INDONESIAN JOURNAL OF SCIENCE AND MATHEMATICS EDUCATION
https://ejournal.radenintan.ac.id/index.php/IJSME/index
08 (1) (2025) 106-118
E-ISSN: 2615-8639
DOI: 10.24042/ijsme.v8i1.26242
March 2025

Augmented reality as an interactive multimedia in developing student's visual intelligence on molecular geometry material

Lily Widya Sari[1], Kusumawati Dwiningsih[2*]
[1,2]Department of Chemistry Education, Faculty of Mathematics and Science, Universitas Negeri Surabaya, Surabaya, Indonesia

**Corresponding author:* kusumawatidwiningsih@unesa.ac.id

Article history:

Submitted: February 5, 2025
Accepted: March 2, 2025
Published: March 30, 2025

Keywords:

augmented reality, interactive multimedia, molecular geometry, visual intelligence

ABSTRACT

Being abstract and diverse, molecular shape material necessitates two or three-dimensional visualization media. This research seeks to develop interactive AR learning multimedia to enhance molecular geometry comprehension and students' visual intelligence. This study focuses on the development phase by employing the 4D Research and Development model, encompassing defining, designing, developing, and disseminating. Instruments include pre-tests, post-tests, student questionnaires, and validation sheets. Validation yields content and construct validity scores of 3 and 4, indicating valid or very valid criteria. Practicality exceeds 90%, deemed very practical. Effectiveness testing reveals that over 80% of students who achieved n-gain scores above 0.3 were classified as medium to high. These findings establish AR-based learning media as feasible for grasping molecular geometry and fostering visual intelligence. The implications of this research highlight AR's capacity to reinforce conceptual understanding and stimulate visual intelligence. Therefore, strategically optimizing technology-driven learning media like AR is crucial to align with the evolving digital landscape in education.

Augmented Reality *sebagai multimedia pembelajaran interaktif untuk meningkatkan kecerdasan visual siswa pada materi bentuk molekul*

Kata Kunci:

augmented reality, *multimedia interaktif, geometri molekuler, kecerdasan visual*

ABSTRAK

Materi bentuk molekul, yang bersifat abstrak dan beragam, membutuhkan media visualisasi dua atau tiga dimensi. Penelitian ini bertujuan untuk mengembangkan multimedia pembelajaran AR interaktif guna meningkatkan pemahaman geometri molekul dan kecerdasan visual siswa. Menggunakan model Penelitian dan Pengembangan 4D, yang mencakup pendefinisian, perancangan, pengembangan, dan penyebaran, penelitian ini berfokus pada tahap pengembangan. Instrumen yang digunakan meliputi tes awal, tes akhir, kuesioner siswa, dan lembar validasi. Validasi menghasilkan skor validitas konten dan konstruk 3 dan 4, yang menunjukkan kriteria valid atau sangat valid. Praktikalitas melebihi 90%, dianggap sangat praktis. Pengujian efektivitas menunjukkan lebih dari 80% siswa mencapai skor n-gain di atas 0,3, diklasifikasikan sebagai sedang hingga tinggi. Temuan ini menetapkan media pembelajaran berbasis AR layak untuk memahami geometri molekul dan mengembangkan kecerdasan visual. Implikasi dari penelitian ini menyoroti kemampuan AR untuk tidak hanya memperkuat pemahaman konseptual tetapi juga merangsang kecerdasan visual. Oleh karena itu, optimalisasi *strategis media pembelajaran berbasis teknologi seperti AR sangat penting untuk menyesuaikan diri dengan lanskap digital yang terus berkembang dalam pendidikan.*

Contribution to the literature

This research contributed to:

- Developing AR-based learning media to improve understanding of molecular geometry concepts.
- Explaining the feasibility of AR-based learning media in supporting the effectiveness of chemistry learning.
- Analyzing the potential of AR technology in improving students' visual intelligence in understanding molecular geometry.

1. INTRODUCTION

An individual may enhance the quality of life using education. The success of a country's development is influenced by the quality of education [1]. Through education, individuals will gain knowledge to determine the future direction. High school education is a phase where students study various sciences, including chemistry, with broad cultural applications and implications [2].

Chemistry includes abstract theories like atomic structure, the periodic table, and chemical bonds. This makes chemistry a challenging subject because it is difficult for students to comprehend and causes students to be reluctant to study chemistry [3]. Understanding concepts is important for preventing misconceptions and supporting in-depth mastery of chemical material. One abstract chemical sub-material is molecular geometry, which requires thinking at a submicroscopic level and three-dimensional visualization [4]. Molecular geometry is one of the chemical materials that studies the shape of molecules in 3 dimensions, which is determined by the number of bonds and the size of the angles around the central atom [5].

According to the outcome of pre-research at a senior high school (SMA) in Gresik, 28 out of 30 students scored below 75 on the molecular geometry material. The main difficulty for students lies in the ability to imagine the three-dimensional structure of molecules and describe them in two dimensions. This issue shows the need to develop students' visual intelligence to help their understanding. This issue occurs due to the limitations of the learning media used to visualize molecular shapes in two or three dimensions [6].

Intelligence is the ability possessed by humans to solve a problem or create a product. Humans have various levels of intelligence; Gardner defines seven categories of intelligence: linguistic, musical, logical-mathematical, visual-spatial, kinetic, interpersonal, and intrapersonal intelligence [7]. This ability includes understanding shapes and images and creating spatial representations that can be applied in chemistry learning. Visual intelligence is the capability to understand and interpret visual forms, which consists of four main aspects: conceptualization, imagination, problem-solving, and pattern identification [8].

Technological advancement presents great opportunities for learning media innovation [9]. In the era of Society 5.0, technological development will be faster, and artificial intelligence will support human work. Furthermore, four 21^{st}-century skills support Society 5.0: communication, creativity, critical thinking, and collaboration [10]. One strategy to deal with Society 5.0 is to apply AR technology in education [11]. One of the potential technologies to support the visualization of abstract concepts in a real form is AR [12]. AR technology does the real-time and interactive integration of two or three-dimensional items in the physical environment, providing an engaging, interactive learning experience that supports spatial understanding [13]. Students can check the correspondence between the visualization of molecular geometry and the imagination imagined using AR technology [14]. AR can improve students' visual intelligence by manipulating 3D objects directly in a real environment [15]. Marker-based AR technology was implemented in this investigation. The marker functions to display 3D objects above the marker [16]. The advantage of using a marker is that when using AR technology, an internet connection is not required [2]. In marker-based AR, the camera must scan the marker to recognize certain points, which will then display a virtual object. However, the virtual object will disappear if the marker is undetected [17].

Visualization in learning media can help students understand difficult concepts in chemistry lessons, especially molecular geometry material [18]. Learning using AR learning media is expected to increase students' enthusiasm for learning and create an interactive learning process [19]. In training students' imagination and creativity, AR technology-based learning media can be used [20].

Previous research shows that AR technology can improve students' conceptual understanding. Research on AR development has been widely conducted, including the development of AR-based flashcards on voltaic cell material [21], the use of AR Geogebra on geometric transformation material [22], AR media development on chemical bonding material [23], AR is integrated with the 5E Learning Model in Biology [24], and the integration of chatbots and AR in biology learning [25]. Although many previous studies discussed AR technology in education, specific studies on AR were still lacking, especially regarding visual intelligence. Research conducted by Safira & Lutfi shows that students with higher visual intelligence better understand chemical concepts. However, previous studies focused more on the role of visual intelligence in understanding chemical bonds, while its impact on learning molecular geometry was still less explored [26]. This research's novelty is combining AR, learning videos, and text material in one learning media to strengthen students' visual intelligence. This research aims to analyze the feasibility of AR-based interactive learning media in improving students' visual intelligence in molecular geometry material. In addition, this research also aims to help students visualize molecular structures in three dimensions to facilitate understanding of abstract chemical concepts.

2. METHOD

This research applied the Research and Development method by utilizing a 4D development model (Definition, Design, Development, and Dissemination stages) [26], [27]. However, the stages were restricted to the development stage. Time, energy, and funding constraints made it impossible to conduct comprehensive research [28].

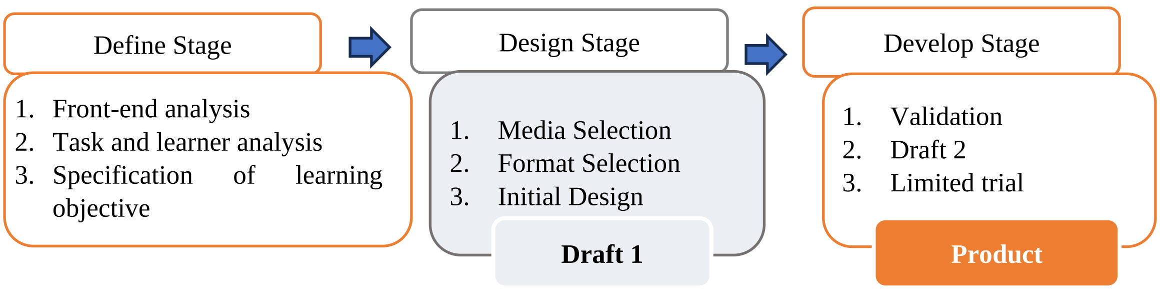


Figure 1. Research Procedure

The Define stage included initial analysis, student analysis, and the determination of learning objectives. After receiving ethics approval, the research was conducted. This stage was carried out through interviews with chemistry teachers and an analysis of the curriculum used at one of the senior high schools in Gresik. During the Design stage, various activities were undertaken. These included the creation of assessments and test instruments, selecting the application used to develop interactive learning based on AR, compiling storyboards and flowcharts for interactive multimedia learning, and the development of AR-based learning media according to the prepared storyboard and flowchart. In the Development stage, the product was assessed by two Chemistry Lecturers and one Chemistry Teacher using content and construct validity instruments. The feasibility of the developed media was evaluated through a response questionnaire completed by students. An effectiveness test was also conducted by analyzing learning outcomes and students' visual intelligence levels using pretest-posttest instruments. The validators assessed the product based on established indicators using a Likert scale with a score range of 0-4, as interpreted in Table 1 [29].

Table 1. Validation Score

Score	Criteria
0	Not Valid
1	Less Valid
2	Quite Valid
3	Valid
4	Very Valid

Validity scores were analyzed using median [30] and were declared valid if they had a median value of more than 3 (valid criteria). Furthermore, a limited trial involved 30 eleventh-grade students at one of the senior high schools in Gresik. After receiving consent from parents and students, the research was conducted. The study aimed to determine the practicality and effectiveness of AR technology-based learning media, as eleventh-grade students had previously studied molecular forms using conventional learning methods. This evaluation allowed researchers to assess the impact of AR-based learning media on students' learning outcomes and visual intelligence. The practicality of the media was measured through a response questionnaire completed by students after using the learning media, utilizing the Guttman scale [31].

Table 2. Guttman Scale

Statement	Answer	Score
Positive	Yes	1
	No	0
Negative	Yes	0
	No	1

The percentage of student response test results is the total value divided by the maximum value and then multiplied by 100%. The interpretation follows the criteria in Table 3 [29].

Table 3. Practical Score Interpretation

Percentage (%)	Criteria
0-20	Very impractical
21-40	Impractical
41-60	Quite Practical
61-80	Practical
81-100	Very Practical

If AR-based learning multimedia scores more than 61%, then the multimedia is practical. The effectiveness was measured through student test scores analyzed using the N-Gain. It is effective if the multimedia obtains an n-Gain score of more than 0.3 [32].

3. RESULTS AND DISCUSSION

This study aims to ensure that interactive learning media based on AR that enhances visual intelligence is also suitable as a learning tool. Interactive learning multimedia developed using AR technology aims to create media that can help students interactively visualize the shape of molecules. The developed product is an application that students can download and access via smartphones. AR technology can be accessed by scanning the QR code from the card students download when downloading the developed media. AR technology enables students to interact with animations of molecular geometry, such as moving and changing sizes. It can clarify material in the learning process and change abstract concepts into three-dimensional object visualizations that appear more realistic [33].

3.1 Define

At the pre-research stage, an interview was conducted with a chemistry teacher at one of the senior high schools in Gresik regarding the chemistry learning process, molecular geometry material, and visual intelligence. This interview aimed to identify challenges in teaching molecular geometry and determine the learning media used in schools. The results revealed that teachers primarily relied on conventional media, such as Microsoft PowerPoint, textbooks, plasticine, and toothpicks, for teaching molecular geometry.

The main difficulties faced by students included the large amount of information they needed to memorize about various molecular structures and the challenge of converting two-dimensional images into three-dimensional forms or vice versa. Students' visual intelligence in understanding molecular geometry was primarily trained using plasticine and toothpicks, which provided a dynamic yet limited representation of molecular structures. In addition to interviews with chemistry teachers, a pre-research questionnaire was administered to 30 students. The results indicated that their knowledge of molecular structures remained abstract, and they struggled to visualize molecules in three dimensions.

Student analysis was conducted based on age and academic ability. The study subjects were grade XI students from one of the senior high schools in Gresik, with an average age of 17. According to Piaget's cognitive development theory, 17-year-olds are in the formal operational stage, where they should be capable of understanding abstract concepts and demonstrating systematic reasoning abilities [34]. However, despite being in this stage, the questionnaire results indicated that students' comprehension was still limited due to the constraints of the learning media available. This limitation underscored the need to develop AR-based learning media to enhance students' visual intelligence. AR technology enables the interactive and in-depth visualization of abstract molecular structures, allowing students to grasp complex concepts more easily. Consequently, this approach makes learning more efficient and effective [35].

3.2 Design

The completed tasks included preparing test instruments and designing and developing learning media. The instruments developed consisted of media review and validation instruments, student response questionnaire sheets, and student cognitive and visual ability test sheets on molecular geometry material, all equipped with answer keys and assessment rubrics. During the Design stage, a storyboard and flowchart were created as the initial plan for developing the learning media. The flowchart used in the media development is shown in Figure 2. The storyboard outlined the multimedia formats that were to be developed. These components served as essential guides in the subsequent development phase. Their clarity and structure ensured the learning media addressed both pedagogical and visual goals effectively.

Designing learning media began with preparing materials based on learning objectives using Microsoft Word. The main components of interactive multimedia learning include several key elements. Instructions for use helped students understand the function of each icon. Competency sections directed students toward learning objectives. Learning videos and materials provided visual and auditory learning content. The AR menu enabled direct interaction with 3D objects, which has been shown to enhance the understanding of abstract concepts, particularly in chemistry learning [36]; practice questions assessed students' comprehension of the material, while the references section provided sources for further learning on molecular geometry. Additionally, the developer's profile was included as supplementary information. These features were carefully designed to ensure alignment with the curriculum and support self-paced learning. The integration of various media aimed to create an engaging and effective learning experience.

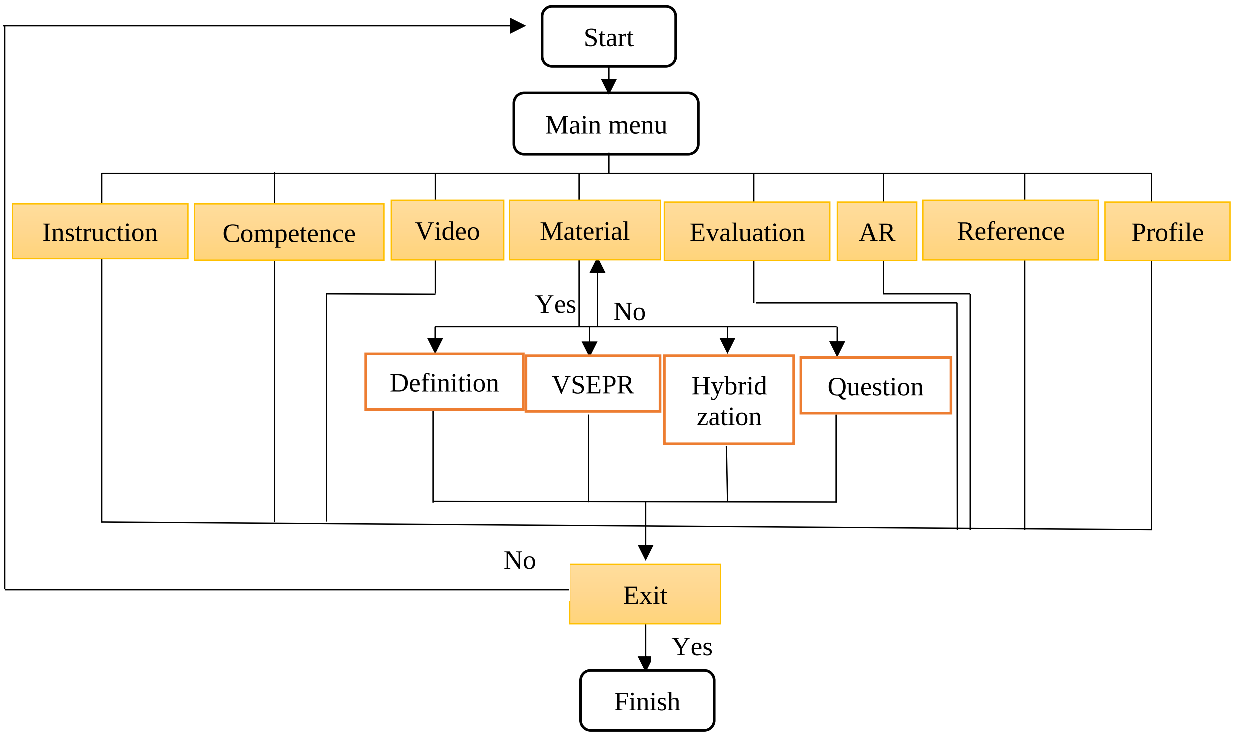


Figure 2. The Flowchart of the Developed Media

Media design was done using Canva, while development was done with Vuforia, Unity, and Blender software. Integrating elements such as video, AR, material, and evaluation in one learning media is expected to improve students' understanding of molecular shapes [37]. This integration offers a more interactive and immersive learning experience. By combining visual, auditory, and kinesthetic modalities, students can engage more deeply with the content. Such a multimedia approach aligns well with current trends in educational technology for enhancing conceptual understanding.

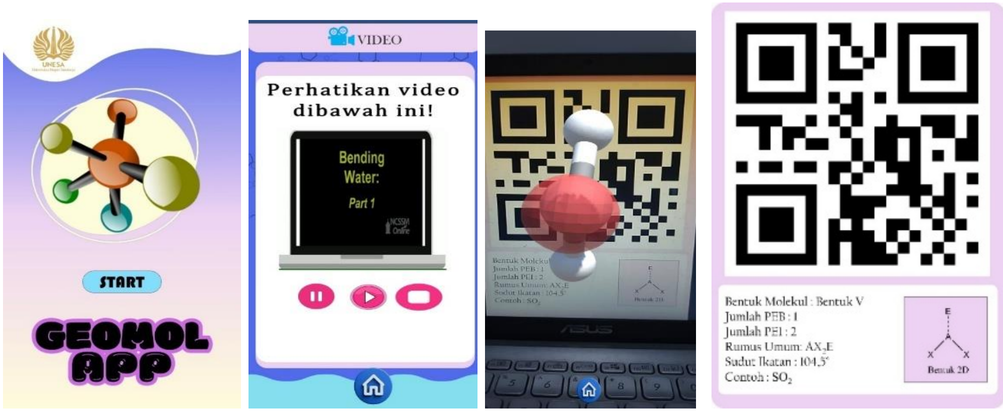


Figure 3. The Design of AR-based Interactive Learning Media

3.3 Development

The validity data of the developed interactive learning multimedia was obtained from validation conducted by three validators using content and construct validity instruments. Content and construct validity data were analyzed using the median, showing that the overall scores obtained were 3 and 4, with valid and very valid criteria.

Table 4. Result of Content and Construct Validity

Aspect	Indicator	Median	Criteria
Content	Suitability to the curriculum	4	Very Valid
	Correctness of concept	4	Very Valid
	Appropriateness of Illustrations and Animations with the Material	4	Very Valid
	Conciseness of Material	4	Very Valid
	Provision of Evaluation	4	Very Valid
	Visual Intelligence Aspect	4	Very Valid
Construct	Ease of using Learning Media	4	Very Valid
	Readability of Text	3	Valid
	Visual and Audio Features and Displays	4	Very Valid
	Language Usage	3	Valid
	Media Benefits	4	Very Valid

Each aspect of the developed AR-based learning multimedia assessment had a minimum score of three for the valid criteria. All aspects received a score of four for content validity, indicating very valid criteria. Regarding construct validity, two aspects received a score of three, classified as valid, while three aspects received a score of four, classified as very valid. These results demonstrated that the developed AR-based learning multimedia could effectively teach molecular geometry content.

Content validity was assessed to determine the alignment between the material in the learning media and the curriculum, scientific concepts, and aspects of visual intelligence. Construct validity was evaluated to ensure that the media aligned with media design principles. As shown in Table 3, each statement received a median score of at least three, falling within the valid and very valid categories. Content validity was reviewed from several aspects, namely:

1. The content's alignment with the curriculum (learning outcomes and objectives) received a four score in the very valid criteria.
2. The accuracy of the material presented with scientific concepts received a four score in the very valid criteria.

3. The relevance of the content with the illustrations presented received a four score in the very valid criteria.
4. The media's presentation of information scored four in the very valid criteria.
5. The media's appropriateness in terms of visual intelligence receives a score of 4, placing it in the very valid criteria.

Construct validity was reviewed from several aspects, namely:

1. The ease of use scored four in the very valid criteria.
2. The text readability, including fonts and colors, scored three in the valid criteria.
3. Features and visual displays, including images, videos, 3-dimensional animations, and audio, received a score of four in the very valid criteria.
4. The language component received a score of three with the valid criteria.
5. Using media as learning media scored four in the very valid criteria.

The research findings indicate that AR-based learning media is valid and approved as a learning medium. This finding aligns with research conducted by Putra and Fajri, showing that AR-based learning multimedia is valid for use in the chemistry learning process at school [38]. The developed multimedia is also equipped with learning videos, material summaries, and practice questions to create more interesting learning, increasing students' enjoyment of learning and visual intelligence. The media developed in this research offers user-friendly learning media for students and can create interactive and interesting learning experiences. This supports the potential of AR technology as an effective tool to enhance student engagement and conceptual understanding.

Validated multimedia was evaluated in a limited trial with 30 students at one of the senior high schools in Gresik. The effectiveness of the produced media was tested in limited trials. The pre-test and post-test results of cognitive ability and visual intelligence were then analyzed using the normality test in Tables 5 and 6.

Table 5. The Normality of the Cognitive Tests

Tests of Normality						
	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Pretest cognitive ability	.215	30	.001	.912	30	.017
Posttest cognitive ability	.241	30	<.001	.822	30	<.001

Table 6. The Normality of the Visual Intelligence Test

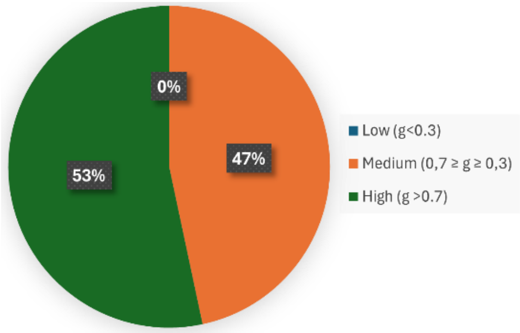
Tests of Normality						
	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Pretest visual intelligence	.129	30	.200*	.954	30	.222
Posttest visual intelligence	.182	30	.013	.916	30	.022
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

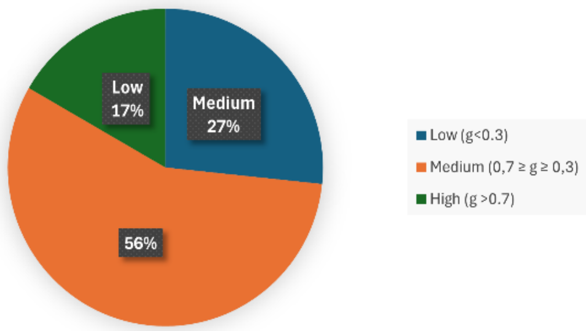
Referring to the Kolmogorov-Smirnov test, the pre-test and post-test data of cognitive ability and visual intelligence had a significant value of less than 0.05, which indicates that the data is not normally distributed [31]. Therefore, the next analysis must use a non-parametric, the Wilcoxon test. The Wilcoxon test was performed because the form of the data analyzed was paired sample data and was ordinal to measure the difference between pre-test and post-test scores [39]. This test is suitable for small sample sizes and does not require the assumption of normality. Thus, it provides a reliable method for analyzing the effectiveness of the treatment in this study.

Table 7. The Result of the Wilcoxon Test

Wilcoxon Test on Visual Intelligence Test		Wilcoxon Test on Cognitive Test	
Posttest Visual Intelligence - Pretest Visual Intelligence		**Posttest Cognitive Ability - Pretest Cognitive Ability**	
Z	-4.809b	Z	-4.799b
Asymp. Sig. (2-tailed)	<.001	Asymp. Sig. (2-tailed)	<.001
a. Wilcoxon Signed Ranks Test		a. Wilcoxon Signed Ranks Test	
b. Based on negative ranks.		b. Based on negative ranks.	

The Wilcoxon test's outcome shows that using AR-based learning media significantly increases students' visual intelligence. The n-gain test of the cognitive abilities and visual intelligence results in Figure 4 supports this claim. Learning molecular geometry using the developed media showed a significant increase in visual intelligence and student learning outcomes based on the n-gain analysis of thirty students. Student learning outcomes in the high category were 53%, and 43% were in the medium category. The students' visual intelligence in the high category was 56%, and in the medium category was 27%. However, 17% of students were in the low category. The results show how students increased their learning outcomes and visual intelligence after using the AR-based media developed.





(a) (b)

Figure 4. The Graph of (a) n-Gain Score of Cognitive Test and (b) n-Gain Score of Visual Intelligence Test

Thus, AR technology is an innovative learning strategy to enhance students' cognitive understanding and visual intelligence in understanding molecular geometry. This follows the research of Miftah et al., which shows that AR-based learning media is useful for helping students understand abstract chemical concepts [40]. Furthermore, in the limited trial, questionnaire response data was collected and analyzed using a percentage formula.

Table 8. Result of Practical Assessment

Assessed Aspect	Percentage (%)	Criteria
Presentation	96	Very Practical
Utilization	97	Very Practical
Material	94	Very Practical
Language	96	Very Practical

In Table 8, all aspects of the questionnaire scored above 90%, with a very practical category. The results of this assessment follow the research of Ramadani et al., who stated that AR-based learning media is practical for use as a chemistry learning medium [41]. However, previous studies have focused more on the application of AR in improving learning outcomes without measuring its impact on students' visual intelligence in understanding three-dimensional molecular structures. This research closes this gap by analyzing the effectiveness of AR in improving students' visual intelligence, which is a factor in understanding abstract concepts such as molecular geometry. Learning that utilizes visual representations and direct interaction with materials can improve understanding of information in line with constructivism theory, which states that knowledge is built through active experience [42]. AR provides a platform that supports such active learning by allowing students to explore learning objects directly. AR technology helps students visualize three-dimensional chemical objects interactively [43]. Previous research results explain that students easily understand complex chemical material using AR technology [44]; 3D visualization allows students to imagine images of molecular shapes [45]. The limitation of this study lies in the limited research subjects, namely, only 30 students in one school. Consequently, the generalization of the research results in a broader population is limited. For future research, researchers can explain the impact of AR on other chemical topics besides molecular geometry.

4. CONCLUSION

The developed AR-based interactive learning multimedia validated received a median score of 4 for content and construct validities with very valid criteria. The questionnaire results scored above 90% with practical criteria, while the n-Gain test results showed that more than 80% of students scored above 0.3 with medium or high criteria. Thus, AR-based learning multimedia is feasible to use in learning molecular geometry and can increase visual intelligence. The application of AR in learning helps students visualize the shape and structure of molecules more realistically to improve their understanding of abstract molecular shape concepts. AR in chemistry learning can also strengthen the link between theory and three-dimensional visualization, which is often challenging in understanding molecule geometry. For future research, it is recommended that research be conducted on the long-term effectiveness of this AR learning media in various other chemistry materials, as well as explore the integration of AR with other AI technologies or other learning approaches. The implications of these findings indicate that AR technology not only supports conceptual understanding but also stimulates visual intelligence.

AUTHOR CONTRIBUTION STATEMENT

LWS contributed to the media development, literature search, data analysis, and article drafting. KD contributed by providing direction and guidance in topic development, assisting in writing and editing, and providing input on relevant literature and media development.

REFERENCES

[1] D. Shavkidinova, F. Suyunova, and J. Kholdarova, “Education is an important factor in human and country development,” *Curr. Res. J. Pedagog.*, vol. 4, no. 1, pp. 27–34, 2023, doi: 10.37547/pedagogics-crjp-04-01-04.

[2] Y. Rahmawati, H. Dianhar, and F. Arifin, “Analysing students’ spatial abilities in chemistry learning using 3D virtual representation,” *Educ. Sci.*, vol. 11, no. 4, pp. 1-22, 2021, doi: 10.3390/educsci11040185.

[3] D. Saputra, B. Gürbüz, and H. Haryani, “Android-based animation for chemical elements and experiments as an interactive learning media.,” *J. Sci. Learn.*, vol. 4, no. 2, pp. 185–191, 2021, doi: 10.17509/jsl.v4i2.28787.

[4] A. Nisa, I. Y. Rifki, A. Alya, and K. Dwiningsih, “The validity of molecular

geometry based virtual reality to improve student visual-spatial intelligence in new normal era," *J. Educ. Sci.*, vol. 5, no. 3, pp. 393–408, 2021.
[5] A. D. Siregar and L. K. Harahap, "Pengembangan e-modul berbasis project based learning terintegrasi media komputasi hyperchem pada materi bentuk molekul," *JPPS (Jurnal Penelit. Pendidik. Sains)*, vol. 10, no. 1, pp. 1925–1931, 2020, doi: 10.26740/jpps.v10n1.p1925-1931.
[6] N. N. Ariska, M. I. Sholeh, and P. J. Laksono, "Pengembangan e-book kimia berbasis augmented reality (ar) pada materi bentuk molekul," *Orbital J. Pendidik. Kim.*, vol. 7, no. 2, pp. 197–207, 2023, doi: 10.19109/ojpk.v7i2.20159.
[7] H. E. Gardner, *Frames of mind: The theory of multiple intelligences*. New York: Basic books, 2011.
[8] P. N. Azizah and A. Lutfi, "Development of a wordpress-based learning website to train students' visual intelligence on chemical equilibrium material," *J. Paedagogy*, vol. 10, no. 3, pp. 692–702, 2023, doi: 10.33394/jp.v10i3.7994.
[9] F. R. S. Zebua, "Analisis tantangan dan peluang guru di era digital," *J. Inform. Dan Teknol. Pendidik.*, vol. 3, no. 1, pp. 21–28, 2023, doi: 10.25008/jitp.v3i1.55.
[10] N. J. Harahap, C. H. Limbong, and E. F. S. Simanjorang, "The education in era society 5.0," *J. Eduscience*, vol. 10, no. 1, pp. 237–250, 2023.
[11] F. E. Nastiti and A. R. Ni'mal'Abdu, "Kesiapan pendidikan Indonesia menghadapi era society 5.0," *J. Kaji. Teknol. Pendidik.*, vol. 5, no. 1, pp. 61–66, 2020, doi: 10.17977/um039v5i12020p061.
[12] R. Ganda, P. Panjaitan, and A. B. Tenriawaru, "Feasibility of augmented reality-based learning media," *Jurnal Pendidikan Sains* Indonesia, vol. 12, no. 4, pp. 820–832, 2024, doi: 10.24815/jpsi.v12i4.39410.
[13] A. Fombona-Pascual, J. Fombona, and R. Vicente, "Augmented reality, a review of a way to represent and manipulate 3d chemical structures," *J. Chem. Inf. Model.*, vol. 62, no. 8, pp. 1863–1872, 2022, doi: 10.1021/acs.jcim.1c01255.
[14] R. Hakiki, M. Muchson, O. Sulistina, and A. Febriana, "The development of learning media based on augmented reality, hologram, and ludo game on the topic of molecular shapes," *Int. J. Interact. Mob. Technol.*, vol. 16, no. 4, pp. 70–84, 2022, doi: 10.3991/ijim.v16i04.28989..
[15] B. H. Majeed and H. T. S. ALRikabi, "Effect of augmented reality technology on spatial intelligence among high school students," *Int. J. Emerg. Technol. Learn.*, vol. 17, no. 24, pp. 131–143, 2022, doi: 10.3991/ijet.v17i24.35977.
[16] D. A. Kurniawan *et al.*, "A study for student perception of mathematical physics e-module based on gender," *J. Turkish Sci. Educ.*, vol. 19, no. 3, pp. 911–936, 2022, doi: 10.36681/tused.2022.156.
[17] S. Dargan, S. Bansal, M. Kumar, A. Mittal, and K. Kumar, "Augmented reality: a comprehensive review," *Arch. Comput. Methods Eng.*, vol. 30, no. 2, pp. 1057–1080, 2023, doi: 10.1007/s11831-022-09831-7.
[18] K. Dwiningsih, F. Fajaroh, P. Parlan, M. Munzil, and H. Habiddin, "3D molecular interactive multimedia for building chemistry students' spatial ability," *Int. J. Emerg. Technol. Learn.*, vol. 17, no. 14, pp. 253–261, 2022, doi: 10.3991/ijet.v17i14.30339.
[19] H. Herwin, L. D. Prasojo, B. Saptono, and S. C. Dahalan, "Analyzing the impact of augmented reality on student motivation: a time series study in elementary education," *Ingénierie des systèmes d Inf.*, vol. 28, no. 5, pp. 1197–1203, 2023, doi: 10.18280/isi.280507.
[20] R. C. Sari, M. Sholihin, N. Yuniarti, I. A. Purnama, and H. D. Hermawan, "Does

behavior simulation based on augmented reality improve moral imagination?," *Educ. Inf. Technol.*, vol. 26, no. 1, pp. 441–463, 2021, doi: 10.1007/s10639-020-10263-8.
[21] L. N. Izzati and A. Kamaludin, "Augmented reality-based flashcard media to improve students' concept understanding in chemistry learning," *Indones. J. Sci. Math. Educ.*, vol. 7, no. 2, pp. 252–266, 2024, doi: 10.24042/ijsme.v7i2.20975.
[22] A. Buchori, F. G. Putra, and N. D. Rahmawati, "AR-based interactive geogebra learning media for optimizing transformation geometry learning in higher education media pembelajaran interaktif geogebra berbasis AR untuk mengoptimalkan pembelajaran geometri transformasi di pendidikan tinggi," *Indonesian Journal of Science and Mathematics Education*, vol. 07, no. 3, pp. 437–450, 2024, doi: *10.24042/ijsme.v7i3.21345*.
[23] E. S. Bahriah, S. Agung, and A. I. Nur, "Development of augmented reality technology-based interactive learning media in chemical bonding materials," *JCER (Journal Chem. Educ. Res).*, vol. 6, no. 2, pp. 93–99, 2022, doi: 10.26740/jcer.v6n2.p93-99.
[24] N. Kozcu Cakir, G. Guven, and C. Celik, "Integration of mobile augmented reality (mar) applications into the 5e learning model in biology teaching," *Int. J. Technol. Educ.*, vol. 4, no. 1, pp. 93–112, 2020, doi: 10.46328/ijte.82.
[25] C. H. Chuang, J. H. Lo, and Y. K. Wu, "Integrating chatbot and augmented reality technology into biology learning during covid-19," *Electron.*, vol. 12, no. 1, pp. 1-29, 2023, doi: 10.3390/electronics12010222.
[26] S. F. Yahya and A. Lutfi, "Multimedia interaktif berbasis articulate storyline untuk melatih kecerdasan visual pada materi ikatan kimia," *PENDIPA J. Sci. Educ.*, vol. 7, no. 1, pp. 106–116, 2023, doi: 10.33369/pendipa.7.1.106-116.
[27] S. Thiagarajan, D. Semmel, and M. Semmel, *Instructional development for training teachers of exceptional children: a sourcebook*. Bloomington: Indiana University, 1974.
[28] L. A. Andreani and B. Yonata, "Validity Test of E-LKPD to improve students' argumentation skills on chemical equilibrium material," vol. 12, no. 3, pp. 429-439, 2024, doi: 10.33394/hjkk.v12i3.11500.
[29] Riduwan, *Skala Pengukuran Variabel-Variabel Penelitian*. Bandung: Alfabeta, 2016.
[30] T. M. Haladyna and M. C. Rodríguez, *Developing and validating test items*. New York: Routledge, 2013.
[31] Sugiyono, *Metode penelitian kuantitatif kualitatif dan R&D*. Bandung: Alfabeta, 2019.
[32] R. R. Hake, "Interactive-engagement versus traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.*, vol. 66, no. 1, pp. 64–74, 1998, doi: 10.1119/1.18809.
[33] R. Haryadi and H. Pujiastuti, "Use of augmented reality learning media to improve higher-order thinking skills in kinematics material," *Thabiea J. Nat. Sci. Teach.*, vol. 6, no. 1, pp. 37–50, 2023, doi: 10.21043/thabiea.v6i1.20780.
[34] Y.-C. Huang, "Comparison and contrast of piaget and vygotsky's theories," in *Proc. 7th Int. Conf. Humanit. Soc. Sci. Res. (ICHSSR 2021)*, 2021, pp. 28–32, doi: 10.2991/assehr.k.210519.007.
[35] C. Macariu, A. Iftene, and D. Gîfu, "Learn chemistry with augmented reality," *Procedia Comput. Sci.*, 2020, pp. 2133–2142, doi: 10.1016/j.procs.2020.09.250.
[36] M. Nazar, Zulfadli, Rahmatillah, K. Puspita, S. Setiawaty, and Sulastri,

"Development of augmented reality as a learning tool to improve student ability in comprehending chemical properties of the elements," vol. 6, no. 3, pp. 241–257, 2024, doi: 10.1515/cti-2023-0070.

[37] K. S. Kartini and N. H. Lukman, "Implementasi media pembelajaran berbasis augmented reality mata pelajaran molekul kimia tingkat SMA," *J. Widya Laksmi J. Pengabdi. Kpd. Masy.*, vol. 4, no. 1, pp. 130–134, 2024, doi: 10.59458/jwl.v4i1.70.

[38] G. Putra and B. Fajri, "Rancang bangun aplikasi android pengenalan unsur atom pada mata pelajaran kimia berbasis augmented reality," *J. Pendidik. Tambusai*, vol. 6, no. 1, pp. 1142–1148, 2022, doi: 10.31004/jptam.v6i1.3047.

[39] M. Ishar, "Pengaruh anger management training terhadap penurunan perilaku agresi pada siswa bermasalah di SMP X bandung," *J. Psychomutiara*, vol. 4, no. 1, pp. 1–10, 2021, doi: 10.51544/psikologi.v4i1.1659.

[40] M. Hurrahman, E. Erlina*, H. A. Melati, E. Enawaty, and R. P. Sartika, "Pengembangan e-modul berbasis multipel representasi dengan bantuan teknologi augmented reality untuk pembelajaran materi bentuk molekul," *J. Pendidik. Sains Indones.*, vol. 10, no. 1, pp. 89–114, 2022, doi: 10.24815/jpsi.v10i1.22579.

[41] R. Ramadani, R. Ramlawati, and M. Arsyad, "Pengembangan modul pembelajaran kimia berbasis augmented reality," *Chem. Educ. Rev.*, vol. 3, no. 2, pp. 152–162, 2020, doi: 10.26858/cer.v3i2.13766.

[42] T. Blazauskas and D. Gudoniene, "Virtual reality and augmented reality in educational programs," in *New Perspectives on Virtual and Augmented Reality*: *Finding New Ways to Teach in a Transformed Learning Environment*. London: Routledge, 2020, pp. 82–94.

[43] M. Ulrich and B. Evans, "AR-some chemistry models:interactable 3d molecules through augmented reality, " in *ACM International Conference on Mobile Human-Computer Interaction.*, 2021, pp. 1–4.

[44] M. Abdinejad, B. Talaie, H. S. Qorbani, and S. Dalili, "Student perceptions using augmented reality and 3d visualization technologies in chemistry education," *J. Sci. Educ. Technol.*, vol. 30, no. 1, pp. 87–96, 2021, doi: 10.1007/s10956-020-09880-2.

[45] F. Solikhin, D. Handayani, and S. Rohiat, "The effect of using augmented reality-based learning media on chemistry students' conceptual understanding on molecular shape," *Acta Chim. Asiana*, vol. 5, no. 2, pp. 237–241, 2022, doi: 10.29303/aca.v5i2.128.