Augmented Reality-Based Interactive Learning Media: Enhancing Understanding of Chemical Bonding Concepts

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ABSTRACT

Purpose of the study: This study aims to produce interactive learning media based on augmented reality technology on chemical bonding material and to determine students' responses to the media.

Methodology: This research is a development research with Warsita development model, which includes design stage, production stage, and evaluation stage. The data obtained were analyzed descriptively.

Main Findings: The results of the limited trial received positive responses from students with the percentage details obtained being 85.75% for the usability aspect, 81.80% for the illustration usage aspect, 74.57% for the future impact aspect, 79.64% for the material usefulness aspect, and 77.20% for the grammar aspect.

Novelty/Originality of this study: Can be used as an alternative interactive learning media in learning activities, especially in chemical bonding materials. Can be used as input and reference in developing interactive learning media on other materials.

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1. INTRODUCTION

In the 21st century, rapid advancements in information and communication technology have transformed numerous sectors globally, including education [1]-[3]. Concepts such as e-learning, virtual laboratories, and digital classrooms have become integral to modern education systems [4]-[6]. These changes have reshaped how teaching and learning are designed and delivered. Technology is no longer an optional tool but a fundamental component in enhancing educational quality and accessibility [7], [8]. It has redefined how learners interact with knowledge, making learning more personalized, flexible, and engaging.

The global shift in education emphasizes the development of 21st-century skills such as critical thinking, creativity, communication, and collaboration [9]-[11]. This paradigm change requires educators to adopt innovative teaching methods and utilize digital tools that support student-centered learning [12]-[14]. Traditional lecture-based instruction is no longer sufficient to meet the needs of diverse learners [15], [16]. Technology-enabled learning environments are now expected to facilitate deeper understanding and active engagement. Consequently, integrating interactive media into education has become a global priority.

Augmented Reality has emerged as a promising educational technology that blends real-world environments with computer-generated content. It allows students to interact with three-dimensional objects in real time, creating immersive and experiential learning opportunities [17], [18]. Globally, educators and researchers have recognized the potential of Augmented Reality to improve learning outcomes across disciplines

[19], [20]. Augmented Reality can make abstract or invisible concepts more tangible and accessible, particularly in subjects that involve complex visualization, such as science [21], [22]. Its interactive nature fosters curiosity, motivation, and deeper cognitive processing.

In chemistry education, many topics such as atomic structure, molecular bonding, and chemical reactions are inherently abstract and difficult to visualize [23], [24]. Students often struggle to understand microscopic interactions that cannot be observed directly. Augmented Reality technology can address this issue by enabling learners to manipulate virtual molecular models in 3D space [25], [26]. This hands-on interaction enhances conceptual understanding and spatial reasoning. As a result, Augmented Reality has gained significant interest as a tool to support chemistry learning in both formal and informal educational settings [27], [28].

Numerous international studies have shown that the use of Augmented Reality in chemistry education positively influences student achievement and engagement [29]-[31]. For example, Augmented Reality applications have been developed to simulate molecular bonding, allowing students to observe and manipulate atoms and ions [32], [33]. These tools help bridge the gap between theoretical knowledge and practical visualization. Learners gain a better grasp of spatial relationships and can explore content at their own pace. Such innovations are particularly effective in supporting diverse learning styles and promoting self-directed learning [34], [35].

Despite its potential, Augmented Reality is still underutilized in many educational contexts, particularly in secondary science education [36], [37]. Challenges such as limited resources, lack of teacher training, and inadequate infrastructure have slowed the adoption of Augmented Reality worldwide [38], [39]. However, with the increasing availability of smartphones and affordable Augmented Reality platforms, its integration into the classroom is becoming more feasible [40], [41]. Continued research and development are essential to create accessible and curriculum-aligned augmented reality educational tools [42], [43]. Educators and policymakers must also be encouraged to explore Augmented Reality's benefits for modern science instruction.

Previous research by Bahriah et al., [44] focused on the development of interactive learning media based on augmented reality technology for chemical bonding material, emphasizing the design and validation process of media to increase learning appeal. On the other hand, Solikhin et al., [45] evaluated the effect of using Augmented Reality-based learning media on students' conceptual understanding of molecular shapes, providing quantitative evidence of its effectiveness. However, both studies have not explored in depth how augmented reality media can be used to improve students' understanding of basic chemical bonding concepts more comprehensively, including integration with a more holistic pedagogical approach. The current research fills this gap by developing Augmented Reality-based learning media that is not only visually appealing but also designed to improve students' understanding of fundamental chemical bonding concepts through a more structured and interactive learning approach.

The novelty of this research lies in the development of augmented reality Augmented Reality-based learning media that is specifically designed to improve understanding of fundamental concepts of chemical bonds through the integration of technology with a pedagogical approach based on high interactivity. This media not only presents interesting three-dimensional visualizations, but also allows students to explore and manipulate molecular models directly, something that has not been widely highlighted in previous research. The urgency of this research lies in the urgent need for innovative learning methods that are able to answer the challenge of students' low understanding of abstract concepts in chemistry, such as chemical bonds, which often become obstacles in the teaching and learning process. By providing more intuitive and interactive media, this research can help improve the effectiveness of learning in the digital era and support efforts to improve the quality of science education at the secondary school and tertiary levels.

This study aims to develop an interactive learning media using augmented reality technology to teach the topic of chemical bonding. By focusing on the visualization of molecular structures, the media seeks to enhance students' understanding of complex concepts through immersive and intuitive learning experiences. The study addresses the global need for innovative, technology-supported teaching tools in science education. Through this development, we hope to contribute to the growing body of research on augmented reality in education and provide a model for its effective implementation. Ultimately, the goal is to support high-quality, engaging, and accessible learning for students around the world.

2. RESEARCH METHOD

2.1. Type of Research

This study refers to the Warsita development model. This model includes three main stages, namely media design, media production and evaluation of interactive learning media based on augmented reality on chemical bonding material that has been developed.

2.2. Research Design

The research design used by the researcher is the Warsita development model. The stages are as follows: The design stage is the initial stage in media development that aims to produce a prototype of learning devices [46], [47]. At this stage, a series of activities are carried out such as needs analysis, compiling an outline of the contents of the material, and compiling a script. Needs analysis is carried out through field surveys and distributing questionnaires to students and teachers to obtain data on learning interests, learning habits, and teaching experience and the availability of learning media [48], [49]. The results of this analysis are used to compile a media position map that shows the position of basic competencies in the curriculum that will be assisted by the media being developed. In addition, task and material analysis is carried out to formulate indicators and learning objectives that will be the basis for designing augmented reality-based media.

The production stage includes three main steps, namely preparation, implementation, and completion, all of which focus on making media concretely [44], [50]. In this stage, the selection of media types is determined, namely augmented reality applications and marker books as the main components of interactive media. Researchers compile their own marker books by paying attention to visual formats such as paper size, type and size of letters, margins, and systematic content, while for augmented reality applications, researchers collaborate with an AR technology expert. The 3D object file format and markers are prepared to be integrated into the AR application that can display visualizations of molecular structures and chemical bonds [51], [52]. After the initial prototype is formed, an initial assessment and simulation are carried out with peers to obtain initial responses as material for improvement.

The evaluation stage is carried out to test the feasibility and effectiveness of the learning media that has been developed before being used more widely [53], [54]. Evaluation is carried out in two steps, namely validation by experts and limited trials on students. Validation involves media experts and material experts to provide input on the initial media design, so that relevant revisions can be made. Furthermore, limited trials are carried out by involving a number of students in real classroom conditions to observe their responses, understanding, and interactions with the augmented reality media that has been developed. Data from this evaluation stage will be the final reference in perfecting the media before being widely implemented in chemistry learning in schools.

2.3. Research Subjects

The research subjects were two chemistry lecturers as material experts and two practitioners as media experts, acting to validate the media before being tested on a limited basis. Meanwhile, two lecturers acted as validators to validate the research instrument. The subjects in this study also included high school students as respondents who provided responses at the limited trial stage.

2.4. Data Collection Techniques

The data collection technique in this study was carried out through questionnaires and validation. The questionnaire was distributed for two purposes: first, to analyze students' needs through questionnaires to 80 students; and second, to assess students' responses to the media through response questionnaires filled out by 40 students. The validation process was carried out to assess the feasibility of the content and learning media developed, involving two material experts and two media experts who each used a validation sheet as an assessment instrument. The validation sheets used consisted of two types, namely material validation sheets and media validation sheets. The grid of the validation sheets and questionnaires used in this study can be seen in the following table:

Table 1. Material Validation Sheet Grid

No.	Aspect	Question Number	Number of Items
1.	Accuracy/precision of the material	1,2,3	3 items
2.	Depth and breadth of the material	4, 5, 6, 7, 8, 9, 10, 11, 12	9 items
3.	Suitability of the material to the indicators	13, 14, 15, 16, 17, 18,19, 20, 21	9 items
4.	Visual conformity to the material	22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34,35,36, 37, 38, 39, 40, 41, 42, 43	22 grains
5.	Adequacy of material	44, 45, 46, 47, 48, 49, 50,51, 52	9 grains
6.	Updated	53, 54, 55, 56, 57, 58, 59, 60, 61	8 grains
	Total		61 grains

Table 2. Media Validation Sheet Grid

No.	Aspect	Question Number	Number of Items
1.	Attractiveness	1, 2, 3, 4, 5, 6, 7,8,9,10, 11,12,13, 14,15,16,1718, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28,29, 30, 31, 32, 33	33 grains
2.	Caption readability and usefulness	34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44	11 grains
3.	Image sharpness	45, 46, 47, 48	4 grains
4.	Visual appropriateness	49, 50, 51, 52, 53, 54, 55, 56, 57	9 grains
5.	Music	58, 59, 60, 61, 62, 63	6 grains
6.	Technical	64, 65, 66, 67, 68, 69, 70, 71, 72	9 grains
		Total	72 grains

Table 3. Media needs questionnaire grid

No.	Aspect	Question Number	Number of Items
1.	Not focused	1	1 grain
2.	Saturated	2	1 grain
3.	Students' need for new learning media	3	1 grain
4.	Can use computers	4, 5	2 grains
5.	Learning methods	6, 7, 8	3 grains
	Total		8 grains

Table 4. Student response questionnaire grid

No.	Indicator	Statement (+)	Statement (-)	Question Number	Number of Items
1.	Use	6	2	1, 2, 3, 4, 5, 6, 7, 8	8 grains
2.	Future impact	3	4	9, 10, 11, 12,13,14, 15	7 grains
3.	Material benefits	7	2	16,17,18, 19, 20, 21, 22, 23, 24	9 grains
4.	Use of illustrations	7	4	25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35	11 grains
5.	Grammar	1	4	36, 37, 38, 39, 40	5 grains
			Total		40 grains

2.5. Data Processing Techniques

The data obtained from the instrument validation sheet, the media availability checklist sheet is then processed to find the percentage. The presentation is found using the following formula:

$$Presentation = \frac{Total\ Score}{Maximum\ Score} x\ 100\%$$

The data obtained from the media needs questionnaire instrument, media validation sheet, material validation sheet, and student responses were processed to find the percentage. In determining the score, it was done using a Likert scale. According to Sugiyono, "with a Likert scale, the variables to be measured are described into variable indicators. These indicators are used as a starting point in compiling instrument items that can be in the form of statements or questions."

Table 5. Statement Description

Positive Statement		Negative Statement	
Very Agree	5	Very Agree	1
Agree	4	Agree	2
Neutral	3	Neutral	3
Disagree	2	Disagree	4
Very Disagree	1	Very Disagree	5

2.6. Data Analysis Techniques

Data analysis is carried out at each stage of development which includes definition, design, and development. The data analysis is carried out by describing everything that has been done. The media that has been developed is assessed for its feasibility with a material and media validation sheet by material experts and media experts. As a provision in providing meaning to media validation decision making, the following provisions are used.

Table 6. Validation Criteria on the Validation Sheet

Achievement Level	Qualifications	Description
81 – 100%	Very Eligible	No revision required
61 – 80%	Eligible	No revision required
41 – 60%	Quite Eligible	Need revision
21 – 40%	Less Eligible	Need revision
0 – 20%	Not Eligible	Total revision

The data collected in this study are classified into quantitative data and qualitative data. Quantitative data is in the form of numbers while qualitative data is in the form of words or symbols. The data generated from the questionnaire responses are then tabulated and their presentations are searched for and then analyzed. After that, researchers can determine whether the development of augmented reality-based learning media is included in the category of very good, good, sufficient, lacking or very lacking.

Table 7. Score Interpretation Criteria

No.	Interval	Category
1.	81 – 100%	Very Good
2.	61 – 80%	Good
3.	41 – 60%	Enough
4.	21 – 40%	Less
5.	0 – 20%	Very Less

3. RESULTS AND DISCUSSION

3.1. Media Validation

After the interactive learning media based on augmented reality was created, the media was checked and refined through validation by 2 media experts and 2 material experts. The validation results are as per Table 8 below.

Table 8. Media Validation Results by Material Experts

No.	Aspects	Percentage (%)	Criteria	Description
1.	Material accuracy/precision	86.66	Very Eligible	No revision required
2.	Material depth and breadth	72.22	Eligible	No revision required
3.	Material suitability with indicators	84.28	Very Eligible	No revision required
4.	Visual suitability with material	81.76	Very Eligible	No revision required
5.	Material adequacy	80.00	Eligible	No revision required
6.	Currency	77.50	Eligible	No revision required
	Average percentage (%)	80.41	Eligible	No revision required

Based on the validation results by material experts, the lowest aspect is "depth and breadth of material" of 72.22% with the criteria of feasible and does not need to be revised. The average percentage of all aspects is 80.41% with the criteria of feasible, meaning it can be tested directly without revision. However, suggestions and input from material experts are made improvements in order to improve the quality of the media developed.

Table 9. Media Validation Results

No.	Aspects	Percentage (%)	Criteria	Description
1.	Material accuracy/precision	94.24	Very Worthy	No revision required
2.	Material depth and breadth	87.27	Very Worthy	No revision required
3.	Material suitability with indicators	90.00	Very Worthy	No revision required
4.	Visual suitability with material	92.22	Very Worthy	No revision required
5.	Material adequacy	90.00	Very Worthy	No revision required
6.	Currency	97.78	Very Worthy	No revision required
	Average percentage (%)	91.92	Very Worthy	No revision required

Based on the validation results by media experts, the lowest aspect is "Readability & benefits of captions" of 87.27% with very feasible criteria with the statement that it does not need to be revised. In addition, all aspects are in the very feasible criteria, meaning that they do not need to be revised so that the media can be directly tested on students to ask for their responses to interactive learning media based on augmented reality.

3.2. Student Responses to Augmented Reality Interactive Learning Media on Chemical Bonding Material

The developed media products were then tested on students to obtain data in the form of user (student) responses to interactive learning media based on augmented reality. To obtain student responses as data from the media trial results, 40 students in the trial class, namely class A in high school, were asked to fill out a questionnaire. So that student responses were obtained on 5 aspects, namely aspects of use (usability), future impact, use of illustrations, usefulness of materials, and grammar. The following is the data from the media product trial results obtained as in Table 10.

Table 10. Results of Student Response Questionnaire

No.	Aspects	Percentage (%)	Criteria
1.	Usage	85.75	Very Good
2.	Future Impact	74.57	Good
3.	Material Utilization	79.64	Good
4.	Use of Illustrations	81.80	Very Good
5.	Grammar	77.20	Good
Average percentage (%)		79.78	Good

Based on the data in Table 10, it can be seen that the assessment aspect with the highest percentage is the usability aspect, which is 85.75% in the very good category, then the lowest aspect is the future impact aspect with a percentage of 74.57% in the good category.

This research has the potential to provide a significant impact in improving the quality of chemistry learning, especially in understanding the abstract concept of chemical bonds. The augmented reality-based learning media developed can help students understand concepts more clearly through three-dimensional visualization and interactive learning experiences. This can also increase student motivation and engagement in the learning process, while contributing to the development of educational technology in the field of science. However, this research has several limitations. First, the implementation of this learning media requires technological devices such as smartphones or tablets that may not be evenly available in all educational institutions. Second, the effectiveness of this media is still limited to certain research contexts and has not been tested on a wider population with diverse student characteristics. In addition, the development of this media requires costs and technical skills that may be obstacles for educators in areas with limited resources.

4. CONCLUSION

Based on the results of the research that has been conducted, it can be concluded that interactive learning media based on augmented reality technology on chemical bonding material produced in the form of applications and marker books developed through the Warsita development model which includes the design, production and evaluation stages. Interactive learning media based on augmented reality technology on chemical bonding material in the form of applications and marker books developed received a positive response from students of 79.78% and was included in the good category. Further research is suggested to explore the effectiveness of this augmented reality augmented reality-based learning media in various age groups and education levels to test the generalizability of the results. In addition, the development of media that integrates augmented reality-based evaluation features can be an innovative step to measure students' understanding in real-time during the learning process.

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