK, which can be accessed offline on Android devices and is equipped with Student Activity Sheets. This multimedia content covers chemical factors that influence reaction rates, namely concentration, temperature, surface area, and catalysts. The learning content is presented as text, audio, images, videos, and 3D models, which will be displayed in real-world space via the Android device's camera (AR). The Augmented Reality feature displays experiments on factors that influence reaction rates while displaying and stating the relationship between three levels of chemical representation, namely macroscopic in the form of real phenomena such as the reaction rate of Mg bands in HCl solution to $MgCl_2$ solution and $H_2$ gas, submicroscopic in the form of particle visualizations, especially particle collision theory, and symbolic in the form of reaction rate equations. It includes several menus: guides, learning objectives, learning content, AR lab experiments, practice questions that students can repeat, and information about the developer profile. AR-based multimedia was developed using Unity, Blender, and Canva. This product aims to improve students' critical thinking skills and conceptual understanding, which are applied in classroom learning.

## Results and Discussion

The goal of this study is to evaluate and test the product's validity and practicality. It employs Research and Development (R&D) with a 4D research model by Thiagarajan et al. (1974). The Research and Development (R&D) approach is utilised to create or validate educational and learning items, claim Borg and Gall in Sugiyono (2019). This study was limited to the limited trial stage because at that stage, it was already possible to answer the specified problem formulation. The results obtained in this study are as follows.

### *Define*

At this definition stage, which aims to determine learning needs, researchers collect preliminary information on the topics covered in multimedia research and development. Researchers obtain facts and alternative solutions that can be used to determine the initial steps in developing teaching materials (Aimmah & Amin, 2025). A literature review analysis by Karima et al. (2025) found that students' critical thinking skills at a high school in Surabaya tend to be low. The average pretest scores for the critical thinking indicators on reaction rate material were low, with interpretation at 82.21%, analysis at 12.99%, evaluation at 3.85%, inference at 9.13%, and explanation at 9.61%. Similarly, research conducted by Ramadhanti & Agustini (2021). A high school in Sidoarjo Regency showed average pretest scores for critical thinking indicators: interpretation at 50.8%, inference at 46.1%, analysis at 48.2%, and explanation at 35.2%. These results demonstrate that students have not yet mastered critical thinking skills in recognising given problems due to their inability to interpret, analyse, and infer the information obtained.

In addition, student analysis was conducted through questionnaires and interviews with teachers. The results showed that 78.6% of students considered chemistry a difficult subject to understand, especially on the topic of reaction rates, because it is abstract and lacks a depiction of the reaction process. In line with this, the results of teacher interviews also indicated that students had difficulty imagining collision theory, activation energy, factors influencing reaction rates, and visualising microscopic particles. Students had difficulty connecting these with real phenomena that occurred. This happened because so far 85.7% of students said that chemistry teachers only used teaching materials in the form of blackboards, and the results of interviews with teachers also confirmed that chemistry teachers often use blackboards and PowerPoint as learning media, so that these learning media cannot visualise the abstract concepts contained in the topic of chemical reaction rates.

Johnstone (1982) divides chemical knowledge into three domains, namely macroscopic, submicroscopic, and symbolic, and emphasises that understanding chemical concepts requires the formation of internal relationships between these three levels of representation. This triplet framework is widely regarded as a key manifestation of conceptual understanding in chemistry (Yaman, 2020). Thus, abstract concepts about chemical reaction rates can be explained by connecting three levels of chemical representation. Connecting these three levels of chemical representation is also closely related to critical thinking. S. D. Mulyani & Rudibyani (2018) explain that students are trained to connect representations from one form to another, which then trains students' ability to analyse, compare, and evaluate information, which is the core of critical thinking. It can be concluded that connecting chemical representations is also related to critical thinking skills. These three levels of representation are related to constructivist theory Piaget's constructivist learning theory explains that knowledge cannot simply be transferred from teacher to student (Slavin, 2014). Learning is the process of constructing knowledge by abstracting experiences resulting from interactions between students and reality, whether personal, natural, or social (Wahab et al., 2021). Through activities that connect these three levels of representation and align them with the six critical thinking activities, students can construct their knowledge.

According to Piaget's theory of cognitive development, high school students between the ages of 15 and 19 have reached the formal operational stage, which is characterised by the capacity for abstract and symbolic thought (Slavin, 2014). Students can use systematic experiments to solve issues and think abstractly and symbolically at the formal operational level (Slavin, 2014). Students can start to think critically at the formal operational level (Suharto et al., 2017). To help connect the three levels of chemical representation in learning, it can be done with learning media, data obtained showed that 96.4% of students need learning materials for chemical materials that can be studied independently. Sudiyono & Sukarmin (2024), in their research, they stated that learning media that connect the three levels of chemical representation is effective in improving critical thinking skills and student learning outcomes. AR-based multimedia can be a solution as a learning media that can display and state the relationship between the three levels of chemical representation. AR-based multimedia can be used independently anytime and anywhere because it runs on the Android operating system and can be carried anywhere by students, by displaying experiments on AR-based multimedia students can learn the material and conduct reaction rate experiments anywhere and anytime, when compared to conventional practicums, AR is superior because there is no need to carry tools and materials everywhere, just bring an Android cellphone that contains AR-based multimedia.

Previous findings by Octaviani et al. (2022) who developed AR multimedia for reaction rate material showed good results, that Augmented Reality learning media is effective for application as a chemistry learning media. However, their research was limited to concentration and catalyst factors that influence reaction rates, and used the Assemblr Edu application base which must be run online. Sudiyono & Sukarmin (2024) developed animation-based learning media that connect the three levels of chemical representation with effective results in improving students' critical thinking skills. What distinguishes the AR-based multimedia developed by researchers is that it will discuss all factors that influence reaction rates, namely concentration, temperature, surface area, and catalysts, in addition to being done in augmented reality, using 3D objects displayed on an Android phone through the camera, so that users seem to see the 3D object directly, namely the chemical reaction rate lab experiment. Developed in APK form so it can run offline on a cellphone, so it does not cost much. AR was chosen because it can display and state the relationship among the three levels of representation in real time and, at the same time, can be realised in the real world, so that students can interact directly. For this reason, AR-based multimedia was developed to help students understand abstract concepts in chemical reaction rates and to train their critical thinking skills simultaneously. At this stage, a concept map and learning objectives using AR-based multimedia were also determined, namely, students are able to: (1) interpret, analyse, evaluate, infer, and provide explanations regarding the influence of factors that influence reaction rates accurately. (2) accurately relate factors that influence reaction rates to collision theory.

### *Design*

After identifying several problems and alternative solutions, including developing AR-based multimedia, in the definition phase, the next step is the design phase, which aims to create a product, namely AR-based multimedia. This AR technology allows students to interact directly with the digital world Macariu et al. (2020). Augmented Reality allows three chemical representations to be displayed virtually to students. This AR-based multimedia was compiled into an Android Package Kit (APK) application installed on mobile phones running Android. The APK was chosen because its features can be customised to suit the developer's needs. Unity was used as the software development engine to build the APK, and the Vuforia engine as the SDK to add AR features to the APK, which was then integrated into Unity. Blender software allows developers to create 3D objects according to their needs, and they can be freely customised. This makes it possible to create 3D objects related to chemistry and reaction rates. With this technology, an AR-based multimedia APK could be developed. The APK is then complemented by a student activity sheet containing problem-based activities designed to enhance critical thinking skills, such as problem formulation, hypothesis development, and data analysis. This stage produces the material to be presented, including 3D objects to be visualised in AR features. A flowchart for the AR-based multimedia developed is also generated.

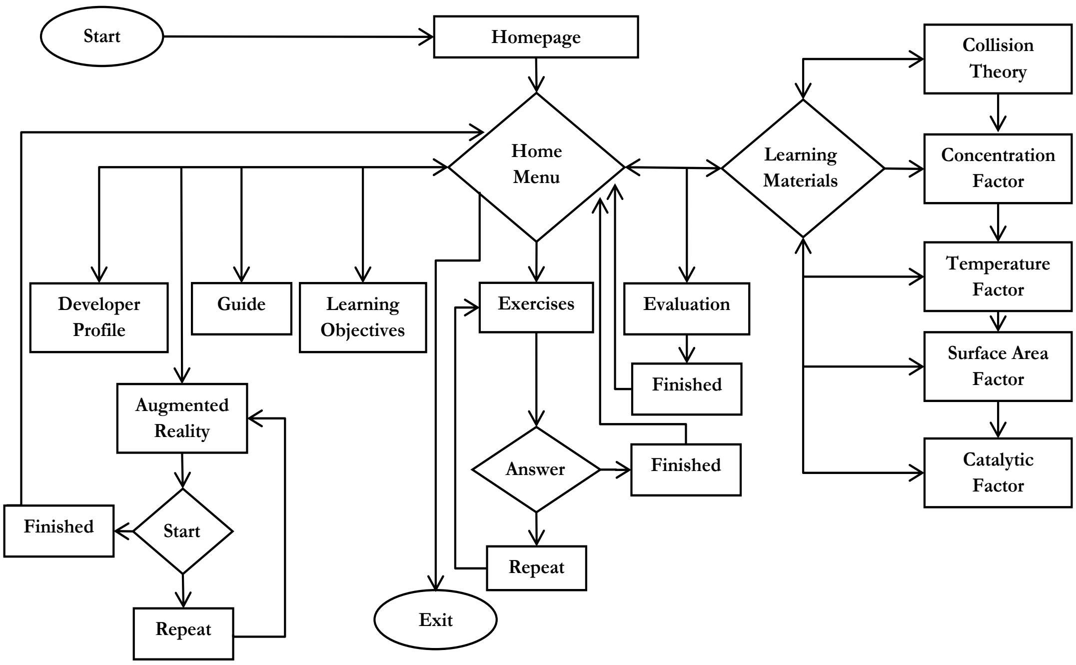


**Image 2.** Flowchart the AR-based multimedia

AR-based multimedia is designed to facilitate user operation. A guide menu provides information on APK usage and the functions of the APK's buttons. A material page covers factors influencing reaction rates in terms of collision theory. A practice page contains questions on reaction rates linked to critical-thinking skill indicators. An AR page also asks users to point their camera at AR markers in the student activity sheet to conduct virtual experiments examining factors influencing reaction rates using the AR feature. The student activity sheet serves as a medium for recording the results of experiments conducted in the Kinetic AR APK. It also includes data analysis activities to train students' critical thinking skills. During this stage, instruments such as validation sheets, pretest-posttest sheets, and student response sheets were developed. These instruments were reviewed and validated by experts, including media specialists and experts in chemistry education. Feedback and recommendations from these validators were then incorporated to refine the instrument, ensuring it aligned with the research objectives.

***Develop***

After the AR-based multimedia design is finalised in the design stage, it proceeds to the development stage. This stage is the process of developing the media design, which has been created and then revised, into an AR-based multimedia product that can be validated and used for limited trials. After the AR-based multimedia product is created in the design stage, expert review and validation are conducted, and criticism and suggestions for improvement are received. The resulting AR-based multimedia product is as follows.


**Image 3.** Kinetic AR APK

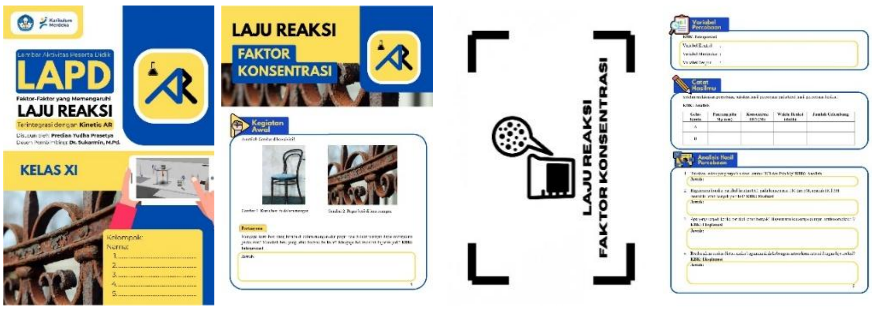


**Image 4.** Student activity sheet reaction rate integrated with Kinetic AR APK

The feasibility of the AR-based multimedia developed is reviewed from three aspects, namely validity, practicality, and effectiveness, according to Plomp & Nieveen (2007). Validation activities are carried out to ensure content and construct validity. The developed device must be based on current knowledge, meaning there is truth in the material and in aspects of critical thinking skills (content validity), and all components must be consistently connected to one another, meaning the presentation of appropriate media and language (construct validity) (Plomp & Nieveen, 2007). To assess the validity of this AR-based multimedia, it was carried out by three experts, namely (1) an expert in learning media, (2) an expert in chemistry education, and (3) a teacher who teaches in high school. This validation includes three main criteria, namely: (1) The truth of the learning material, (2) The suitability of AR-based multimedia to improve critical thinking skills, and (3) Clarity of language and media layout. Based on the validation results, it was obtained that AR-based multimedia as a whole obtained a mode of 5 in the aspect of content validity and construct validity interpreted with a Likert scale according to Riduwan (2015) obtained the criteria of "Very good", so it can be concluded that this AR-based multimedia is valid in content and construct as a learning media to improve critical thinking skills. The validity results are shown in Image 5 and 6 below.

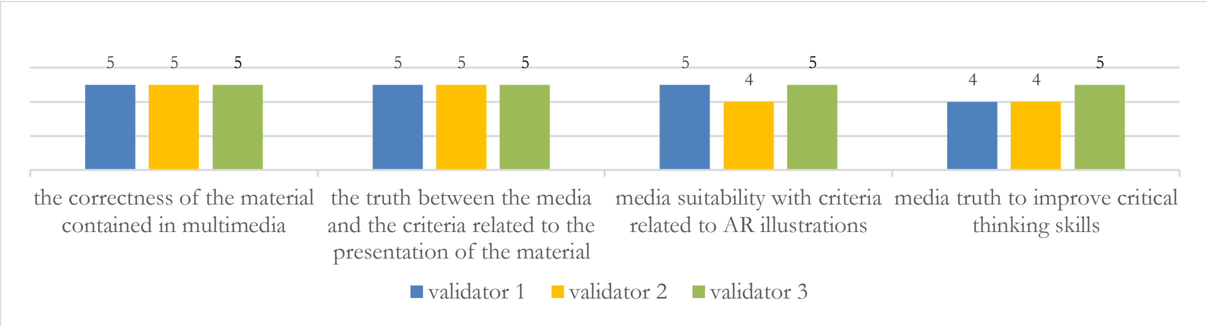


**Image 5.** Content Validity Chart

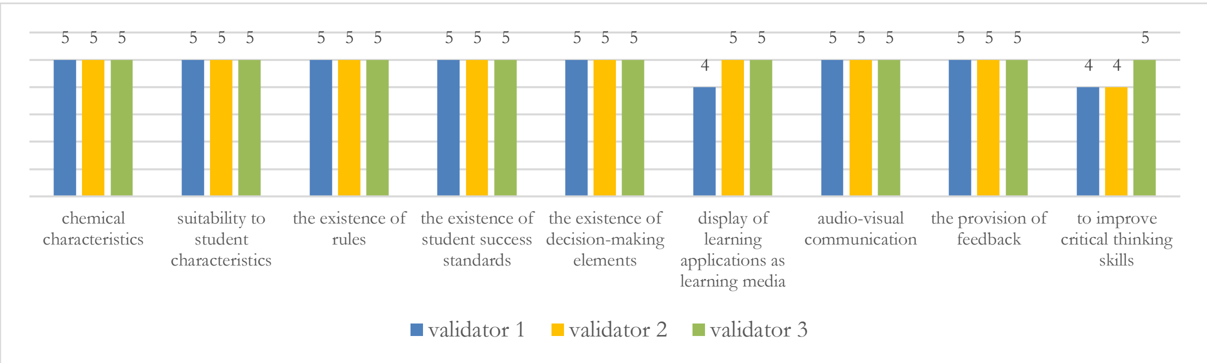


**Image 6.** Construct Validity Chart

Practicality refers to the ease with which students can use AR-based multimedia in accordance with the design and materials selected, covering aspects such as ease of operation, the availability of necessary resources (e.g., hardware and software for multimedia), and the time and cost required to use the product. A practical product is one that can be applied smoothly in the field without significant obstacles, thereby supporting the learning process effectively (Plomp & Nieveen, 2007). This practicality comprises two main criteria: ease of use and usefulness in improving critical thinking skills and learning outcomes. The findings of the student response questionnaire and the student activity observation sheet are used to assess the practicality of AR-based multimedia. Based on the analysis of the questionnaire results, the overall practicality percentage was 91.4%, supported by a student observation result percentage of 99.4%, with a "very good criterion, thus stating that this AR multimedia is practical to use, in line with the opinion (Riduwan, 2015) which states that a developed product is practical if it achieves a practicality percentage of ⩾ 61% and is categorised as good to very good. The practicality results are described in the practicality graphs in Images 7 and 8 below.

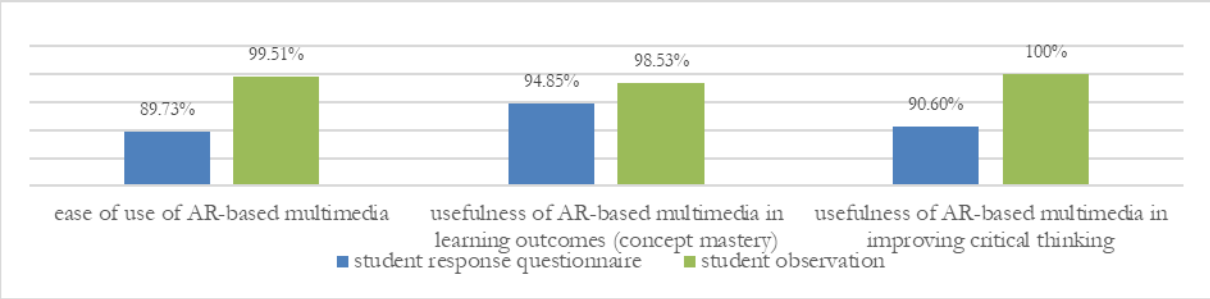


**Image 7.** Practicality chart

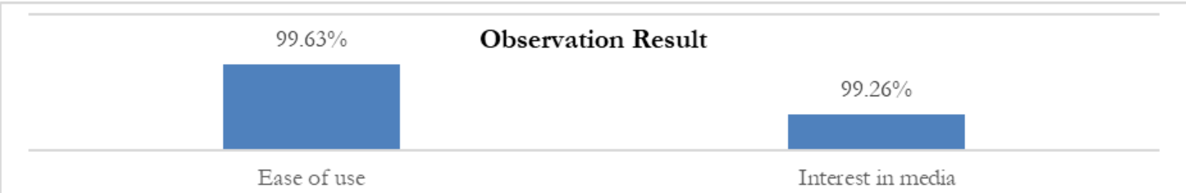


**Image 8.** Observation Result

These results show that students find it easy to operate the AR-based multimedia developed, including smooth operation, no need for specific tools, quick access, reasonable pricing, high mobility, and simple management. The student finds it helpful for understanding chemical concepts and improving learning outcomes, and their critical thinking skills also improve because the multimedia content includes activities that train them. This is in line with the findings of Bimanyu & Sukarmin (2024). The multimedia running on the Android system (APK) that connects these three chemical representations is practical for use as a learning medium, supports the understanding of chemical concepts, and improves students' critical thinking skills. Observations also showed that students were interested in AR-based multimedia, allowing them to focus on the learning process. This is consistent with Macariu et al. (2020) statement that AR, which attracts more student attention in class, supports traditional teaching methods.

Effectiveness relates to the benefits and contributions of a product to the actual achievement of learning objectives (Plomp & Nieveen, 2007). Effectiveness is measured by how well a learning product can achieve its objectives, particularly in improving students' critical thinking skills. Effectiveness data were obtained from pretest and posttest results conducted on 34 twelfth-grade students at SMAN 1 Driyorejo Gresik.

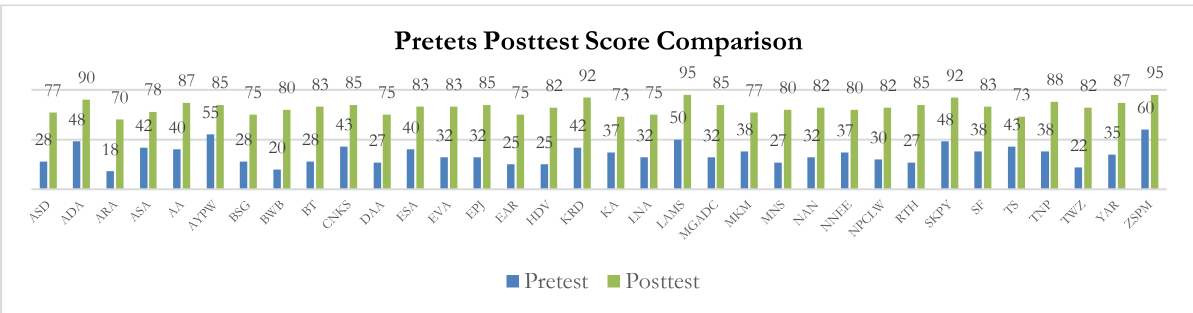


**Image 9.** Pretest and Posttest Score Result

For tests measuring critical thinking skills, the average pretest score was 35.26, and after learning with AR-based multimedia was implemented, the average posttest score was 82.32. An analysis using N-gain yielded a score of 0.73 in the "high-g" category, with a breakdown of the students' N-gain scores in the following diagram.

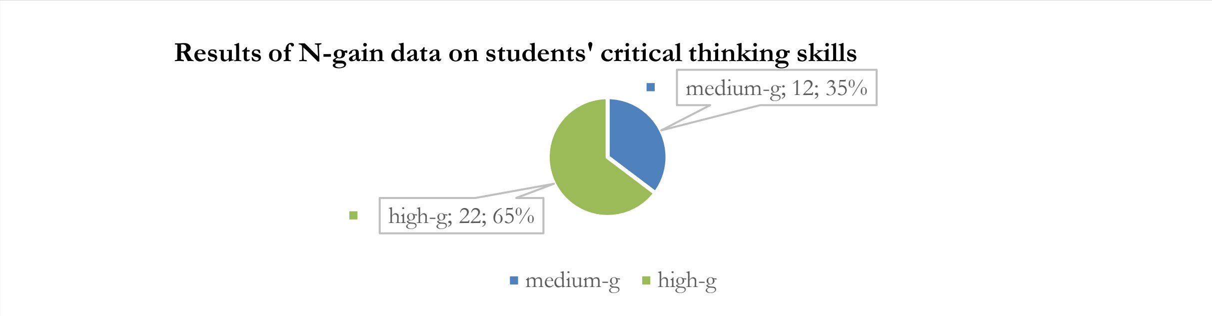


**Image 10.** Results of N-gain data on students' critical thinking skills chart

Sixty-five per cent of students were classified as high-g, and 35 per cent as medium-g. This shows that 100% of students experienced an increase in critical thinking skills after learning using AR-based multimedia, with N-gain scores ranging from 0.53 to 0.90. When the N-gain score is > 0.3 with a minimum category of medium-g, critical thinking abilities are improved (Jannah & Ismaniati, 2019). The critical thinking skill indicators were used to analyse students' pre- and post-test data, and the results were compared, as shown in Table 7.

**Table 7.** N-Gain on each indicator of critical thinking

| Critical thinking indicators | Pretest score | Posttest score | N-gain score | Criteria |
|---|---|---|---|---|
| Interpretation | 44.36 | 84.56 | 0.72 | High-g |
| Analysis | 30.39 | 81.62 | 0.74 | High-g |
| Evaluation | 37.50 | 81.37 | 0.70 | High-g |
| Inference | 33.58 | 83.58 | 0.75 | High-g |
| Explanation | 30.39 | 80.39 | 0.72 | High-g |

All trained critical thinking skill indicators received a High-g category, so all critical thinking indicators experienced an increase in the high category. Facione & Gittens (2016) explain that each critical thinking ability indicator comprises several sub-skills. The discussion of each critical thinking ability indicator is as follows. These results show that using AR-based multimedia during learning can improve students' critical thinking skills, such as the ability to interpret, analyse, evaluate, infer, and explain. (1) The first is the interpretation indicator, which is the ability to understand and express meaning. Students' critical thinking skills in the interpretation can increase from an average pretest score of 44.36 to an average posttest score of 84.56 with an N-Gain score of 0.72 in the high-g category. Thus, AR-based multimedia is effective in improving students' ability to categorise, analyse, and clarify meaning, all of which are sub-skills of the interpretation indicator (Facione & Gittens, 2016). (2) Next is the second critical thinking indicator, namely analysis, which is the ability to identify inferential relationships between statements to express judgments. Students' critical thinking skills in the analysis indicator can increase from 30.39 to 81.62 with an N-Gain score of 0.74 in the high-g category. Thus, AR-based multimedia is effective in improving students' ability to test ideas, identify arguments, and analyse arguments, all of which are sub-skills of the analysis indicator (Facione & Gittens, 2016). (3) The third critical thinking indicator is evaluation, which is the ability to assess the credibility of statements or other representations. Students' critical thinking skills on the evaluation indicator can increase from 37.5 to 81.37 with an N-Gain score of 0.7 in the high-g category. Thus, AR-based multimedia is effective in improving students' ability to assess the credibility of claims and evaluate arguments, both of which are included in the evaluation indicator sub-skills (Facione & Gittens, 2016). (4) Next is the fourth indicator, inference, which is the ability to identify and obtain the elements needed to draw conclusions. Students' critical thinking skills in the inference indicator can increase from 33.58 to 83.58 with an N-Gain score of 0.75 in the high-g category. Thus, AR-based multimedia is effective in improving students' abilities to ask questions, generate alternatives, and write conclusions, all of which are sub-skills of the inference indicator (Facione & Gittens, 2016). (5) The fifth critical thinking indicator is explanation, which is the ability to state and justify reasoning based on evidence, and present it in the form of convincing arguments. Students' critical thinking skills in the explanation indicator can increase from 30.39 to 80.39 with an N-Gain score of 0.72 in the high-g category. Thus, AR-based multimedia is effective in improving students' ability to state results, clarify methods, and convey arguments, all of which are sub-skills of the explanation indicator (Facione & Gittens, 2016).

Critical thinking skills are also defined as mental activities, one of which involves perception, which is then used as a guide for the reasoning process (Widana, 2022). The AR-based multimedia displays experiments on factors that affect the reaction rate as a macroscopic representation. For example, in the concentration factor, there is an experiment comparing HCl solutions and Mg strips, in which two HCl solutions with concentrations of 3 M and 1 M are used as manipulation variables, and both are reacted with Mg strips of the same length. Students can start the experiment on the AR page and observe the reaction process. For the submicroscopic representation, illustrations of collisions that occur in each reaction are provided, and, symbolically, reaction equations for HCl with Mg strips are shown. Students are expected to be able to connect the processes across these multiple representations. This process trains students to analyse, compare, and evaluate information, which is an important part of critical thinking. In addition, chemical representations will gradually build students' mental models. Students' critical thinking abilities can be enhanced by teaching them to make connections between the three levels of representation. This is consistent with constructivist theory, which posits that learning is a cognitive process rather than a simple transfer of knowledge from teacher to students. Learning is a process of constructing knowledge by abstracting experiences as a result of interactions between students and reality, whether personal, natural, or social (Wahab et al., 2021). This finding is in accordance with the literature study research by Musyadi et al. (2025) that the application of AR media in chemistry learning can provide a significant contribution to a better understanding of abstract concepts, AR can also visualise abstract concepts in chemistry to be more real during the learning process, and this is in accordance with the literature study research by Retnaningtiyas et al. (2021) where AR significantly influences students' critical thinking skills.

To assess the importance of the increase in students' critical thinking abilities, the improvement was also statistically evaluated using a paired-samples t-test (two-tailed) in Jamovi. To determine whether the data were normally distributed, a necessary test called a normality test was performed first. Since a significance value (p-value) of 0.287 was found, the data are normally distributed because the p-value is greater than 0.05. The Paired Sample t-test (two-tailed) is a parametric statistical test that can be used if the data is normally distributed. It was conducted using Jamovi software, and a p-value of 0.01 was obtained. If the p-value is less than 0.05, it can be concluded that the increase in students' critical thinking skills was due to the learning treatment using AR-based multimedia, not just to an accidental increase. This increase also occurred because the AR-based multimedia contains interesting 3D objects, images, videos, and audio, as well as verbal and visual information. This is consistent with dual coding theory, which holds that knowledge stored in one modality is more difficult to recall than information encoded in both verbal and visual modalities (Slavin, 2014). This will provide a learning experience that makes it easier for students to understand the abstract concept of reaction rate in a more concrete and realistic way. The AR-based multimedia is designed to be engaging and accessible at any time, this proven by the results of the practicality percentage of 91.4% so that students can be interested in learning using AR-based multimedia and can be used anytime and anywhere, because sensory reception requires stimuli that capture attention, with the hope that these engaging stimuli are selected and sent to working memory or short-term memory. Then, in short-term memory, stimuli originating from AR-based multimedia will be repeated continuously, where students try to understand new stimuli and connect them with what they already know so that they can enter long-term memory according to Slavin (2014) information processing theory.

The findings of this study align with those of Octaviani et al. (2022) who stated that AR multimedia based on Assemblr Edu is highly valid, excellent, practical, and effective for use as a chemistry learning medium. However, their research only examined the concentration and catalyst factors that influence reaction rates. Ghifari et al. (2025) also found that AR can improve critical thinking skills in the analysis and inference aspects of science students. Sudiyono & Sukarmin (2024) also stated that using learning media that connects three chemical representations can help students develop their critical thinking skills. Macariu et al. (2020) also stated that AR can support classroom learning and engage students' attention. AR-based multimedia can significantly enhance understanding of abstract concepts. However, the novelty of this research compared to previous studies is that the multimedia produced is based on AR, with a 3D model of the reaction rate lab experiment included, in contrast to Sudiyono & Sukarmin (2024) multimedia based on animation. Then, the four factors that influence the reaction rate are discussed: concentration, temperature, surface area, and catalyst. Then, this multimedia is packaged as an Android package kit (APK) and installed directly on an Android device, allowing it to be run offline, making it more practical for students to use. In contrast to Octaviani et al. (2022) who developed only two factors, namely concentration and catalyst, and is based on Assemblr Edu, which must be run online. This shows that AR-based multimedia in this study provides a more practical alternative learning medium. Users can do practicums only on Android devices, which can be done offline anytime and anywhere, with more comprehensive material on factors that influence the reaction rate, while also improving students' critical thinking skills (Widana, 2018).

The findings of this study also have theoretical and practical implications. The theoretical implications include strengthening and expanding the theoretical foundations of learning, particularly dual coding theory, constructivism theory, and information processing theory. The results, which demonstrate improved learning outcomes and critical thinking skills, provide empirical support that the integration of visual, verbal, and symbolic elements in an interactive learning environment aligns with the principles of dual channels and cognitive load management. These findings reinforce the assumption that learning that simultaneously integrates multiple representations can enhance the organisation and integration of information within students' cognitive structures. Furthermore, the interconnectedness of three levels of chemical representation (macroscopic, submicroscopic, and symbolic) in the context of technology-based learning is highlighted. While previously, the relationship between multiple representations was largely discussed in conventional or two-dimensional media, AR offers a new perspective, allowing representations to be presented contextually and interactively. Furthermore, the practical implications include: For students, the use of AR helps them understand abstract concepts more concretely through interactive visualisation and the integration of three chemical representations. This results in increased motivation, active engagement, and ease in relating experimental phenomena to particle models and chemical equations. In practice, students no longer merely memorise concepts but are better able to explain, conclude, and evaluate chemical phenomena logically. For teachers, AR-based multimedia is an alternative, innovative learning medium that can improve the quality of the learning process. Teachers can more easily explain difficult concepts without relying entirely on laboratory experiments, which are sometimes limited by time, equipment, or materials. AR also helps teachers create more varied, interactive, and student-centred learning, thereby making teaching and learning activities more effective and efficient. Meanwhile, for schools, the results of this study provide practical recommendations that integrating AR technology can be a strategy to improve the quality of learning and learning outcomes in a classroom setting. Implementing AR-based media can also support educational digitalisation programs and the development of 21st-century skills such as critical thinking and technological literacy.

However, this study has several limitations. First, it addresses only the research question: to explain the feasibility of the AR-based multimedia in terms of validity, practicality, and effectiveness. Consequently, it is limited to the development and testing phase in a single school on a small scale, limiting the generalizability of the findings to a wider student population. This AR product is limited to the material of factors that influence reaction rates, and it is not yet known whether it can be applied to other chemical materials, so it needs to be tested on other chemical materials or even in other subject areas. In addition, this product is limited to smartphones and tablets running Android, so it needs to be developed for other operating systems, such as iOS. Therefore, further research is recommended to expand the 4D research stage to the dissemination stage and be tested in various schools on a wider scale, covering various other chemical topics, and needs to be developed into various devices, not only Android but also iOS, so that the product can be said to be more practical.

## Conclusion

According to the research, AR-based multimedia can enhance critical thinking skills in reaction-rate content. This result is examined from three feasibility criteria. In particular, AR-based multimedia is considered valid under the "Very Good" criterion for content and construct validity. Based on the student answer questionnaire and the student observation results, AR-based multimedia is deemed practicable. The enhancement of critical thinking abilities is the basis for the effectiveness of AR-based multimedia, with a high-g N-gain category, and the Paired Sample T-test results indicate a significant difference in the use of AR-based Multimedia in improving students' critical thinking skills. The usage of AR-based multimedia has a substantial impact on students' development of critical thinking skills. Based on these findings, AR-based multimedia can be considered an effective alternative as a learning medium in chemistry, as integrating digital media in the form of AR in the classroom can increase student motivation, reduce learning difficulties, and improve learning efficiency. Teachers are recommended to adopt AR-based media in other chemistry topics to teach deeper conceptual understanding and critical thinking skills. Future research should be conducted for other operating systems, such as iOS, and the media should be tested on other topics and subjects.

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