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Development of Chemis 3D Augmented Reality Media for Discovery Learning Model in Chemical Bonding

Fiska Sahrawati*, Muhammad Danial, Pince Salempa, Muhammad Jasri Djangi
Universitas Negeri Makassar, Jalan Daeng Tata Makassar,Kampus UNM Parangtambung 90224
* Corresponding Author e-mail: fiskasahrawati@gmail.com

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Abstract
The goal of this research and development (R&D) study was to develop a 3D Chemis media product that included cards and applications for three-dimensional display. The 4-D development model by Thiagarajan et al., which comprised the phases of defining, designing, developing, and distributing, was consulted in the creation of this 3D chemistry media. The study's findings included the following: 1) two media experts and two material experts' evaluations of the media's viability and validity fell into the extremely valid group; 2) During the limited testing phase, which involved 29 students from class X MIA 5 SMAN 16 Makassar, each student received an average learning outcome test score of 83.3 out of 100, with 86.2% of the class completing the course. Additionally, the evaluation of student motivation for this media fell into the very high category, suggesting that the media was effective; 3) both students' and teachers' responses to the developed learning media fell into the very high category, suggesting that the media was useful. Following a validation stage by experts and validators, development revisions, and a small number of trials, this learning material was found to be reliable, useful, and efficient. The Chemis 3D media model was shown to be reliable, useful, and efficient.

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INTRODUCTION

Augmented reality (AR) has surfaced as a significant asset in education, providing immersive and interactive learning experiences that conventional methods fail to deliver. The use of AR in chemistry education can improve students' understanding, engagement, and retention of complex concepts. AR applications increase student interest and motivation by making learning more interactive and enjoyable. Students report higher levels of satisfaction and enthusiasm when using AR tools, which can lead to better learning outcomes (Chen & Liu, 2020; Singh & Kaur, 2024; Wong et al., 2021). AR has been particularly beneficial for students with lower academic performance, helping them improve their knowledge and problem-solving skills through hands-on interaction and visual learning (Cheng et al., 2022; Wan et al., 2018). AR is a powerful tool in chemistry education, offering significant benefits in terms of conceptual understanding, engagement, and retention.

The creation of Chemis 3D AR is driven by the need to improve educational outcomes in chemistry. AR technology allows for the visualization of molecular structures in three dimensions, providing a deeper and more intuitive understanding of chemical bonds compared to two-dimensional diagrams or text descriptions. AR technology allows students to interact with 3D chemical structures, providing a more intuitive understanding of molecular geometry and spatial relationships compared to static 2D images. This interactive experience can make abstract concepts more tangible and easier to comprehend (Fombona-Pascual et al., 2022). AR applications can be accessed via web platforms, making them widely available and cost-effective. This accessibility allows for the integration of AR into various educational settings, including those with limited resources, thereby democratizing access to advanced learning tools (Fombona-Pascual et al., 2022; Pinsky et al., 2023). Chemis 3D AR offers a promising tool for enhancing educational outcomes by improving the visualization and understanding of complex chemical structures.

Research indicates that students often struggle with understanding chemical bonding due to its abstract nature, which is compounded by the use of oversimplified models in textbooks and traditional teaching methods that can present an incorrect picture of bonding concepts (Nahum et al., 2010; Yovanie, 2024). These challenges are further exacerbated by Students' limited conceptual knowledge and low visual-spatial abilities, which contribute to difficulties in understanding bonding at a microscopic level (Mahmudah et al., 2020). Observations and interviews at a school using the 2013 curriculum revealed that teacher-centered methods and repetitive use of PowerPoint presentations made chemistry lessons, especially on chemical bonding, monotonous and difficult for students to understand. Additionally, time constraints and the lack of engaging media resulted in low student motivation and participation.

Traditional learning media, such as textbooks and static diagrams, fall short in providing the interactive and engaging experiences needed to fully understand chemical bonding. These methods often fail to capture the dynamic nature of molecular interactions, leaving students with a superficial understanding of the topic. This is particularly evident in traditional classroom settings where direct teaching methods are employed without the aid of interactive or multimedia tools (Kartikaningrum & Mulyani, 2024; Syahid et al., 2024). Additionally, conventional media tend to focus heavily on content delivery rather than fostering problem-solving skills and critical thinking, which are essential for deeper understanding and application of knowledge (Putri et al., 2023).

AR offers significant advantages over conventional media in education by enhancing engagement, motivation, and learning outcomes. This proved in 2024, where AR-based books significantly and effectively enhance students' learning outcomes with a 60% improvement compared to conventional media (Pahlevi et al., 2024). Additionally, AR can decrease cognitive load, making it easier for students to process and understand complex information (Bölek et al., 2021). By this reason AR is a valuable tool in modern education.

The primary challenge in teaching chemical bonding lies in its abstract and complex nature, which often leads to student disengagement and poor comprehension. Traditional methods do not provide the necessary interactivity and visual support to address these challenges effectively. This gap underscores the need for innovative approaches, such as AR, to make learning more accessible and engaging. AR media like Chemis 3D are particularly relevant in addressing the shortcomings of traditional teaching methods. By providing a tangible, interactive way to explore molecular structures, AR can help students develop a more accurate and profound understanding of chemical bonding. This relevance is supported by numerous studies highlighting the efficacy of AR in educational settings.

Evidence of the effectiveness of AR in education is growing. Hoai et al found (2024) that students' scores after the experiment, having used the AR tool in learning, are significantly higher than the scores before the experiment, indicating the impact of the experimental process. Based on feedback, students showed that 87% found that using AR technology for chemistry subjects was an effective teaching method that enhanced their learning (Wong et al., 2021).

The quality of present learning is thought to be improved by implementing the discovery learning model into the teaching and learning process in the classroom. Student-oriented learning replaces teacher-oriented learning in the discovery learning approach (Safriani et al., 2015). In the beginning, Jerome Bruner developed the discovery learning model with the intention of assisting students in improving their ability to think critically, solve problems, and comprehend the concepts or framework of the field (Kadri & Rahmawati, 2015).

According to Daryanto (2010), the learning process is a communication process that occurs within a system; without media, communication would not take place and would not be able to proceed as efficiently. Consequently, in order to increase students' interest in the learning process, the discovery learning paradigm should be used in conjunction with media in the classroom. In order for pupils to comprehend the process of chemical bonding, the media utilized also aids in their visualization in three dimensions. This is due to the fact that the information regarding chemical bonding is really challenging to acquire or comprehend.

Given the above problem's background, the researcher is interested in creating 3D chemistry media for classroom use using augmented reality technology on smartphones. This research and development project is titled "Development of Chemis 3D Augmented Reality Media for Discovery Learning Model in Chemical Bonding."

METHOD

This research was development research, often known as research and development (R&D), with the goal of creating a specific product. According to Sugiyono (2013), the research and development process was a research technique used to developed a specific product and evaluate its efficacy.

There were two sections to the study's subjects. Expert testing (validation) or product design trials were conducted in the first section by validators, who were media and material experts. Product and usage trials were the focus of the second section. Two material specialists and two media experts conducted the product design or expert tests. Individuals skilled in their industries were chosen as subjects for expert or product design tests. At least 20 class X MIA students were the subjects of usage trials with field trial respondents. All trial participants were SMA Negeri 16 Makassar class X students.

To measure the cognitive aspects that students possessed after learning with Chemis 3D media based on augmented reality technology on chemical bonding material, the study used tools in the form of material expert validation sheets and media expert validation sheets to determine the validity of the Chemis 3D media, learning outcome tests, and student motivation questionnaires. The device implementation sheet aimed to determine how the learning process was implemented, and the student and teacher response questionnaire aimed to determine the responses of the students and teachers to the Chemis 3D media.

The research stages utilized referred to the 4D research and development technique created by Thiagarajan et al. The 4D R&D model research was best suited for usage in the production of learning devices, and it was employed in several studies on the creation of media or learning devices.

This model, which was adapted into a 4-D model, comprised four stages of development: define, design, develop, and disseminate. The definition process aimed to identify and restrict the scope of learning in the creation of this learning media, while the planning process aimed to develop learning media and gather benchmark tests. Development involved providing educational materials on chemical bonding that were reliable, efficient, and useful. This phase consisted of the following: expert (lecturers and teachers) validation of the learning materials, followed by revision; actual limited trials on class X MIA students to gather learning outcome data (cognitive); learning motivation surveys; and media practicality through implementation and student and teacher feedback, as well as observation sheets for implementation and distribution.

This study was only carried out up to the point of development. The developer decided that limited trials or quantitative tests were adequate to gather information on the validity, practicality, and effectiveness of learning media in evaluating the feasibility of learning media, so they did not conduct additional trials, specifically the dissemination stage, after receiving expert validation (validity test). In order to obtain the necessary data, data collection techniques were employed to gather data in accordance with study guidelines. Since gathering data was the primary goal of research, data collection procedures were the most strategic stage of the process (Sugiyono, 2013). This study's data collection methods included interviewing, documenting, and observation.

To gather feedback on the products being developed, questionnaires were distributed to expert validators, teachers, and students. Interviews with teachers and students were also conducted during the needs analysis stage, as were observations of the implementation of learning during limited media trials. Quantitative descriptive analysis methods were used to analyze the data. This method was used to analyze quantitative data from questionnaires used in expert tests. The procedure can therefore be expressed as follows if it is expressed in a formula:

$$average\ rating = \frac{total\ rating\ score}{number\ of\ rater}$$

Table 1 lists the validity criteria that uses to assess the media's reliability.

Table 1. Media Validity Criteria

Average score	Criteria
3,26 - 4,00	Strongly valid
2,51 - 3,25	Valid
1,76 - 2,50	Poorly valid (need revision)
1,00 – 1,75	Not valid (major revision)

Data from learning result tests and student motivation observation sheets are processed and analyzed to determine how successful Chemis 3D media based on augmented reality is. Individual completion scores and class completion percentages are used to produce the effectiveness analysis. Individual completion scores are calculated using the formula below:

$$\text{individual completion value} = \frac{\text{student score}}{\text{maximum score}} \text{ x } 100$$

Accordingly, students are classified as completed if their individual completion scores are more than or equal to KKM, and as not completed if their individual completion scores are less than or equal to KKM.

The following formula is used to calculate the proportion of students who complete the course:

$$\text{class completetion} = \frac{\text{number of student completing}}{\text{number of students}} \text{ x } 100\%$$

The effectiveness of the learning materials developed can be demonstrated by the findings of the analysis of the class completion %. If the class completion rate is at least 80%, then the augmented reality-based Chemis 3D media is considered effective.

The following formula will be used to assess the findings of this learning motivation survey:

$$\text{P} = \frac{\text{obtained score}}{\text{ideal score}} \text{ x } 100\%$$

where: P = percentage number, Ideal score = highest score for each item x number of respondents x number of items. The analysis results can be categorized as follows in Table 2

Table 2. Qualifications of Student Motivation Questionnaire

Percentage number	**Category**
81%-100%	Very high
61%-80%	High
41%-60%	Moderate
21%-40%	Low

(Iskandar, 2013).

By processing and evaluating data from the device deployment observation sheet and student and teacher response questionnaires, the practicality of Chemis 3D media based on augmented reality are evaluated. The following formula is then used to modify the device implementation observation data results:

$$\text{Successful precentage} = \frac{\sum x}{N} \text{ x } 100\%$$

Where Σx = total score of each item, and N = maximum score.

The two observers' implementation percentages are then averaged. Table 3 provides an explanation of the analysis's outcomes.

Table 3. Criteria for the Level of Implementation of Devices

Student Activity Level	**Category**
81-100%	Very high
61-80%	High
41-60%	Moderate
21-40%	Low
5-20%	Very low

(Supardi, 2015)

The following formula was used to analyze the data from the instructor and student response questionnaires:

$$average\ student\ response = \frac{\sum_{j=i}^{n} \overline{K\imath\jmath}}{N}$$

$$\%\ student\ response\ = \frac{average\ student\ response}{4} x\ 100\%$$

Where $\sum_{j=i}^{n} \overline{K\imath\jmath}$: average number of each category, N : number of categories, 4 : maximum score. The average of the observations' implementation percentage are then calculated. Table 4 provides an explanation of the analysis results.

Table 4. Criteria for Student and Teacher Response Levels

Student Activity Level	**Category**
81-100%	Very high
61-80%	High
41-60%	Moderate
21-40%	Low
5-20%	Very low

(Supardi, 2015)

RESULTS AND DISCUSSION

Using the 4-D model, chems 3D media with cards and three-dimensional (3D) visualization applications based on augmented reality on chemical bonding material for grade X SMA were developed. This study only used three of the four steps in this development model: the definition stage, the planning stage (design), and the development stage (develop). Based on curriculum analysis and interview results about the use of learning media in schools, it was determined to developed learning materials using Chemis 3D media with cards and augmented reality-based three-dimensional (3D) visualization applications that were developed using the discovery learning model. This will allow students to discover the concept of chemical bonds on their own, which leads to increased student learning outcomes and learning motivation.

According to the findings of the student analysis based on observations and interview data, students at X MIA SMA Negeri 16 Makassar in the 2018–2019 academic year continue to have a low cognitive level for chemical bonding material. This is due to the fact that most students found it difficult to comprehend chemical bonding material when it was presented to them verbally without a clear illustration during the previous semester.

Further interview results conveyed that students require educational materials that enable them to understand the concepts of the subjects they are studying. Text, images, animations, sounds, and films that can give abstract content a more tangible feel are all wanted. Therefore, the researcher developed a learning tool called Chemis 3D, which consists of cards with an augmented reality-based three-dimensional visualization application that includes chemical bonding information and easily understandable explanations.

The competency achievement indicators in the chemical bond material are used to determine the task analysis based on the primary content of chemical bonds. Students must be able to fulfill all indicators in order to attain basic competences, according to the task analysis. For the KKM value of 75, the assignment activities for these students are tailored to the content in the Chemis 3D media that has already been developed using the discovery learning approach.

Key concepts that will be taught using Chemis 3D media with cards and three-dimensional (3D) visualization applications based on augmented reality with the use of discovery learning models on chemical bonding materials are analyzed using concept analysis based on a review of literature from multiple sources. To make the preparation of the material easier, the content covered in this study was generally transformed into a concept map.

In order to determine the shape of molecules using the theory of valence shell electron pair repulsion (VSEPR) or Electron Domain Theory, students must be able to compare ionic bonds, covalent bonds, coordinate covalent bonds, and metal bonds and their relationship to the properties of substances. As a result, learning goals and concept achievement metrics that students need to meet are developed. Researchers process data from the definition stage (define) and use the concept map of chemical bonding material from the previous stage to develop learning devices with learning achievement indicators in the second stage, which involves designing the Chemis 3D card and the Chemis 3D application of chemical bonding material. Based on the aforementioned achievement indicators, a benchmark test is developed using an assessment method, namely a written multiple-choice test with a question item as the instrument and 20 numbers. Researchers gather information based on the definition stage, specifically media that can sequentially explain chemical bonding material and visually and realistically depict the formation of chemical bonds and molecular shapes in each sub-material to make it easier for students to understand and enable them to learn more on their own. Thus, the researchers developed Chemis 3D, a learning media.

In keeping with its original goal of enhancing student learning outcomes for chemistry content, the Chemis 3D program is made as user-friendly as feasible. The program that was developed for three-dimensional (3D) visualization is called Chemis 3D. This application was developed in compliance with the implemented design. The following is a description of the application design stages:

1) Creating Cards and Application Designs
2) Creating Objects in Three Dimensions (3D)
3) Creating Indicators
4) How to Use Unity to Combine Markers and 3D Objects
5) Completing the Application

The Chemis 3D marker or card and the Chemis 3D application look like this:

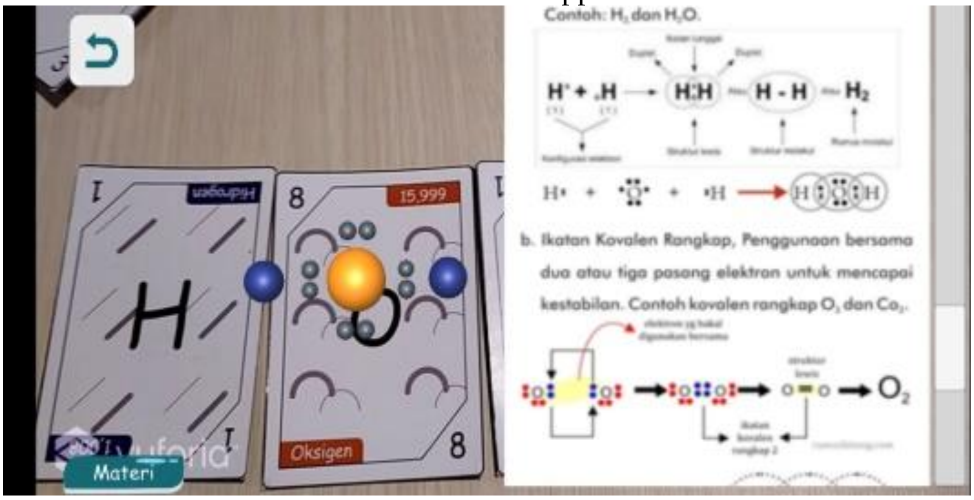

Figure 1. 3D Chemis Media View

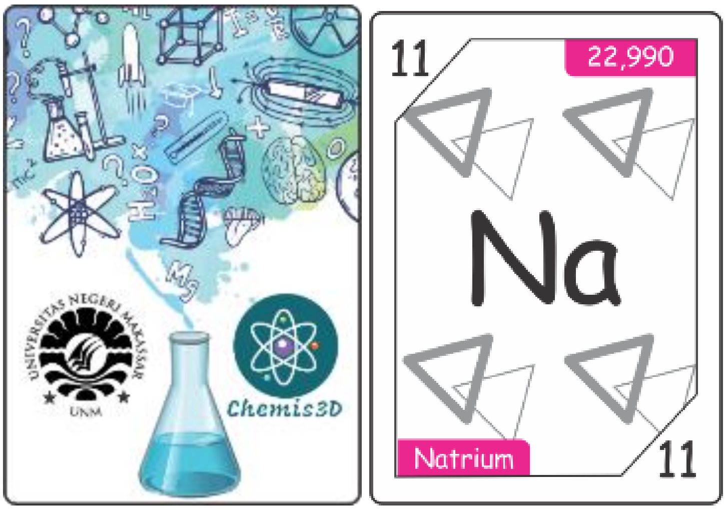

Figure 2. 3D Chemis Card View

The appropriateness of learning objectives, material quality, and presentation of material content are some of the factors that material experts consider when validating learning media. The function of the learning objective suitability aspect is to ascertain whether the learning objectives created using the content in the learning media are appropriate. The function of the material quality element is to ascertain whether the learning media's content is appropriate for use in classroom instruction. In addition to assessing the clarity of the language used, the presentation of material content serves to determine the appropriateness of the arrangement and advantages of the content in the form of text, photos, and three-dimensional graphics. The information gleaned from the material's validation is then explained in table 5 below.

Table 5. Expert Assessment Data for Material

Rating aspect	Rater		Average	Category
	Rater 1	Rater 2		
Suitability of Learning Objectives	4,0	4,0	4,0	Very valid
Quality of Materials	3,5	3,6	3,50	Very valid
Presentation of Material Content	3,75	3,75	3,75	Very valid
Overall score average			**3,75**	**Very valid**

The expert assessment data presented in Table 5 demonstrates that the developed materials, including the Chemis 3D media for chemical bonding, achieved a high level of validity, with an overall average score of 3.75, categorized as "Very Valid." The evaluation process, conducted by two material experts, was supplemented with comments and recommendations, which informed subsequent revisions and improvements to the media. These revisions focused on key aspects such as media advantages, design, and navigation/operation, which are critical components in validating the effectiveness of learning media. The high scores reflect the success of these efforts, as the media's immersive and interactive features, enhanced by Augmented Reality (AR), provide a significant advantage in visualizing complex chemical concepts (Bölek et al., 2021; Cheng et al., 2022).

The media design component ensured that the chosen elements, colors, and layout were visually appealing and appropriate for the learning material, while the navigation and operational features contributed to the usability and seamless interaction with the media. These factors are crucial for AR-based educational tools, which rely on intuitive user interfaces to promote engagement and exploration (Singh & Kaur, 2024). Additionally, the principles of Discovery Learning, emphasizing active student participation and self-paced exploration, further support the high validity scores ((Kadri & Rahmawati, 2015). Overall, the rigorous validation process and iterative improvements underscore the potential of Chemis 3D to serve as an effective and innovative educational resource that aligns with curriculum standards and modern pedagogical approaches. Table 6 then provides a description of the collected data.

Table 6. Media Expert Assessment Data

Rating aspect	Rater		Average	Category
	Rater 1	Rater 2		
Media Benefits	3,8	4,0	3,9	Very valid
Media Design	3,8	3,8	3,8	Very valid
Media Navigation/ Operation	3,25	3,75	3,5	Very valid
Overall score average			**3,73**	**Very valid**

The expert assessment data for media evaluation in **Table 6** reveals an overall average score of 3.73, categorized as "Very Valid," highlighting the effectiveness and quality of the Chemis 3D media in supporting the learning process. The media benefits scored 3.9, reflecting its substantial contribution to enhancing comprehension of complex chemical concepts. The integration of Augmented Reality (AR) technology is pivotal in this result, as it facilitates visualization and interactive engagement with abstract topics like chemical bonding, a feature well-supported by research on AR's role in improving conceptual understanding (Hoai et al., 2024; Mahmudah et al., 2020).

The media design, with a score of 3.8, underscores the thoughtful selection of visual elements, colors, and layout, ensuring that the materials are both visually appealing and aligned with the learning objectives. This aligns with findings that effective design enhances learner motivation and engagement by providing a structured yet flexible environment for exploration (Wan et al., 2018). The navigation and operation of the media, scoring 3.5, emphasize its usability, indicating that learners can easily interact with and navigate through the system. While slightly lower than other components, this score reflects iterative improvements based on expert feedback, ensuring functionality without diminishing the overall learning experience.

These results align with the principles of Discovery Learning, which emphasize the role of interactive and self-directed exploration in fostering deeper learning (Nahum et al., 2010). By integrating AR with these principles, the Chemis 3D media provides an intuitive platform that supports active engagement and critical thinking. The consistently "Very Valid" ratings across all aspects validate the potential of this media as a transformative tool in chemistry education, capable of bridging the gap between theoretical knowledge and practical understanding.

The limited testing of Chemis 3D media was conducted to evaluate its usefulness and efficacy as a teaching tool for chemistry, specifically focusing on chemical bonding material. Through assessments involving teachers, students, and observations of the media's implementation, its practicality was demonstrated, achieving a very high category in both teacher and student evaluations. With an average score of 3.27 from students and a 93% approval rating from teachers, the Chemis 3D media has been shown to effectively engage learners, improve motivation, and support the achievement of learning outcomes. These findings align with research emphasizing the critical role of interactive and innovative learning media in fostering deeper understanding and enthusiasm among students (Arsyad, 2011; Gusmida et al., 2016).

The effectiveness of Chemis 3D media is further evidenced by students' performance in learning outcome tests and motivation questionnaires. With a class completion rate of 86.2% exceeding the minimum criteria of 80%, and a motivation score averaging 81%, the media demonstrates significant potential to enhance student comprehension and enthusiasm. The application of AR technology in Chemis 3D enables immersive and interactive learning experiences that transform abstract chemical concepts into tangible and engaging visuals. This aligns with Cheng et al. (2022) and Hoai et al. (2024), who highlight the ability of AR to create hands-on learning environments that support cognitive engagement and concept mastery, particularly for complex subjects like chemistry.

The development of Chemis 3D media, based on the Thiagarajan 4D model, involved rigorous iterative processes incorporating expert feedback. Media experts validated its design, navigation, and usability, resulting in an average score of 3.73 (very valid). Material experts evaluated the appropriateness of its objectives, material quality, and presentation, also categorizing it as very valid. These validations underscore the media's alignment with educational principles, particularly the constructivist foundation of Discovery Learning, which encourages exploration, interaction, and student-driven knowledge construction (Nahum et al., 2010; Singh & Kaur, 2024).

Chemis 3D was designed to address specific challenges in chemistry education, such as low student motivation and engagement. Observations from SMA Negeri 16 Makassar reveal that students often struggle with abstract concepts due to limited interest in traditional instruction and inadequate integration of technology. Chemis 3D addresses these issues by combining AR's dynamic visualizations with user-friendly interfaces, enabling students to interact with three-dimensional models and simulations. Such approaches are proven to enhance motivation and improve learning outcomes by contextualizing knowledge and making it accessible (Wong et al., 2021; Mahmudah et al., 2020).

However, the study acknowledges certain limitations. Chemis 3D media covers only two fundamental competencies in chemical bonding, excluding topics such as hybridization and intermolecular forces. Additionally, due to logistical constraints, the distribution and broader application of the media were not implemented. These limitations present opportunities for further development, including expanding the content coverage and conducting large-scale trials to evaluate broader applicability. Despite these constraints, the Chemis 3D media has demonstrated its viability as an effective educational tool that integrates AR with Discovery Learning principles to foster student motivation, engagement, and achievement in chemistry education.

CONCLUSION

According to the research findings, the 4D development model by Thiagrajan was used to develop the 3D chemistry media on chemical bonding material using the discovery learning model. This model consists of the following steps: defining (Define), where the researcher analyzes the needs of the media being developed, designing (Design), where the researcher develop and designs the media, and developing (Development), where the researcher validates it with media experts and material experts and conducts limited trials on grade X students of SMA Negeri 16 Makassar to produce legitimate, useful, and efficient media.

The Chemis 3D media was tested on class X of SMA Negeri 16 Makassar following validation by media and material experts. Because it enhances learning outcomes and student motivation for learning, the developed media was deemed valid with the Very Valid category, practical with the Very High category, and successful for use in education.

RECOMMENDATIONS

There were still a lot of issues with the development research on Chemis 3D media for chemical bonding material employing the discovery learning model. As a result, the following recommendations for product development and usage are required. First, other fundamental materials can be used to expand the creation of augmented reality-based three-dimensional visualization applications. Improving learning media resources is essential for schools in order to help the teaching and learning process. Schools can use the discovery learning paradigm to incorporate Chemis 3D media for chemical bonding materials into their classroom instruction. In order to maximize the developed media, future researchers will need to perform additional studies to gather more input and suggestions. The distribution stage can be included in these studies. Teachers should be encouraged to develop and employ educational media as a substitute for traditional classroom instruction, allowing students to grasp concepts on their own.

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