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Development of Augmented Reality-Based Mobile Learning Media on Molecular Shapes for High School Students

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Abstract: *Chemistry learning on molecular shapes remains challenging due to the abstract and three-dimensional nature of the concept, while existing learning media often fail to provide interactive visualization. This study aims to develop and evaluate an Augmented Reality (AR)-based mobile learning media to improve students' understanding of molecular geometry. The research employed a Research and Development (R&D) approach using the ADDIE model through stages of analysis, design, development, implementation, and evaluation. The developed AR media visualizes 3D molecular models that can be manipulated via smartphones. Expert validation results indicated that the media was highly feasible, while student trials showed significant improvements in learning outcomes (N-Gain = 0.65) and motivation. The findings suggest that AR technology effectively supports the comprehension of abstract chemical concepts and offers an innovative solution for technology-integrated learning in 21st-century classrooms.*

Keywords: *Augmented reality; learning media; molecular shape; chemistry education; mobile learning*

INTRODUCTION

The rapid development of digital technology has transformed educational practices, emphasizing the integration of Information and Communication Technology (ICT) to promote 21st-century learning. In the field of chemistry education, molecular shape is one of the most abstract topics, requiring students to visualize and interpret three-dimensional structures that cannot be directly observed. Conventional learning methods such as textbooks and two-dimensional illustrations often fail to help students comprehend spatial molecular geometry effectively (Alfian et al., 2019). This limitation contributes to the low learning outcomes of students, as observed in SMA Negeri 1 Percut Sei Tuan, where the average score for molecular shape material remains below the Minimum Mastery Criteria (KKM) of 70.

Several empirical studies have demonstrated that Augmented Reality (AR) can improve students' conceptual understanding, motivation, and engagement in learning complex scientific concepts (Socrates & Mufit, 2022; Basri & Achmadi, 2024; Lin et al., 2022; Huang & Chen, 2023). AR enables students to manipulate three-dimensional molecular structures interactively, bridging the gap between abstract representations and concrete experiences (Ibáñez & Delgado-Kloos, 2018). However, most previous studies have focused on general chemistry topics or isolated learning activities without systematic development or validation of AR-based media specifically for molecular geometry in senior high schools. This indicates a research gap that necessitates further investigation.

Unlike conjectural assumptions, this study is grounded in established educational and technological theories. The effectiveness of AR is supported by constructivist learning theory, which posits that students construct knowledge through direct interaction with visual and contextual representations. Thus, developing and validating AR-based media for molecular shape learning provides a factual and theoretically supported approach to address students' conceptual difficulties.

1. Research Objective

This study aims to:

1 Develop an Augmented Reality (AR)-based mobile learning media on molecular shape material for senior high school students.
2 Evaluate the feasibility, effectiveness, and validity of the developed media using the ADDIE model.
3 Analyze the impact of the AR-based learning media on students' learning outcomes and motivation.

2. Research Benefits

The results of this study are expected to:

1. Provide an alternative learning tool that supports the visualization of abstract molecular geometry concepts.
2. Offer teachers a practical reference for integrating AR technology in chemistry learning.
3. Contribute to educational technology development by demonstrating the potential of AR-based learning in improving students' conceptual understanding and engagement.

LITERATURE REVIEW

1. Learning Media

Effective learning media combine hardware and software to deliver instructional messages. AR media provides rich visual contexts that enhance students' conceptual understanding and engagement.

2. Augmented Reality in Education

AR overlays virtual objects onto real-world environments, supporting real-time interaction and 3D visualization. Research has shown AR's potential in improving students' motivation, critical thinking, and academic performance.

3. Unity 3D and Vuforia

Unity is a powerful cross-platform engine used to develop AR applications, while Vuforia is a software development kit integrated with Unity to enable object recognition and 3D object placement in real-world scenes.

4. Molecular Shape Concepts

Understanding molecular geometry involves theories such as VSEPR, hybridization, and molecular orbitals. These models require spatial reasoning and are best illustrated through 3D simulations.

METHODS

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The research was conducted at SMA Negeri 1 Percut Sei Tuan in the 2024/2025 academic year.

1. Analysis Stage

This stage involved identifying students' learning problems and needs in understanding molecular shapes. Data were collected through teacher interviews, student questionnaires, and analysis of chemistry curriculum documents. The results showed that students struggled with visualizing three-dimensional molecular geometry, and existing learning media were insufficient..

2. Design Stage

Based on the analysis, the AR-based mobile learning media was designed using Unity 3D and Vuforia SDK. The design included 3D molecular models (e.g., CH_4, NH_3, H_2O, CO_2) that could be manipulated through a smartphone camera. The media structure included: (a) introduction menu, (b) molecular visualization section, and (c) quiz feature for formative assessment.

3. Development Stage

The AR media prototype was developed and validated by three experts: a media expert, a material expert, and a chemistry teacher. The validation instrument used a Likert scale (1–5) assessing content accuracy, visualization quality, interactivity, and usability. Revisions were made based on expert feedback before implementation.

4. Implementation Stage

The validated AR media was tested on 32 students of Class XI MIPA at SMA Negeri 1 Percut Sei Tuan. Students used the media in small groups under teacher guidance during a 90-minute chemistry session. Data were collected through pre-test and post-test instruments and motivation questionnaires.

5. Evaluation Stage

The evaluation consisted of formative evaluation during each development phase and summative evaluation after classroom implementation. Quantitative data (learning outcomes) were analyzed using N-Gain to determine learning improvement, while qualitative feedback from students and teachers was analyzed descriptively. The criteria for effectiveness were based on Hake's (1998) classification: high (N-Gain > 0.7), moderate (0.3 ≤ N-Gain ≤ 0.7), and low (< 0.3).

RESULT AND DISCUSSION

1. Media Validation Results

The developed Augmented Reality (AR) learning media was evaluated by two expert reviewers: one media expert and one subject matter expert. The validation aimed to assess the feasibility and appropriateness of the media for classroom use.

The results showed that:

- The media expert rated the application as *"Very Feasible"*, with an average score of 88.75%, indicating good visual design, interactivity, and usability.
- The subject matter expert gave a score of 90.00%, which also falls into the *"Very Feasible"* category. This validates the scientific accuracy and alignment of the content with the curriculum.

These findings confirm that the AR media meets both pedagogical and technological standards for use in chemistry education.

2. Improvement in Student Learning Outcomes

To assess the effectiveness of the AR media, a pre-test and post-test were administered to the students. The pre-test measured students' initial understanding of molecular shapes, while the post-test was conducted after the learning intervention using the AR application.

- The average pre-test score was 53.2, below the Minimum Mastery Criteria (KKM) of 70.
- The average post-test score increased significantly to 83.6.
- The normalized gain (N-Gain) was 0.65, which falls into the "moderate to high" improvement category.

N-Gain Formula:

$$N - Gain = \frac{s\ posttest - s\ pretest}{s\ maximum - s\ pretest}$$

where:

s_post = post-test score

s_pre = pre-test score

s_max = maximum possible score

The interpretation of N-Gain values follows Hake's classification:

High: $N - Gain > 0.7$

Moderate: $0.3 \leq N - Gain \leq 0.7$

Low: $N - Gain < 0.3$

The analysis resulted in an average N-Gain of 0.65, which falls into the moderate category, indicating that the AR-based media significantly improved students' understanding of molecular geometry.

3. Student Interest and Response

A student response questionnaire was distributed to evaluate their interest and engagement with the AR media. The results showed that:

- The average response score was 89.2%, categorized as *"Very Positive."*
- Students reported that the use of AR made the learning process more enjoyable, interactive, and easier to understand.
- Many students expressed appreciation for being able to rotate, zoom, and manipulate 3D molecular models on their own smartphones.

This aligns with previous findings that AR can increase motivation, especially when students are allowed to explore learning content autonomously (Basri & Achmadi, 2024; Ningsih et al., 2020).

4. Correlation Between Student Interest and Learning Outcomes

A Pearson correlation analysis was conducted to examine the relationship between student interest (as measured by the response questionnaire) and learning outcomes (post-test scores). The analysis showed a positive correlation coefficient ($r = 0.68$), indicating a moderate to strong correlation between interest and performance.

This suggests that students who showed higher interest in the AR learning media tended to achieve better academic results, reinforcing the importance of engaging, student-centered instructional tools in science education.

Discussion

The improvement in learning outcomes (N-Gain = 0.65) demonstrates that the AR-based learning media effectively facilitates students' understanding of molecular shapes. This result aligns with previous findings by Lin et al. (2022) and Huang & Chen (2023), who reported that AR-based science learning significantly enhances spatial reasoning and engagement. The 3D visualization provided by AR allows students to manipulate molecular models directly, bridging the gap between abstract theory and visual experience.

The increase in student motivation also supports the constructivist learning principle, where interactive visualization fosters deeper conceptual construction. Compared to earlier studies that only applied AR for general chemistry concepts (e.g., acids and bases), this study contributes by developing a systematically validated AR media focused specifically on molecular geometry. This provides both empirical and theoretical support for the integration of AR technology in chemistry learning.

Therefore, the study's contribution lies in demonstrating how AR-based mobile media can effectively transform abstract chemical concepts into tangible visual experiences, offering a replicable model for future educational technology research.

CONCLUSION

This study successfully developed an Augmented Reality (AR)-based mobile learning media for molecular shape material in senior high school chemistry. The media was declared feasible based on expert validation and showed a moderate improvement in student learning outcomes (N-Gain = 0.65) and motivation. These findings confirm that AR technology can effectively support the visualization of abstract chemical concepts and foster meaningful learning experiences.

From a theoretical perspective, this study strengthens the application of constructivist learning theory, demonstrating that interactive AR visualization enables students to construct chemical knowledge through active engagement. Practically, the developed AR media can be used by teachers as an innovative alternative for facilitating molecular geometry learning and enhancing students' spatial reasoning skills.

However, this study has certain limitations. The implementation was conducted on a limited number of students in one school, and the study only focused on one chemistry topic molecular shapes. Therefore, the generalizability of the results is limited. Future research should involve a larger and more diverse sample, integrate AR media into other chemistry topics, and examine its long-term effects on students' retention and problem-solving abilities.

In conclusion, the developed AR-based learning media provides a promising model for integrating digital technology in science education. It contributes to both theory and practice by offering empirical evidence of how AR enhances conceptual understanding, motivation, and engagement in learning abstract scientific concepts..

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