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Design and Validation of Augmented Reality–Based Assessment to Measure Students' Multiple Representation Ability

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ABSTRACT

This study aims to develop and validate a test assessment design assisted by Augmented Reality to measure students' multiple representation abilities. The development model used in this research is the 4D Model (Define, Design, Develop, and Disseminate). The research subjects were students of the Chemistry Education Study Program in the 2024/2025 academic year. The trial subjects consisted of 18 students. Product validation was carried out by three chemistry education experts. The data collection technique used was a questionnaire. The research instruments consisted of an expert validation questionnaire and a student response questionnaire. The data analysis technique employed a quantitative approach with predetermined criteria. The results showed that Validator 1 provided a score of 87.96%, Validator 2 92.59%, and Validator 3 84.26%. The results of the study show that the validation of the developed product obtained an average percentage of 88.27%, categorized as very valid. The small-scale trial gained an average percentage of 94.99%, classified as very practical. The medium-scale trial obtained an average percentage of 91.71%, also categorized as very practical. These findings indicate that the AR-assisted MBKM assessment for measuring students' multiple representation skills is highly practical to use.

INTRODUCTION

The development of the curriculum in Indonesia continues to evolve over time, aiming to improve the quality of the learning process. The MBKM (*Merdeka Belajar Kampus Merdeka*) program is designed to produce high-quality human resources, enabling both lecturers and students to broaden their knowledge, expand professional networks, and strengthen character values that have begun to fade in recent times. (Rahmadia et al., 2022; Rodiyah, 2021). In addition, the MBKM program aims to prepare graduates who are more ready to face ongoing changes, particularly the rapid development of technology. The key to successful implementation of MBKM lies in achieving learning outcomes that are flexible and adaptive. Furthermore, the implementation of MBKM itself requires collaboration with relevant partners in the respective fields of study to achieve the intended learning objectives. Through MBKM, it is expected that issues related to the quality of education in Indonesia can be effectively addressed(Maghfiroh & Sholeh, 2022; Mudrikah et al., 2022; Rodiyah, 2021).

The Chemistry Education Study Program has made continuous efforts to optimize the existing curriculum so that graduates are not left behind by technological advancements. The rapid development of technology has also prompted the program to include technology-based courses, enabling students to compete with those from similar programs at other universities after graduation. Therefore, the study program has taken steps to update the curriculum by replacing several courses deemed no longer relevant to current technological developments. Within the MBKM curriculum of the Chemistry Education Study Program, there are already technology-oriented courses such as Computer Applications in Chemistry, Utilization of Artificial Intelligence (AI) in Research, and Digital Classroom Management. Based on interviews with lecturers teaching the Computer Applications in Chemistry course, several topics covered include the use of chemistry software such as ChemDraw and Avogadro. One of the main functions of these applications is to create three-dimensional molecular structures, which support students in visualizing and understanding chemical concepts more effectively.

In addition to technology-based courses, the study program has also implemented the MBKM Program through collaboration with external partners, one of which is SEAMOLEC. As part of this partnership, students participated in a three-day online training program focused on designing Augmented Reality (AR)-based learning materials. This AR media development training enhanced students' technological skills through the use of various applications such as 3D Paint, Sketchfab, Spark AR, and Canva. Based on the results of the training, it was found that students had developed an understanding of how to create molecular structures in three-dimensional form. This reflects the submicroscopic level of chemical multiple representations. Incorporating multiple representations in chemistry learning is essential, as it plays a crucial role in both chemical reasoning and practice. Through chemical representations, students are able to connect macroscopic phenomena with chemical models, thereby facilitating a deeper understanding of the chemical properties of substances in their environment (Robert A, 2020). The ability to use multiple representations is essential in problem-solving, particularly in chemistry learning. Multiple representation-based learning aims to help students solve problems by utilizing various forms of representation, such as macroscopic, submicroscopic, and symbolic levels, to develop a deeper and more comprehensive understanding of chemical concepts (Huda et al., 2016). Learning that incorporates multiple representations enables students to understand the cognitive, motivational, and socio-emotional processes required by learners across different educational levels. Through this approach, students not only grasp chemical concepts more effectively but also develop the necessary skills to support diverse learning needs in various educational contexts (Van Meter et al., 2020). Another objective of multiple representation learning is to facilitate students' understanding of abstract chemical concepts. Through the integration of various representations—such as macroscopic observations, submicroscopic models, and symbolic expressions—students can visualize and relate complex chemical phenomena, making abstract ideas more concrete and comprehensible (Ningrum, 2021).

The importance of multiple representation learning has not yet been fully implemented in the learning process. Based on interviews with students, it was revealed that multiple representation-based learning is still rarely practiced. In chemistry content courses, teaching and learning activities are still largely focused on the macroscopic and symbolic levels. Documentation studies also indicate that most of the exercises and exam questions given to students remain at the macroscopic and symbolic levels, with limited emphasis on submicroscopic representations.

The learning process involving multiple representations is not an easy task for most people. This approach naturally presents various challenges, both for students and for teachers. Students may struggle to connect and translate information across different representation levels, while teachers must design and implement effective instructional strategies to help learners build these connections meaningfully (Cromley, 2020; Robert A, 2020). Each representation contains unique information that must be interconnected with other representations, especially when drawing conclusions. However, skills related to multiple representations are rarely taught in classrooms, even though they are often assessed. Based on this condition, it is necessary to conduct research on the design of an MBKM-based assessment supported by Augmented Reality to measure students' multiple representation abilities. The purpose of this research is to help students develop a strong understanding of multiple representations so that, after graduating from the study program, they can effectively teach these skills to high school students. Emphasizing multiple representation assessment is a crucial component of instruction. In learning, it is important to first present concrete representations before moving to abstract ones, as this approach enhances the effectiveness of teaching multiple representations. (Lin et al., 2016).

Several previous studies, including one conducted by (Nakhleh & Postek, 2008) demonstrated that the use of the Synchronized Multiple Visualization of Chemistry (SMV Chem) module provided students with numerous opportunities to explore the macroscopic, microscopic, symbolic, and mathematical levels in developing their understanding of chemistry, particularly on the topic of limiting reactions using the reaction between vinegar and baking soda as the study material. The findings revealed that the module was effective in helping students build a deeper understanding through four levels of representation: real-time video of chemical reactions (macroscopic level), computer animations of reactions (microscopic level), graphical representations (symbolic level), and textual representations of problems using mathematical concepts related to limiting reactions.

Another study conducted by (Rau, 2020) found that learning involving multiple representations using different symbols such as text and visuals can help students learn more effectively by providing complementary information about complex concepts. However, multiple representations may also hinder learning if students are unable to understand each level—macroscopic, submicroscopic, and symbolic. The study suggested that students need to develop both verbal comprehension and nonverbal perception skills across different representations. Research has shown that teaching through multiple representations can significantly enhance students' understanding of these representations, and one of the most well-known models of multiple representation learning in chemistry is the chemical triplet proposed by Johnstone (Lin et al., 2016). Augmented Reality enhances motivation, engagement, and understanding of molecular structures and can serve as a foundation for using AR as a modern chemistry learning (Handoyo et al., 2024) Students using AR-based resources demonstrated higher engagement and comprehension compared to those using traditional material (Arymbekov & Turekhanova, 2025). Earlier studies only demonstrated Augmented Reality as an instructional medium for illustrating submicroscopic representations. Traditional assessments often fail to capture students' spatial abilities in understanding molecular structures in real-time, whereas Augmented Reality (AR) enables a more authentic evaluation of the practical competencies required by the MBKM program. Based on several previous studies, assessments related to MBKM supported by Augmented Reality have not yet been conducted by earlier researchers. Therefore, it is necessary to carry out a study on the design of an MBKM-based assessment utilizing Augmented Reality to measure students' multiple representation abilities. The long-term implications of this study for the pedagogical competence of pre-service teachers lie in enhancing their ability to design meaningful instruction that aligns with the characteristics of chemistry content at the secondary school level. Through mastery of instructional and assessment approaches based on multiple representations pre-service teachers will be better equipped to support students in developing a comprehensive conceptual understanding. Furthermore, this competence strengthens pre-service teachers' readiness to develop assessment instruments that go beyond measuring rote memorization to assess higher-order thinking skills and students' conceptual understanding. In the long term, this contributes to improving the quality of science learning at the secondary school level and to strengthening teacher professionalism in responding to curriculum demands and advancements in modern science based pedagogy.

METHODS

Research Design

This study aims to produce a design of an Augmented Reality–based assessment within the *Merdeka Belajar Kampus Merdeka* (MBKM) framework to enhance students' multiple representation abilities. The development pattern adopted in this research follows the 4D Model (Define, Design, Develop, and Disseminate). The designed product was then subjected to feasibility testing through validity and product trials. In this study, the developed product is an Augmented Reality–based test instrument designed to measure students' multiple representation abilities.

Research Target

The research subjects were students of the Chemistry Education study program in the 2023/2024 academic year. The trial subjects consisted of 18 students. The participants in this study were students from the 2nd, 4th, and 6th semesters. The product validation was carried out by two experts, both of whom are lecturers in chemistry education.

Research Data

The data collection techniques used in this study consisted of two methods. First, interviews were conducted to gather information regarding the need for an Augmented Reality–based MBKM assessment to measure students' multiple representation abilities. These interviews were carried out with lecturers and students of the Chemistry Education study program. Second, questionnaires were administered, including a student needs questionnaire, a student response questionnaire, and an instrument validation questionnaire. The needs questionnaire was used to obtain an overview of students' requirements in designing an Augmented Reality–based MBKM assessment. The student response questionnaire was used to collect feedback on the developed instrument. The validation questionnaire was given to experts to evaluate the validity of the instrument.

Research Instruments

The instruments used in this study consisted of interview guidelines and questionnaires. The interview guidelines served as a reference for conducting the interviews. A semi-structured interview format was used, in which predetermined questions were posed and further developed based on the respondents' answers. The interviews were conducted with both lecturers and students. Meanwhile, the questionnaires in this study consisted of a student response questionnaire and a validation questionnaire. The questionnaire incorporates three levels of multiple representations: a). Macroscopic: Students observe videos or images of real chemical reactions presented on the task cards; b). Submicroscopic: Students scan the cards using an AR application to visualize 3D molecular structures that are physically invisible;c) Symbolic: Students match the AR visualizations with the correct chemical equations or molecular formulas.

Data Analysis

1. **Instrument Validity and Reability**

   The validity analysis was carried out using validation sheets that had been assessed by expert validators. The expert validation instrument employed a Likert scale ranging from 1 to 4. The steps for analyzing the validation sheet are as follows:

a. Collect all data obtained from each validator for every assessment aspect, indicator, and item.
b. Determine the average score for each component using the formula:

$$\bar{X} = \frac{\sum X}{n}$$

Explanation:
$\bar{X}$= average score
X= total score obtained
n= number of validators
The resulting data are then matched with the predetermined evaluation criteria. The criteria for student responses are based on the rating guideline shown below:

Table 1. Validity Criteria

Percentage (%)	Category
0% – 20%	Not valid
21% – 40%	Less valid
41% – 60%	Fairly valid
61% – 80%	Valid
81% – 100%	Very valid

Afterward, verification is performed on the validation results, including feedback and suggestions provided by the validators. The validation of test items is based on three aspects: content, construct, and language.

Subsequently, a reliability test was conducted on the developed test items. Reliability measurement was carried out using the Cronbach's Alpha coefficient through IBM SPSS version 26. Decision-making regarding the level of instrument reliability was based on the following criteria: the instrument is considered reliable if the Cronbach's Alpha value is greater than 0.6, whereas it is considered not reliable if the Cronbach's Alpha value is less than 0.6(Sugiyono, 2022).

2. Practicality of the Critical Thinking Skills Test Items

The practicality of the test items developed to measure students' critical thinking skills is calculated using the following formula:

$$\boldsymbol{P = \frac{R}{SM}}$$

Description:
P = practicality value
R = score obtained
SM = maximum score

The value of P, or the practicality score for all aspects, is then categorized based on the criteria presented in the following table:

Table 2. Practicality Criteria

Percentage (%)	Category
85,01% - 100%	Very Practical
75,01% – 85,00%	Practical
65,01% - 75,00%	Fairly Practical
55,01%- 65,00%	Less Practical
0% - 55,00%	Not Practical

The practicality of the developed test items is determined by referring to the criteria above. The test items are considered practical if the practicality value meets at least the practical category.

RESULTS AND DISCUSSION

This study is a Research and Development (R&D) project. It focuses on designing a *Merdeka Belajar Kampus Merdeka* (MBKM)–based assessment supported by Augmented Reality to measure the multiple representation abilities of students in the chemistry education program. The Merdeka curriculum was developed with the expectation of fostering meaningful learning that can adapt to and utilize advancing technology for the application of scientific knowledge (Fahmi et al., 2023). This curriculum can serve as a solution for learning recovery aimed at supporting learning effectiveness and improving the quality of education in Indonesia. The concept of *Merdeka Belajar* is also expected to encourage various innovations in education in line with the development of science and technology (Mukhlishin, 2023). One of the technologies that can be utilized in chemistry learning is Augmented Reality (AR). his study is limited to the development of Augmented Reality–assisted test items on chemical reactions in aqueous solutions. The Augmented Reality application used in this research is named AR-Musi (Augmented Reality–Multiple Representations). Augmented Reality (AR) technology can depict molecular shapes in a realistic manner, enabling students to better understand abstract chemical concepts by making them more concrete (Rita & Guspatni, 2024). Augmented Reality technology has the potential to enhance chemistry learning by making invisible concepts visible and illustrating scientific phenomena at the particle level (Ripsam & Nerdel, 2024)AR technology also allows the visualization of images from two dimensions (2D) into three dimensions (3D) (Duc & Quang, 2024; Kuswinardi et al., 2023; Latifah et al., 2022). A high level of spatial ability can lead to better learning outcomes compared to low spatial ability; therefore, strong spatial visualization skills are important to help students analyze the molecular shapes of chemical compounds more easily (Hurrahman et al., 2022). The assessment developed consists of seven essay items, each containing several interrelated questions that cover multiple levels of representation, including the macroscopic, submicroscopic, and symbolic levels. The instrument is designed as a paper-based test. These items can function as formative, diagnostic, or summative assessments within the MBKM curriculum. Formative assessment provides information on the extent to which students have achieved the intended learning outcomes. It allows instructors to measure students' understanding of the learning material, reflect on teaching strategies, adjust instructional methods, and strengthen the connection between learning, media, and feedback (Bahriah et al., 2021; Putri & Rinaningsih, 2021).

Identify students' learning difficulties, particularly those related to multiple chemical representations. Topics on chemical reactions in solution are also studied further in analytical chemistry courses, such as precipitation reactions and acid–base titrations. This indicates that foundational understanding of these concepts must be well developed to avoid difficulties in subsequent coursework. Diagnostic tests can also support the formation of heterogeneous discussion groups. The Augmented Reality–assisted test design can also serve as a summative assessment to evaluate the extent to which students are able to progress from one unit of material to the next. Summative assessments are administered once all topics have been completed or during final examinations, which are part of summative evaluation (Bahriah et al., 2022). The Augmented Reality–assisted assessment was developed using the 4-D development model, which consists of four stages: define, design, develop, and disseminate. However, this article presents only the design and development stages.

Design Stage

This design phase aims to produce an Augmented Reality–assisted MBKM assessment capable of measuring students' multiple representation abilities in a comprehensive manner. The article not only outlines the development process but also presents the results of expert validation, ensuring that the assessment design is academically sound and feasible for use in chemistry learning.

a. Media Selection

The Augmented Reality media were developed using the Unity application. This platform was chosen for its ability to create real-time 3D animations, interactive visualizations, and its support for multiplatform development. The use of Unity enables the presentation of molecular models more concretely, helping students understand abstract chemical concepts through immersive visualization.

b. Format Selection

The assessment format combines AR-based molecular visualization with conventional paper-based test items. Molecular models and chemical phenomena are displayed through the AR application, while the test questions remain in paper format. This combination facilitates the measurement of students' multiple representation abilities, particularly when interpreting or illustrating molecular structures and submicroscopic processes, without drastically altering the structure of traditional assessments.

c. Development of the AR-Based MBKM Assessment Blueprint

The assessment blueprint was constructed to evaluate the multiple representation abilities of pre-service chemistry teachers in the Multiple Representation Chemistry course, which encompasses macroscopic, microscopic, and symbolic representations. The blueprint was developed based on concept analysis and the required competencies, ensuring that each indicator aligns with the targeted learning outcomes.

Table 3. Blueprint of the Augmented Reality–Assisted MBKM Assessment

No	Concept	Item Indicator
1	Solutions in water and solubility	Students can identify electrolyte and non-electrolyte solutions at both macroscopic and submicroscopic levels
2	Precipitation Reactions	Students can determine precipitation reactions at submicroscopic and symbolic levels
3	Acid–Base Titration	Students can analyze acid–base titration reactions at macroscopic, submicroscopic, and symbolic levels
4	Concentration	Students can identify the macroscopic uses of alcohol and explain dilution at the submicroscopic level
5	Acid–Base Reactions	Students can determine acid–base reactions at the symbolic level
6	Redox Reactions	Students can analyze redox reactions at submicroscopic and symbolic levels
7	Ionic Compound Solubility	Students can analyze soluble and insoluble ionic compounds at macroscopic, submicroscopic, and symbolic levels

The following are several initial displays of the application:

1. Initial Interface of the AR Musi Chemical Multiple Representation Application

Figure 1. Initial display of the AR Musi Chemical Multiple Representation Application

2. Next, there is a menu that contains the test items, which will show their multiple representations

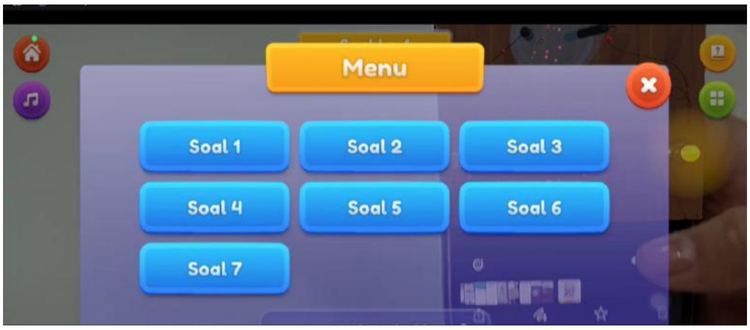


Figure 2. Display of the Test Item Menu

Validation Results

Expert validation was conducted to determine the feasibility of the developed product. In this study, the validation process involved three experts in the field of chemistry education, who provided comments and suggestions regarding the quality and suitability of the product. The following are the results obtained from the validators:

Table 4. Validation Results of the Developed Product

Validator	Total Score Obtained	Maximum Score	Percentage	Average	Category
Validator 1	95	108	87.96%	88.27%	Very Valid
Validator 2	100	108	92.59%		
Validator 3	91	108	84.26%		

Based on the validation results, the three validators obtained an average percentage of 88.27%, which falls into the "very valid" category. Meanwhile, the validation results of the Augmented Reality–assisted test for each aspect are as follows:

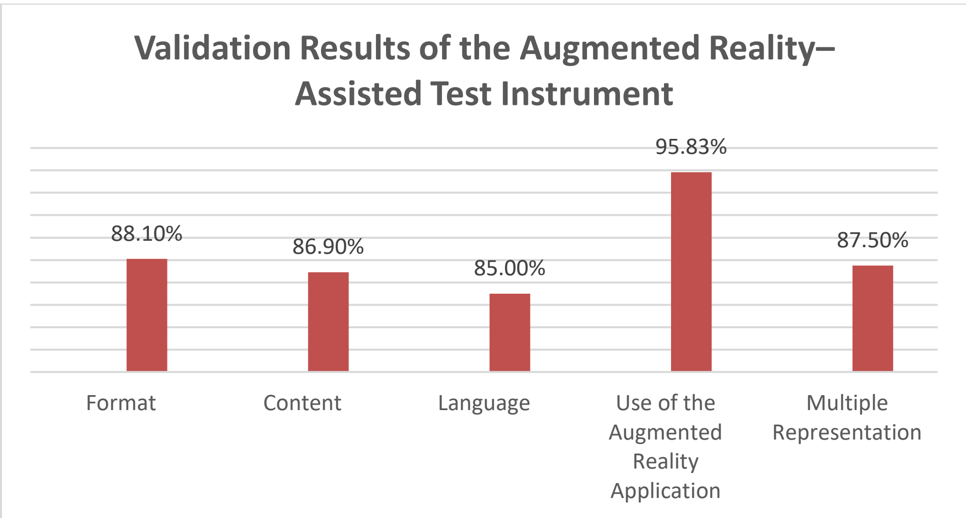
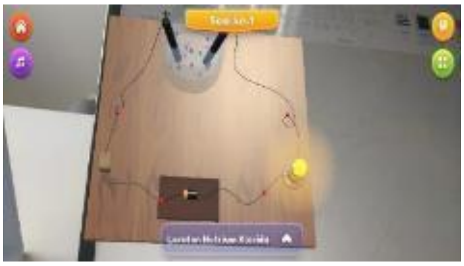
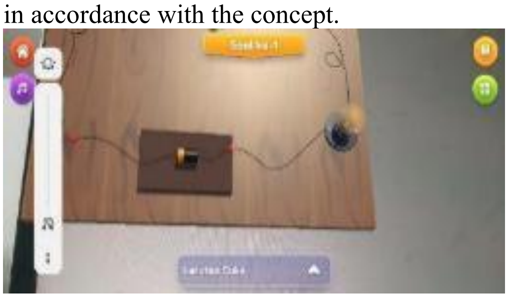
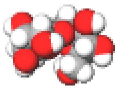


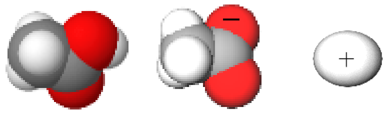
Figure 3. Validation Results for Each Aspect

The validation results from the three validators for each aspect show that the format aspect obtained a percentage of 88.10%, the content aspect 86.90%, the language aspect 85.00%, the

Augmented Reality usage aspect 95.83%, and the multiple representation aspect 87.50%. These percentages indicate that the Augmented Reality usage aspect achieved the highest score at 95.83%. Meanwhile, the language aspect received the lowest score compared to the other aspects, at 85.55%. The high percentage for the Augmented Reality usage aspect suggests that the developed application already provides clear instructions, the three-dimensional images are displayed clearly when the smartphone is placed near the provided marker, and the camera quickly captures the marker and displays the 3D visualization with ease. On the other hand, the language aspect obtained the lowest score because some questions were still confusing and could potentially lead to student misconceptions, indicating a need for improvement in the wording of the items. The comments and suggestions from the validators can be seen in the following table:

Table 5. Improvements to the AR-Musi Application

No	Before Revision	After Revision
1	In item number 1, the light on the sodium chloride solution was too dim compared to the vinegar solution. 	The light on the sodium chloride solution now appears bright. 
2	In item number 1, the light on the vinegar solution appeared bright. 	The light on the vinegar solution now appears dimmer than that of the sodium chloride solution, in accordance with the concept. 
3	The molecular model developed did not match the actual structure of the sugar molecule 	The developed sugar molecule model has been adjusted to match the actual molecular structure of sugar, as shown below:  

No	Before Revision	After Revision
4	The molecular model of the vinegar solution needed to be adjusted to match the molecular structure of CH_3COOH and the CH_3COO^- ion. 	The molecular model has been adjusted to match the structures of CH_3COOH and the CH_3COO^- ion, as shown below:  

The validators' comments and suggestions for revision include improvements to both the Augmented Reality application and the developed assessment items. Recommendations for the AR application focus on adjusting the molecular models to match the actual molecular structures and adding or replacing certain images to ensure alignment with the concepts being taught. Meanwhile, improvements to the assessment items should ensure that the questions are interconnected and that the submicroscopic representations correspond to the AR application that has been developed. Conducting this validation is expected to ensure the alignment of the materials with the characteristics of the content presented and prevent conceptual errors (Nazar et al., 2020).

The Cronbach's alpha coefficient for the test reliability is 0.75, which falls into the good category. Furthermore, the good reliability category demonstrates that students responded to the test items consistently. This consistency suggests that the wording, structure, and difficulty level of the items were appropriate and clearly understood by the respondents. As a result, variations in students' scores are more likely to reflect real differences in understanding rather than measurement inconsistencies. Studies in educational instrumentation similarly report that an alpha value above the acceptable threshold supports the use of the instrument for further analysis of learner outcomes, ensuring that the test functions as intended in capturing concept mastery(Edelsbrunner et al., 2025) .

Overall, the reliability findings confirm that the developed test instrument is suitable for assessing students' learning outcomes. With an acceptable level of internal consistency, the instrument can be confidently used for further data collection and analysis in research or instructional evaluation contexts. International research on instrument validation emphasizes that demonstrating internal consistency reliability through Cronbach's alpha strengthens the psychometric soundness of educational tools and supports the credibility of subsequent findings(Julieanatasha Juma'at et al., 2025; Villena-Martínez et al., 2024).

The trial phase was carried out in two stages: a small-scale trial and a medium-scale trial. The small-scale trial involved 6 university students, while the medium-scale trial involved 12 learners. The activity began with students downloading the application through the link provided, installing it, and then completing a response questionnaire regarding the developed design. The following section presents the results of both the small-scale and medium-scale trials. The small-scale trial was administered to 6 students to obtain their responses to the product that had been developed. The results of the trial are presented in the following table:

Table 6. Results of the Small-Scale Respondent Trial

Aspect	Score Obtained	Maximum Score	Maximum Score
Interest	156	168	92.86%
Language	112	120	93.33%
Use of Augmented Reality	94	96	97.92%
Multiple Representation	92	96	95.83%
	Average Percentage		94.99%
	Category		Very Practical

Based on the table, the average percentage obtained was 94.99%, which falls into the *very practical* category. From the small-scale response trial, no improvement notes or suggestions were provided. The next stage involved conducting the trial with a larger number of participants. The following presents the data from the medium-scale trial.

Table 7. Results of the Medium-Scale Respondent Trial

Aspect	Score Obtained	Maximum Score	Maximum Score
Interest	311	336	92.56%
Language	222	240	92.50%
Use of Augmented Reality	176	192	91.67%
Multiple Representation	173	192	90.10%
	Average Percentage		91.71%
	Category		Very Practical

Based on the medium-scale response trial, the highest percentage was obtained in the aspect of interest, with an average of 92.56%, while the lowest percentage was found in the multiple representation aspect. Overall, the medium-scale trial yielded an average score of 91.71%, classified as very practical. These results indicate that the MBKM assessment assisted by Augmented Reality is highly practical for measuring students' multiple representation abilities. The findings show that the use of AR transforms real objects from two-dimensional images into three-dimensional visualizations through the application, allowing students to observe the objects directly rather than merely imagining the available images (Ramadani et al., 2020; Wijayanti et al., 2024)

CONCLUSION AND RECOMMENDATIONS

The validation results for the assessment assisted by Augmented Reality show that Validator 1 provided a score of 87.96%, Validator 2 92.59%, and Validator 3 84.26%. The average percentage is 88.27%, which falls into the very valid category. These results indicate that the AR-assisted MBKM assessment is suitable for measuring chemistry students' multiple representation abilities. The small-scale trial responses show that the interest aspect obtained 92.86%, the language aspect 93.33%, the Augmented Reality usage aspect 97.92%, and the multiple representation aspect 95.83%. The average percentage is 94.99%, categorized as very practical. The medium-scale trial results show that the interest aspect obtained 92.56%, the language aspect 92.50%, the Augmented Reality usage aspect 91.67%, and the multiple representation aspect 90.10%. The average percentage is 91.71%, also categorized as very practical. Overall, these findings demonstrate that the AR-assisted MBKM assessment is highly practical for measuring students' multiple representation abilities. Future studies may develop other learning media for different subject topics and assess students' critical thinking skills and scientific argumentation abilities.

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