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DEVELOPMENT OF AUGMENTED REALITY MEDIA BASED ON ASSEMBLER EDU ON MOLECULAR GEOMETRY

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Abstract. This study aimed to develop and evaluate the effectiveness of Augmented Reality (AR)-based learning media using Assembler Edu to enhance the understanding of molecular geometry concepts at the Senior High School (SMA) level. The research employed a Research and Development (R&D) approach, incorporating both the Spiral and Waterfall development models. These models consisted of four main stages: setting objectives, identifying and mitigating risks, designing, and developing. Data were collected through expert validation, student trials, and user satisfaction questionnaires. Five validators assessed the media, and its validity was analyzed using Aiken's V formula, while reliability was measured through inter-rater agreement. The results showed that all Aiken's V values were above 0.8, indicating strong agreement among experts and confirming the validity across all categories. The inter-rater agreement values exceeded 75% (kappa > 0.70), demonstrating a high level of consistency among validators. Trials were conducted with 60 students from two schools: MAN 1 Prafi Manokwari and SMA 3 Kendari. The findings indicated a low difficulty level and reflected positive student responses toward the use of AR media for learning molecular structures. In conclusion, this study demonstrated that AR-based learning media offers an innovative and effective solution for enhancing chemistry education.

Keywords: assembler edu, augmented reality, molecular geometry

INTRODUCTION

Chemistry is one of the subjects that students must master at the senior high school (SMA) level, especially in the specialization of Natural Sciences (IPA). This subject covers fundamental concepts that form the basis for understanding advanced materials. One of the most essential materials in chemistry is molecular geometry. This material is studied in grade X, semester 1, with an allocation of 4 teaching hours. A molecular geometry or structure is a three-dimensional arrangement of atoms in a molecule. A good understanding of molecular geometry is essential because it plays a role in determining the polarity, reactivity, phase of matter, color, magnetism, and biological activity of a substance (Härmälä-Braskén et al., 2020).

However, molecular shape is often challenging for students because it is abstract and difficult to imagine in three dimensions. Research shows that many students have difficulty visualizing molecular shapes only through two-dimensional representations found in textbooks or static images (Alharbi, 2025; Rahmawati et al., 2021). Conceptual understanding of molecular shape also requires an understanding of electron domain theory and intermolecular interactions, which can be complex for students who do not have adequate spatial visualization experience (Edwards et al., 2017; Szalewicz & Jeziorski, 2022). According to Mayer's Multimedia Cognitive Theory (Mayer, 2024), learning that involves dynamic and interactive visual

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representations can help improve students' understanding of abstract concepts such as molecular geometry. Therefore, a learning approach is needed that can facilitate conceptual understanding through more interactive and accessible technology.

Along with technology development, students are increasingly familiar with digital devices daily. Therefore, learning methods must be adjusted to the times to make them more engaging and effective. The use of technology in learning, especially in chemistry subjects, has become a widely used strategy to improve understanding of concepts more interactively (Suparman, 2024). Learning technology refers to a series of digital tools and media used in teaching and learning activities, including communication, information, and technology tools that improve learning quality (Cavanagh & Kiersch, 2023). One form of utilization of learning technology is interactive multimedia that can help students understand complex material through visual simulations and direct interactions (Suparman et al., 2023).

Various modern technologies, including Augmented Reality (AR), have been applied in education. AR is a technology that combines virtual elements with the real world through digital devices to create a richer interactive experience (Cao & Yu, 2023). This technology allows students to see and interact with virtual objects displayed in a real-world environment, thereby increasing the appeal and effectiveness of learning. Luca et al. (2023) stated that AR allows the integration of virtual information into the real environment to enhance the learning experience. Thus, the application of AR in education can help students understand abstract concepts better.

AR in chemistry learning, especially in molecular geometry material, can help students understand the three-dimensional structure of molecules in more depth. OShaughnessy (2019) emphasized that the three-dimensional structure of molecules is fundamental in chemistry because it affects a substance's physical and chemical properties. However, many students have difficulty imagining the three-dimensional molecular geometry only through two-dimensional images in textbooks. Therefore, learning media are needed to provide more transparent and interactive visualizations.

Several applications have been developed to support the implementation of AR in education, including Vuforia, Google ARCore, Apple ARKit, MaxST, Wikitude, and Assembler Edu (Čep et al., 2023; Voinea et al., 2019). Assembler Edu is one of the leading choices in education because it is specifically designed for learning purposes (Mura & Dini, 2021). Assembler Edu is a platform that allows the creation of AR content easily and can be accessed via mobile devices. Using Assembler Edu, educators can design three-dimensional simulations of molecular geometry that can be scanned via students' smartphones.

Using Assembler Edu to learn molecular geometry is expected to provide students with a more enjoyable and innovative learning experience. One of the main challenges in understanding molecular geometry is the difficulty of visualizing the three-dimensional arrangement of atoms in a molecule (Alharbi, 2025; Suparman et al., 2024b). Textbooks typically present only two-dimensional images, which cannot accurately depict molecular geometry. With Assembler Edu-based AR, students can view three-dimensional molecular models directly through their devices. Compared to conventional learning methods that rely solely on static illustrations, previous studies have shown that AR-based learning can increase student engagement and strengthen conceptual understanding through direct exploration (Li et al., 2024; Wang, 2022). The use of AR in chemistry education has also been shown to significantly improve academic achievement (Elford et al., 2022). This indicates that Assembler Edu, as an AR-based platform, offers the advantage of providing a more immersive and contextual learning experience. With more active interaction, students

can understand molecular structures more intuitively and retain concepts more effectively than with traditional methods.

This technology allows students to explore various types of molecular geometry interactively, enhancing their understanding. Additionally, Assembler Edu is easy to implement, as it can be accessed via mobile devices without the need for special equipment (Salsabila et al., 2024). Teachers can print markers containing molecular geometry information, and students simply point their smartphone cameras at the marker to view the three-dimensional molecular model. In this way, learning becomes more flexible and accessible from anywhere.

The development of Augmented Reality (AR) media based on Assembler Edu for molecular shape material presents an innovative solution for enhancing the effectiveness of chemistry learning. The development process involves several stages, including needs analysis, designing AR media using Assembler Edu, conducting limited trials, and evaluating its effectiveness in improving students' understanding of molecular shape concepts. Unlike previous studies that primarily emphasize the implementation of AR in science learning, this study focuses on the development of AR specifically based on Assembler Edu, tailored to the characteristics of chemistry instruction and students' needs for interactive molecular structure visualization. This technology not only enhances students' understanding of molecular shapes but also increases their engagement in the learning process. Therefore, this study aims to develop AR-based learning media using Assembler Edu to improve students' comprehension of molecular shapes in chemistry and to address existing challenges in chemistry education.

METHOD

This research is a form of research and development (R&D). The development model used is a combination of the Spiral Model and the Waterfall Model, as proposed by Martin and Betrus (2019). This collaborative model consists of four main stages: determining objectives, identifying and resolving risks, designing, and developing.
A detailed explanation of each development stage in this study is as follows:

1. Determining Objectives

At this stage, the primary focus is on analyzing the needs at the high school level in the field of chemistry, specifically regarding molecular geometry material. The intended goal is for students to be able to distinguish various molecular geometries and directly view three-dimensional representations of key molecules studied in Grade X, Semester 1, using their own mobile phones

2. Identifying and Resolving Risks

This stage involves identifying and addressing potential risks. The focus is on assessing the technological capabilities of both teachers and students, particularly their ability to use the Assembler Edu application on their mobile devices. Another key concern is ensuring that the application runs smoothly and does not cause performance issues on the devices used by teachers and students.

3. Design

At this stage, the design of the AR media using Assembler Edu is carried out. The design includes elements such as the rotation direction, color scheme, scale, and rotation speed of the three-dimensional molecular geometries displayed in the augmented reality media.

4. Development

In the development stage, the results from the design phase are validated by five experts: media experts, chemists, education experts, and practitioners. Once validated, a trial implementation was conducted in two schools: MAN 1 Prafi Manokwari and SMA 3 Kendari.

Data Collection and Analysis Techniques

The validation instrument sheet was distributed to five validators to assess the media product being developed. The results of the expert validation were analyzed using Aiken's V formula. An item is considered valid if the Aiken's V value is ≥ 0.75(Aiken, 1985; Istiyono, 2018). After validation based on expert assessments, additional data were collected through a user satisfaction questionnaire completed by students at the trial schools.

The expert validation results were analyzed using Aiken's V formula, and the reliability level of the instrument was determined using the inter-rater agreement method. The instrument is considered reliable if the kappa value exceeds 0.70, indicating a high level of agreement among validators (Chow et al., 2020). The empirical test results, obtained through the student questionnaire, were further analyzed using the Rasch model with the R program. This analysis aimed to evaluate the metrics of the questionnaire items, determine item difficulty levels, and assess the data's fit with the Rasch model (Guzmán & Grajo, 2023; Yunita et al., 2021).

RESULTS AND DISCUSSION

This study aims to develop and evaluate the effectiveness of Assembler Edu-based Augmented Reality (AR) media in chemistry learning, specifically focusing on the concept of molecular geometry at the Senior High School (SMA) level. The media was developed using a combination of the Spiral and Waterfall model approaches, which include determining objectives, identifying and resolving risks, designing, and developing the media. The study successfully developed and assessed AR-based learning media using the Assembler Edu platform for teaching molecular geometry. It followed a structured Research and Development (R&D) process that integrated the Spiral and Waterfall models to ensure a systematic approach to media design and validation. The findings indicate that the AR media developed is highly valid and reliable, as confirmed by expert validation. Trials conducted in two high schools demonstrated significant improvements in students' understanding of molecular structures, with most participants reporting a positive learning experience. Furthermore, statistical analysis using the Rasch Model confirmed the media's effectiveness and positive reception by students.

The outcomes of this study include expert validation of the media, student trials, and quantitative data analysis using the Rasch Model. Validation results indicate that the AR media has high levels of validity and reliability. Additionally, trial outcomes show that the majority of students felt that the media helped them understand molecular geometry more effectively than conventional methods.

The first stage in this development is determining objectives. At this stage, the study identified student needs regarding their understanding of molecular geometry at the high school level. Brief interviews with students revealed that they often struggled to grasp the three-dimensional structure of molecules. These findings align with those of Abdinejad et al. (2021), which showed that students often have difficulty visualizing the three-dimensional molecular geometry chemical studied in class. The results of interviews and previous research became the basis for developing augmented reality media based on Assembler Edu to replace conventional methods using plasticine.

The second stage in this development is to identify and resolve risks. Risk identification is carried out to ensure the success of the implementation of AR media. The direct monitoring results showed that teachers and students at SMA Negeri 3 Kendari and MAN Prafi Manokwari did not experience difficulties downloading and using the Assembler Edu application. In addition, the AR media developed has a light

application size so that it does not hinder the performance of the devices used by teachers and students. Further analysis showed that 95% of students could run the application smoothly without significant technical constraints.

Another risk identified was related to the battery capacity used during AR-based learning. The measurement results showed that this application only reduced battery power by 10-15% in one 45-minute learning session, which is still within reasonable limits and does not interfere with the teaching and learning process. This is to the results of research by Xiong et al. (2021), which states that AR displays based on traditional geometric optics have a relatively simple design with FoV (~60°) and eye box (8 mm), which shows reasonable efficiency. In addition, other technical aspects, such as application stability and device compatibility, were also tested, and the results showed that the application can run well on various types of mobile phones with minimal specifications.

The third stage in this research is the media design process. At this stage, an augmented reality concept based on Assembler Edu was developed to display the molecular geometry chemical in a three-dimensional model. This design process includes various visual and interactive aspects so that the developed media can be used optimally in learning.

The design developed includes setting the direction of rotation of chemical molecules in three-dimensional space, selecting appropriate colors to distinguish types of molecules, and adjusting the scale so that the display remains proportional. In addition, the rotation speed of the molecules in the augmented reality media is also taken into account so that students can observe the molecular geometry without having difficulty following their movements.

Experts performed initial design validation before proceeding to the development stage to ensure that the developed media met quality standards in terms of visual, interactive, and functional aspects. This validation process includes several main stages: design suitability testing, functionality evaluation, and final adjustments based on expert input. The design suitability test assesses visual aspects, such as color selection, scale, and animation of chemical molecule movement. The second part, functionality evaluation, includes testing the ease of navigation and user interaction with augmented reality media. The last part is a revision based on input from the validator before the press is declared ready for further development. The initial design reviewed by the validators is illustrated in Figures 1 and 2.

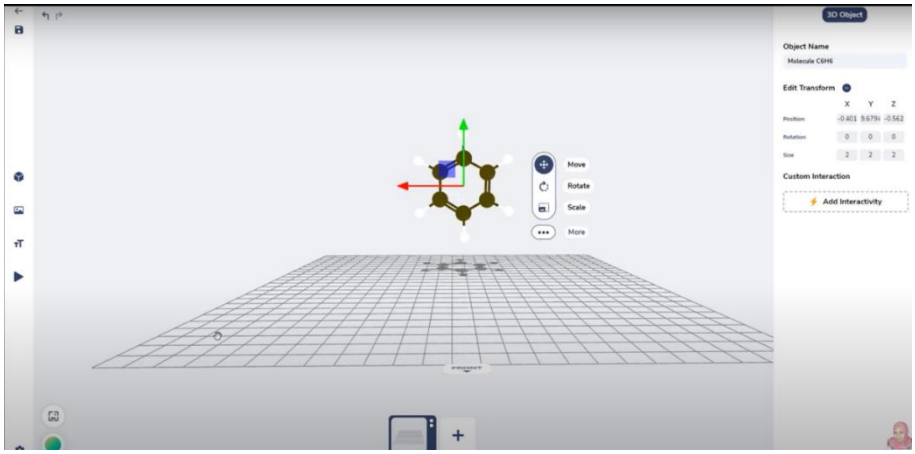

Figure 1. Initial design of the C_6H_6 molecular scale

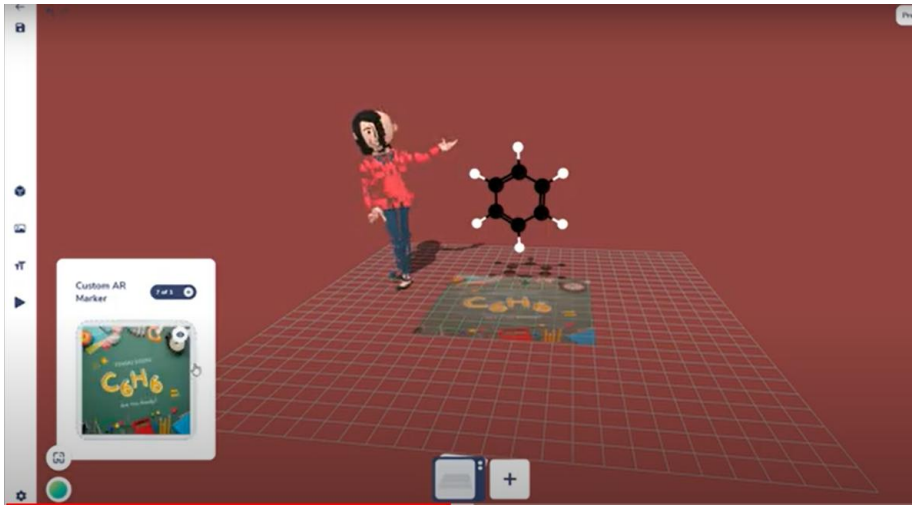

Figure 2. The initial design of the C_6H_6 molecular navigation

Figure 1 shows the initial design of the C_6H_6 molecular scale in augmented reality media. This scale is designed to remain proportional so students can observe the molecule's shape accurately. In addition, the size selection and scale comparison aim to ensure that chemical molecules can be displayed clearly on the device screen without distortion.

Figure 2 shows interactive navigation for the C_6H_6 molecule in augmented reality media. This navigation allows users to rotate the molecule, zoom in or out, and change the viewing angle. With this navigation feature, students can understand the molecular structure more profoundly and interactively.

After the design stage, it continues to the fourth stage, namely development. This stage is the implementation of the design results into augmented reality-based learning media. This implementation includes integrating the design that has been developed into the Assembler Edu platform so students can access and use it optimally.

At this stage, technical testing is carried out to ensure that the media runs well on various devices. Testing includes compatibility with the operating system, application stability, and the responsiveness of interactive features. In addition, media performance was evaluated, such as processing speed and accuracy of the three-dimensional model display. The results of this technical test are the basis for ensuring that the media can be used optimally in learning without experiencing technical constraints.

After the technical test was completed, five validators, consisting of media experts, chemists, education experts, and practitioners, carried out validation. This validation assesses how much the media has met visual, interactive, and functionality quality standards. The validation process was carried out by providing assessment instruments to the validators, which were then analyzed using V Aiken to measure the level of validity. The results of V Aiken using R are shown in Table 1.

Table 1. Aiken values

Items	V Aiken	Items	V Aiken
1	1.00	9	0.80
2	0.95	10	1.00
3	0.95	11	0.95

4	1.00	12	0.95
5	1.00	13	1.00
6	0.95	14	1.00
7	1.00	15	0.80
8	1.00	16	0.95

Table 1 shows that all Aiken V values are above 0.8, indicating high agreement among experts to declare all categories valid (Aiken, 1980; Suparman et al., 2024a). After being validated, an inter-rater agreement analysis is continued to assess the consistency of the assessment results between validators. This analysis aims to ensure that the validation results obtained are not only individually valid but also have a high level of agreement among experts. The reliability analysis results using inter-rater agreement are shown in Table 2.

Table 2. Inter-rater agreement values

Aspect	Inter Rater Agreement	Aspect	Inter Rater Agreement
1	100%	9	80%
2	80%	10	100%
3	80%	11	80%
4	100%	12	80%
5	100%	13	80%
6	80%	14	100%
7	100%	15	80%
8	100%	16	80%

Table 2 shows that all Inter-Rater Agreement values are above 75% or kappa values> 0.70, indicating that the level of agreement between validators is very high. This suggests that the assessment instrument is reliable and can consistently assess media quality. In other words, the validation results from experts show that the media developed has met the established standards.

After the media was declared valid and reliable, the study was continued with a field trial to measure its effectiveness in learning. The trial was conducted in two schools, MAN 1 Prafi Manokwari West Papua and SMA 3 Kendari Southeast Sulawesi, involving 60 students. In this trial, students were asked to use the augmented reality media developed using their respective mobile phones. The results and implementation of the trial of the developed augmented reality media are shown in Figures 3 and 4.

Figure 3. Results of C_2H_4 molecule augmented reality media

Figure 4. Implementation of augmented reality media trials in schools

After the trial, students filled out a satisfaction questionnaire to evaluate their experience using augmented reality media. The data obtained from the satisfaction questionnaire were further analyzed using the Rasch Model with R software to measure the extent to which the media could improve students' understanding and

assess the suitability of the media to learning needs. The results of the Rasch Model analysis are shown in Table 3.

Table 3. Results of analysis with the Rasch model

Item	Dffclt	Item	Dffclt
A1	-0.0064	A11	-0.0062
A2	-0.0063	A12	-0.0061
A3	-0.0063	A13	-0.0067
A4	-0.0066	A14	-0.0066
A5	-0.0063	A15	-0.0065
A6	-0.0063	A16	-0.0068
A7	-0.0060	A17	-0.0065
A8	-0.0062	A18	-0.0056
A9	-0.0064	A19	-0.0066
A10	-0.0063	A20	-0.0068

Table 3 presents the analysis results using the Rasch Model, which shows the difficulty level of each statement item in the user satisfaction questionnaire. Based on the analysis results, all items A1 to A20 have relatively low difficulty values and a fairly uniform distribution. This shows that students can easily understand the items in the questionnaire, and no statements are considered too complex or confusing.

A low difficulty value indicates that most respondents responded positively to each statement in the satisfaction questionnaire. In other words, students tend to agree or give a good assessment of using augmented reality (AR) media in learning the molecular geometry chemical. These results confirm that the AR media developed successfully met students' expectations and provided a practical and enjoyable learning experience. In addition, the consistency of the low difficulty value indicates that each statement item has a stable level of discrimination, so this questionnaire can be used as a valid and reliable instrument to measure user satisfaction with AR-based learning media.

This study highlights significant contributions to chemistry learning, primarily visualizing molecular geometry through augmented reality (AR). Unlike previous studies that used conventional methods such as plasticine models or static illustrations, developing Assembler Edu-based media provides a more interactive and dynamic approach. This study's findings indicate that AR improves students' understanding and provides a more enjoyable and practical learning experience. In addition, integrating the Spiral and Waterfall model approaches in developing this media offers a systematic framework to ensure its validity and effectiveness in learning. The implications of this study can be a guideline for developing similar technologies in other subjects or even in the broader context of STEM learning. Thus, this study opens up opportunities for further studies on optimizing AR technology in education and its influence on student engagement and understanding at various levels of education.

CONCLUSION

Based on the research and data analysis results, it can be concluded that the augmented reality media on the molecular geometry chemical developed using a collaborative media development model between the Spiral Model and the Waterfall Model has been proven valid and reliable. The validation results by experts show that this augmented reality media has met the visual, interactive, and functionality standards, making it suitable for use in learning. Additionally, the reliability analysis results demonstrated a high level of agreement between validators, indicating that the instruments used had good consistency.

The trials conducted in two schools revealed that most students were satisfied with using augmented reality media to learn molecular geometry chemistry. This is proven by the Rasch Model analysis, which shows that all statement items in the satisfaction questionnaire have a low difficulty level and are well received by students. More importantly, augmented reality media has been shown to enhance students' conceptual understanding of molecular geometry chemistry. By visualizing molecular structures in a three-dimensional interactive format, students can better understand spatial arrangements and molecular geometry, which are often challenging to grasp through conventional learning methods. Thus, the augmented reality media developed can not only provide a more engaging learning experience but also serve as an effective tool in improving students' conceptual understanding of chemistry.

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