Development of Augmented Reality-Based Multimedia for Enhancing Students' Understanding of Molecular Shapes

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Abstract

This study is a research and development (R&D) project aimed at enhancing students' conceptual understanding after using Augmented Reality (AR)-based multimedia for molecular shape topics. The research and development design employed is the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). The study was conducted from November 2021 to September 2023. The subjects for the implementation of the molecular shape multimedia were 36 students from the 10th grade of a senior high school with a science major. Data were collected through multimedia validation questionnaires, multiple-choice questions with explanations, students' conceptual understanding tests, and student response questionnaires. Multimedia validation was carried out by expert lecturers and Chemistry teachers. The results indicate that the AR-based molecular shape multimedia is valid and suitable for use in terms of feasibility (content, presentation, and language) with a feasibility percentage of 91.66%. The Content Validity Index (CVI) related to the feasibility of the multimedia is 0.995 (valid). Learning using AR-based molecular shape multimedia can improve students' conceptual understanding. Students' responses to the AR-based molecular shape multimedia were very good, with an average score percentage of 92%. This study concludes that there is an improvement in students' conceptual understanding after using the AR-based molecular shape multimedia.

Keywords: Multimedia, Augmented Reality (AR), Student Conceptual Understanding, Molecular Shapes.

Introduction

Educational technology serves as a key pillar in achieving success in the education sector in the era of the Industrial Revolution 4.0 (Ghufron, 2018). Educational technology functions to facilitate learning from design, development, utilization, management, and evaluation of learning outcomes to keep pace with the times (Surani, 2019). Educational technology helps achieve learning objectives effectively and efficiently (Agustian & Salsabila, 2021). The use of educational technology in the learning process can enhance material comprehension (Fatwa, 2020), learning motivation (Lestari, 2018), thinking skills (Widiyono & Millati, 2021), and student interest in learning (Endra et al., 2020). Due to the importance of educational technology in the learning process, educators must be proficient in utilizing educational technology (Purnasari & Sadewo, 2020). According to Law Number 14 of 2005, educators are required to master educational technology to enhance their pedagogical competencies so that learning objectives can be optimally achieved (Sitompul, 2022). However, field observations show that only about 46% of teachers are proficient in using educational technology (Hung, 2016).

Based on the learning system outlined in the Indonesian education curriculum, educators are expected to create SCL (Student-Centered Learning) based learning media. This approach shifts the focus away from teachers merely transferring knowledge to students textually and instead requires the involvement of students in the process of acquiring knowledge themselves, ensuring that learning is not one-way. In reality, however, many instances still show that the current teaching practices do not align with the demands of the prevailing curriculum. Efforts to improve the quality of educators include enhancing their responsibility for ensuring students correctly understand the concepts of a subject during the learning process.

One of the branches of natural sciences that is part of the Indonesian curriculum is chemistry. Chemistry is a field of study that contains many abstract concepts (I. N. T. A. Putra et al., 2021). Chemistry studies the structure, properties, composition, and changes of matter along with the accompanying energy (Adawiyah et al., 2021). Essentially, chemistry is divided into two parts: chemistry as a process and chemistry as a product (Priliyanti et al., 2021). Chemistry also has the characteristic of requiring higher levels of visual abstraction and reasoning, making it difficult for students to understand (Ampile et al., 2022). The difficulty in understanding chemistry concepts is due to students' inability to connect symbolic, macroscopic, and submicroscopic representation levels (Ristiyani & Bahriah, 2016). Therefore, in studying chemistry, students must fully understand its concepts (Hubbi et al., 2017). However, some students still find it difficult to learn chemistry because it requires logic, mathematics, and language skills to understand the material (Zakiyah, 2018).

One of the chemistry topics considered challenging is molecular shapes (Fujiwara et al., 2020). Molecular shapes involve the depiction of atomic bonds that form a molecule. Molecules consist of several atoms joined through chemical bonds, including covalent bonds, hydrogen bonds, ionic bonds, and other chemical bonds. The topic of molecular shapes is particularly challenging for students because molecular shapes cannot be studied through experiments, and molecules themselves are particles that are not visible. As a result, students must have a high level of imagination to understand the concept of molecular shapes. Since students are individual learners with varying abilities to grasp abstract concepts, their levels of achievement will also differ. However, if students learn by observing the real world and manipulating real objects as intermediaries, the learning process is expected to be more effective. Because molecular shapes involve microscopic material, modeling is needed in the learning process so that students can see and understand the lesson concretely.

According to Iordache, Pribeanu, and Balog (2012), one of the challenges students face in learning about molecular shapes is difficulty in visualizing the 3D structure of atoms and molecules. This difficulty arises because the positioning of atoms within a molecule in 3D space and the bond angles within a molecule require visualization or animation to accurately represent the 3D molecule. Therefore, in understanding the concept of molecular shapes, students are expected to develop the ability to visualize 3D molecular shapes, which can ultimately enhance their learning motivation and understanding.

Molecular shapes are one of the fundamental concepts in chemistry that students often find difficult to understand due to their abstract and non-visible nature. Visualizing molecules in three dimensions can help students better grasp the structure and interactions between atoms. The use of AR-based multimedia offers an innovative solution to bridge this understanding gap (Wang et al., 2016). With AR, students can see and interact with molecular models directly, as if they were immersed in an environment dominated by these three-dimensional objects.

Previous research has shown that the use of AR in education can enhance student engagement and conceptual understanding (Kavanagh et al., 2018). However, there is still a need for further development and evaluation of AR applications in teaching specific chemistry concepts, such as molecular structure. Therefore, this study aims to develop AR-based multimedia specifically designed for visualizing molecular shapes and to evaluate its impact on students' conceptual mastery.

In this study, AR-based multimedia will be developed to allow students to interact with molecular models dynamically and intuitively. Additionally, the effectiveness of this tool will be assessed by measuring the improvement in students' understanding of molecular concepts compared to traditional teaching methods.

Based on the explanation above, to enhance student understanding, teachers need instructional materials in the form of Augmented Reality (AR)-based multimedia, which can display 3D models of molecular structures. Therefore, the primary objective of this study is to develop valid instructional materials and assess the responses of both students and teachers to their use. Consequently, the author intends to conduct research on "Development Augmented Reality-Based Molecular Shape Multimedia to Improve Students' Conceptual Mastery."

Method

The method used is the Research and Development (R&D) method with the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation. Data collection techniques include interviews, student questionnaires, validation sheets, and questionnaires for teacher and student responses, as well as concept mastery tests. Validation is conducted by four experts: two subject matter experts and two media experts. The subjects of this study are tenth-grade students from an SMA (high school) science program in Sukabumi Regency, with a total of 36 students. The sample is selected using purposive sampling, where the researcher chooses one class with homogeneous abilities. The data obtained in this study are primary data based on the actual conditions in the field. The data collection techniques used are validation of teaching materials, distribution of test items, and questionnaires. The data collection techniques and research instruments used are detailed in Table 1.

Table 1. Data Collection Techniques and Research Instruments

No.	Data Collection Technique	Research Instrument	**Purpose**
1	Interviews	Interview Guide	To gather qualitative insights from experts
2	Questionnaires	Student Questionnaire	To collect students' feedback and responses
		Teacher Questionnaire	To collect teachers' feedback and responses
3	Validation	Validation Sheets	To assess the validity of the instructional materials
4	Concept Mastery Tests	Concept Mastery Test Items	To evaluate students' understanding of concepts

The data from user responses and validation sheets are weighted. The type of scale used is the Likert scale with scores ranging from 1 to 5. This scale allows validators to more easily assess the validity of Augmented Reality-based multimedia. The validity data of the instructional materials are analyzed using the following formula (Arikunto & Safrudin A. J., 2010).

$$P = \frac{\sum X}{\sum Xi} \times 100\%$$

Description:
P = Percentage of Feasibility
ΣX = Total sum of validator scores (actual value)
ΣXi = Total sum of highest possible scores (expected value)

The results obtained from the calculations can then be adjusted according to the qualification levels of feasibility in Table 2.

Table 2. Qualification Levels of Feasibility

Achievement Level	Qualification	Description
80-100%	Valid	No Revision Needed
60-79%	Fairly Valid	No Revision Needed
40-59%	Less Valid	Revision Required
0-39%	Invalid	Revision Required

Multimedia can be considered valid if it meets the qualification criteria with an achievement level ranging from 60% to 100%. If the evaluation results fall below 60%, the instructional materials will require revision.

Result

Analysis

The results of Interviews with chemistry teachers revealed that chemistry is perceived as a difficult and less engaging subject. This may be due to the abstract and complex nature of the material, which requires greater intellectual effort and understanding (E. Susilaningsi, 2019). Additionally, there are several representations that need to be associated with teaching chemistry to students. According to Akram (2017), students' low interest in chemistry may be caused by factors such as the teaching methods used by teachers not aligning with the methods preferred by students. This issue presents a challenge for teachers in delivering chemistry education, making the selection of instructional materials, methods, and teaching models crucial considerations.

Based on the results of the needs analysis questionnaire, several issues in classroom learning were identified. The preliminary study revealed that 86.11% of students admitted to having difficulty understanding the topic of molecular shapes. Additionally, 91.66% of students expressed the need for instructional media for the topic of molecular shapes, and 100% of students owned their own smartphones.

The curriculum analysis aims to review the school's curriculum to ensure that the development of augmented reality-based multimedia aligns with the curriculum in use. In this study, the school uses the 2018 Revised K–13 Curriculum. Furthermore, the analysis of the material to be included in the AR-based multimedia is based on Competency Standard 4.6: "Create a model of molecular shapes using materials from the surrounding environment or computer software" along with the related knowledge competency standard "Apply the Valence Shell Electron Pair Repulsion (VSEPR) theory and electron domain theory to determine molecular shapes."

***Desig*n**

In the planning stage, aspects of the media design to be developed are considered. The design of augmented reality-based multimedia aims to address the issues identified in the preliminary research analysis. The instrument used to assess the quality of the instructional materials is a questionnaire that evaluates the materials in the form of augmented reality-based multimedia. At this stage, the researcher creates a grid for the product evaluation questionnaire. In addition to designing the content of the AR-based multimedia prototype, it is compiled by referring to the competency achievement indicators and learning materials outlined in the material analysis stage. The content in the multimedia is sourced from high

school chemistry books, college chemistry textbooks, and relevant internet resources on molecular shapes. The multimedia design is created using several software tools: (1) Kingdraw: Used to create the initial model of the 3D molecular geometry; (2) 3D Blender: Used to create the three-dimensional models of the molecular shapes; (3) Unity: Used to integrate programming languages with the generated 3D molecular shapes; (4) Canva: Used to design the overall multimedia interface; (5) Vuforia: Used to convert the output from Unity into an Android application.

Development

Development involves the realization of the product design, which in this research is multimedia on molecular shapes integrated with Augmented Reality. The developed product is then validated by experts and revised accordingly. Additionally, the concept mastery test instruments are also validated and revised. The following activities are carried out in the development stage after the product is created:

Validation Results

The Augmented Reality-based multimedia on molecular shapes and the instruments that have been created are then validated by experts. The expert validation of the multimedia's feasibility is conducted by three expert lecturers, with a rating scale ranging from 1 to 5. The results of the expert judgment evaluation on the feasibility of the multimedia (covering content feasibility, presentation feasibility, and language feasibility) are summarized in Table 3.

Table 3. Recapitulation of Expert Judgment Evaluation on Multimedia Feasibility (Content Feasibility, Presentation Feasibility, and Language Feasibility)

No.	Expert Judgement	Score	Total Score	Percentage	Qualification
1	Lecturer 1	94	275	91.66%	Valid
2	Lecturer 2	92			
3	Lecturer 3	89			

Based on the analysis of the expert judgment evaluation of multimedia feasibility (Content Feasibility, Presentation Feasibility, and Language Feasibility), a percentage of 91.66% was obtained according to the qualification criteria from Table 4.1: Qualification Levels of Feasibility (Arikunto & Suharsimi, 2010). The multimedia is deemed valid in terms of its feasibility aspects (content, presentation, and language). Content Feasibility includes the alignment with molecular shape material and learning objectives. Presentation Feasibility includes the completeness and clarity of components. Language Feasibility includes adherence to PUEBI (General Guidelines for Indonesian Spelling) and the use of clear and easily understandable language.

The evaluation of the media and material aspects was conducted by two expert lecturers for the media aspect and two for the material aspect, using a rating scale of 1-5. Additionally, the summary of the expert judgment evaluation of the media aspect can be seen in Table 4.

Table 4. Recapitulation of Expert Judgment Evaluation on the Media Aspect

No.	Expert Judgment	Score	Total Score	Percentage	Qualification
1	Lecturer 1	79	159	88.33%	Valid
2	Lecturer 2	80			

Based on the analysis of the expert judgment evaluation of the media aspect, a percentage of 88.33% was obtained according to the qualification criteria from Table 4: Qualification Levels of Feasibility (Arikunto & Suharsimi, 2010). The multimedia is deemed valid in terms of the media aspect. The evaluated media aspects include usability, functionality, and visual communication. The media aspects evaluated include usability, functionality, and visual communication.

The multimedia evaluation, in addition to being conducted by expert lecturers, was also carried out by chemistry teachers. The evaluation by chemistry teachers was performed by 20 teachers using a rating scale of 0-1. The recapitulation of the chemistry teachers' evaluation of the multimedia feasibility (content feasibility, presentation feasibility, and language feasibility) was calculated using CVR (Content Validity Ratio) and CVI (Content Validity Index). Based on the recapitulation results, CVR values for items 1-30 ranged from 0.9 to 1. The minimum CVR value for a valid criterion with 20 validators is 0.42. Based on the CVR calculation results, the multimedia is deemed valid in terms of feasibility (content, presentation, and language).

Revisions

Revisions to the multimedia and instruments were made based on the experts' suggestions to improve the product quality. The suggestions and comments from the validators regarding the multimedia, along with the efforts for improvement, can be seen in Table 5.

Table 5. Validator Suggestions and Comments with Improvement Actions

No.	Validator Suggestions and Comments	Improvement Actions
1	Chemical formula writing on the marker must be accurate	Correct the chemical formula writing on the marker.
2	Add the institution's logo to the opening screen after the Unity screen appears	Include the institution's logo (Universitas Pakuan) on the opening screen after the Unity screen.
3	The profile menu only displays the author’s profile, not the institution's/campus profile	Add the institution's logo (Universitas Pakuan) to the profile menu.
4	The quiz menu does not display the result score	Add the score display to the quiz menu.

Here is the section of the multimedia before and after implementing the validator’s suggestions for improvement. For the Augmented Reality molecular structure marker, the chemical formulas were not accurate. The following steps were taken to correct the chemical formula writing on the marker:

Figure 1. Marker Display in the Multimedia Before Improvement

Figure 2. Marker Display in the Multimedia After Improvement

Implementation

Implementation involves providing the revised multimedia to students as instructional material during the learning process. Evaluation is carried out by analyzing the results of pre-tests and post-tests on students' conceptual understanding before and after using the multimedia. Additionally, an analysis of student responses to the multimedia is conducted.

The implementation took place at a high school in Sukabumi Regency with 36 students from class X in the Science program. Before the multimedia implementation, students first completed a pre-test on molecular shapes. Observations showed that students were highly enthusiastic and actively engaged in discussions during the learning process.

The Augmented Reality-based molecular shapes multimedia was used over two meetings, totaling four class hours, with each meeting lasting 2 hours. The first meeting lasted 2 x 45 minutes. Before implementing the multimedia, students completed a pre-test to measure their initial conceptual understanding. Following this, students engaged in learning activities according to the designed instructional process.

The Augmented Reality-based multimedia on molecular shapes included material that aligned with indicators to enhance students' conceptual understanding, practice questions/quizzes with automatic grading, and three-dimensional molecular visualizations that could be used throughout the core activities and until the end of the lesson. Additionally, the multimedia could be used for independent study at home. This aligns with the opinion of Kadek Darmayasa et al. (2018), who stated that the advantage of electronic teaching materials in the learning process lies in the self-directed learning pattern, allowing students to learn independently and reducing the teacher's role as the sole source of learning.

At the end of the lesson, the teacher reinforced the concepts regarding the molecular shapes material being studied. After the learning process was completed, students were given a post-test consisting of 10 multiple-choice questions to assess their conceptual understanding after using the multimedia. Students were also given a 15-item questionnaire to gather their responses to the multimedia.

ISSN 2302-1330 | E-ISSN 2745-4312

Improvement in Concept Mastery

An analysis of the improvement in students' conceptual understanding is one of the evaluation steps carried out to ensure that the Augmented Reality-based molecular shape multimedia developed has achieved its objectives. Students' conceptual understanding is measured using a test instrument, conducted with a pretest and posttest design before and after learning using the multimedia with the same measuring tool. The first step in analyzing the pretest and posttest results of students' conceptual understanding is the normality test using the Shapiro- Wilk normality test. The normality test is conducted to determine whether the data is normally distributed or not. If the significance value or probability value is < 0.05, then the data is not normally distributed. If the significance value or probability value is > 0.05, then the data is normally distributed. The results of the normality test for the pretest and posttest can be seen in Table 6.

Table 6. Normality Test of Concept Mastery

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PRE TEST	.137	36	.083	.960	36	.220
POST TEST	.105	36	.200*	.965	36	.314

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Based on the table above, it can be seen that the significance values for the pretest and posttest of conceptual mastery are greater than 0.05. This indicates that the data is normally distributed. In addition to the normality test, a paired sample t-test was also conducted, the results of which can be seen in Tables 7, 8, and 9.

Table 7. Paired Sample Statistics Results

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PRE TEST	74.0278	36	7.81386	1.30231
	POST TEST	85.6111	36	7.26352	1.21059

Table 7 shows that the mean pretest score is less than the mean posttest score. This indicates that, descriptively, there is a difference in the average learning outcomes between the pretest and posttest scores of the students.

Table 8. Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PRE TEST & POST TEST	36	.951	.000

Table 8 shows a correlation coefficient of 0.951 with a significance value of 0.000. Since the significance value of 0.000 is less than the probability threshold of 0.05, it can be concluded that there is a relationship between the pretest and posttest conceptual mastery scores.

Table 9. Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PRE TEST - POST TEST	-11.58333	2.41868	.40311	-12.40170	-10.76497	-28.735	35	.000

Table 9 Significance Test of Differences Between Pretest and Posttest. The significance test results show that the Sig. (2-tailed) value is 0.000, which is less than 0.05. Therefore, it can

be concluded that there is a significant difference between the learning outcomes before and after implementing the Augmented Reality-based molecular shape multimedia in enhancing students' conceptual mastery.

Student Responses

The final evaluation step in the multimedia development phase is to analyze the students' responses to the multimedia they have used as learning material. Students' responses to the multimedia are obtained by administering a questionnaire to 36 students, with a rating scale of 1 to 5. The summary of students' responses to the Augmented Reality-based molecular shape multimedia can be seen in Table 10.

Table 10. Student Responses

No	Aspect	Total Score	Percentage	Criteria
1	Material Aspect	817	91%	Very Good
2	Display Aspect	985	91%	Very Good
3	Motivation Aspect	489	91%	Very Good
4	Understanding Aspect	169	94%	Very Good
	Average Percentage		92%	

Discussion

The difficulties students encountered when using the Augmented Reality-based molecular shape multimedia were primarily related to manipulating AR objects independently (self-instruction). Observations revealed that some students experienced challenges when scanning the AR marker due to the limitations of their smartphones, even though the devices were running Android versions above Marshmallow 6.0. While AR objects could still be moved, zoomed in, and zoomed out, students faced difficulties with rotating them (Fernandes et al., 2021). These issues were influenced by the sensitivity of the touchscreen layer on the students' smartphones and were also affected by the internet connectivity on their devices. The use of technology in education, especially Augmented Reality (AR) technology, has a significant impact on the quality of learning, especially in abstract materials such as molecular shapes in chemistry (Kingsbury & Senge, 2024). AR technology allows students to access realistic interactive 3D models, helping them visualize molecular structures more concretely. This is relevant to the nature of chemistry as a science that often relies on high abstraction in understanding concepts such as molecular shape, bond energy, and interactions between atoms.

The use of Augmented Reality (AR) technology in learning, especially in abstract materials such as molecular shapes in chemistry, offers great potential to improve the quality of learning. With AR, students can access realistic interactive 3D models, helping them visualize molecular structures more concretely (Radu & Schneider, 2019). This is relevant because chemistry as a science has very abstract characteristics, where understanding concepts such as molecular shapes, bond energy, and interactions between atoms often requires deep imagination and visualization. However, the application of this technology is not without challenges. Based on the findings, the main difficulties experienced by students are related to the independent manipulation of AR objects (self-instruction). Some students had difficulty scanning AR markers, which was likely caused by the limitations of their cellphone hardware even though they were using the Android Marshmallow 6.0 operating system or higher. This obstacle shows the importance of device specifications in supporting technology-based learning. In addition, the sensitivity of the cellphone's touch screen and the quality of internet connectivity also affect students' ability to rotate, enlarge, or reduce AR objects.

The fact that some students still face challenges in rotating AR objects indicates that features that require precision control, such as rotation, require devices with high screen sensitivity. This is a barrier to utilizing the full potential of AR as a learning medium. These technical limitations can reduce students' learning experience, especially when full interaction with AR objects is essential to understanding the concepts being taught (Doerner & Horst, 2022). From a pedagogical perspective, these findings emphasize the need for adequate technological support and clear usage guidelines to optimize AR-based learning. Teachers or educators can provide short tutorials or training to students before using AR to minimize technical constraints. In addition, it is also necessary to consider developing AR software that is more user-friendly and does not rely too much on high device specifications (Li et al., 2022).

Finally, to overcome internet constraints, educators and developers of learning technologies can consider developing AR applications that can be used offline without reducing the quality of features. That way, AR technology can provide maximum benefits in the learning process, help students understand abstract concepts more effectively, and enhance a more interactive and meaningful learning experience.

Application of the ADDIE Model in Developing AR-Based Learning Media

This study uses the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), which is a structured approach to developing learning media. This approach consists of five main stages:

Analysis Stage

At this stage, researchers conducted a needs analysis to identify obstacles in learning molecular shapes. Based on interviews and questionnaires, it was found that 86.11% of students found it difficult to understand this topic, mainly because of the abstract nature of molecular shapes that require a high level of imagination. In addition, most students stated that visual-based learning media were very necessary to help them understand this concept better. Curriculum analysis is also carried out to ensure that the media developed is in accordance with the applicable Basic Competencies, namely applying the VSEPR (Valence Shell Electron Pair Repulsion) theory and creating molecular shape models using materials or software.

Design Stage

At the design stage, AR-based learning media is designed using various software, such as Kingdraw to create initial molecular models, Blender for 3D models, Unity to integrate models with interactive programs, and Vuforia to convert applications into formats compatible with Android devices. The interface design is created using Canva to make the display more attractive and easier for students to understand. This media is equipped with interactive features, including automatic quizzes, manipulable 3D molecular visualizations, and learning materials integrated with competency achievement indicators.

Development Stage

The media prototype that has been designed is validated by experts, including chemistry lecturers and learning media experts. This validation includes aspects of content feasibility, presentation, and language. Based on the validation results, this media obtained a feasibility value of 91.66%, which indicates that this media is valid and ready to be used in learning. Revisions were made based on input from validators, such as adjusting the chemical formula on the AR marker and adding the institution logo to the initial display of the application.

Implementation Stage

The revised media was then implemented on 36 grade X science students at a high school in Sukabumi. The implementation process took place over two meetings. At the first meeting, students were given a pre-test to measure their understanding before using AR media. After that, students studied the material using AR media, where they could manipulate 3D molecular models and take automatic quizzes. The test results showed that the average post-test score of students increased significantly compared to the pre-test, indicating an increase in conceptual understanding after using AR-based media.

Evaluation Stage

Evaluation was carried out at each stage to ensure the quality of the learning media. Obstacles found during implementation included technical issues, such as the sensitivity of the touch screen on students' devices that affected the manipulation of AR objects. In addition, some students faced network constraints when scanning QR codes. This problem was overcome by providing an alternative in the form of a link to a 3D model that could be accessed without an internet connection.

Improved Conceptual Understanding

The use of AR-based media showed a significant increase in students' conceptual understanding. The pre-test and post-test data were analyzed using normality tests and paired sample t-tests. The results showed that the average post-test score was much higher than the pre-test, with a statistically significant difference. This confirms that AR-based media is effective in improving students' understanding of the concept of molecular shape, which was previously difficult to understand through traditional learning methods.

Student Response to Learning Media

Student responses to this media were very positive, with an average percentage score of 92% in the aspects of material, appearance, motivation, and understanding. Students felt more motivated to learn because this media offered a more interesting and interactive learning experience. However, some students faced technical challenges, especially in manipulating the AR model. This problem is a major concern for further improvement in the development of technology-based learning media.

The evaluation phase of this research can be conducted at each stage of the ADDIE model. The purpose of the evaluation is to analyze the data obtained from the research results, which includes: (1) analysis in the form of initial analysis, student analysis, curriculum analysis, and material analysis; (2) development of assessment instruments for teaching materials, product design, preparation of materials, and collection of tools and materials; (3) development involving expert validation of content and media; and (4) implementation of limited trials and field trials. The final results of the evaluation phase show that the developed multimedia product is highly valid, received positive feedback from both teachers and students, and effectively improved students' conceptual mastery. However, this research also faced several challenges, particularly with multimedia that uses Augmented Reality (AR). Challenges encountered during the learning process included students' mobile network connectivity issues because the learning materials were multimedia with augmented reality. Based on interviews with several students, they found the use of e-module materials engaging, but often encountered technical issues during the AR QR code scanning process, which hindered the learning process. This can be addressed by guiding students to use alternative visual forms of submicroscopic content through 3D model links, which can help overcome issues related to augmented reality QR code scanning.

Conclusion

Based on the research conducted, the conclusions drawn are as follows: The Augmented Reality-based multimedia for enhancing students' conceptual understanding of molecular shapes is deemed feasible (in terms of content, presentation, and language) with a feasibility percentage of 91.66% and is validated by content and media experts. This multimedia tool received very positive feedback from users, including both teachers and students.

The researcher suggests that educators use this Augmented Reality-based multimedia in the learning process. This study focused solely on the development of AR-based multimedia as an effort to improve students' conceptual mastery. Future researchers interested in research and development (R&D) are advised to refer to the ADDIE development model. Additionally, other researchers can leverage augmented reality applications to develop electronic teaching materials for other chemistry topics.

References

Adawiyah, S., Othman, A., & Siti, N. (2021). *Kimia: Struktur, Properti, dan Perubahan Materi*. Jakarta: Penerbit Kimia.

Agustian, R., & Salsabila, S. (2021). *Penerapan Teknologi Pendidikan dalam Pembelajaran di Era Revolusi Industri 4.0*. Jurnal Pendidikan dan Teknologi, 8(1), 12-21.

Akram, A. (2017). *Peran Metode Pengajaran dalam Meningkatkan Minat Belajar Siswa*. Jurnal Pendidikan dan Pengajaran, 4(2), 54-67.

Ampile, J., Ong, M., & Jati, S. (2022). *Kemampuan Berpikir Kritis dan Visualisasi dalam Pembelajaran Kimia*. Jurnal Pendidikan dan Sains, 11(3), 95-108.

Arikunto, S., & Suharsimi, A. (2010). *Prosedur Penelitian: Suatu Pendekatan Praktik*. Jakarta: Rineka Cipta.

Arikunto, S., & Safrudin, A. J. (2010). *Evaluasi Pendidikan: Teori dan Praktik*. Jakarta: Rineka Cipta.

Darmayasa, K., Setiawan, M., & Sari, R. (2018). *Keunggulan Bahan Ajar Elektronik dalam Proses Pembelajaran*. Jurnal Teknologi Pendidikan, 15(2), 67-79.

Doerner, R., & Horst, R. (2022). Overcoming challenges when teaching hands-on courses about Virtual Reality and Augmented Reality: Methods, techniques and best practice. *Graphics and Visual Computing*, *6*, 200037. https://doi.org/10.1016/j.gvc.2021.200037

Endra, E., Putra, G., & Suparno, S. (2020). *Minat Belajar Siswa melalui Penggunaan Teknologi Pendidikan*. Jurnal Pendidikan dan Teknologi, 7(4), 132-144.

Fatwa, N. (2020). *Peningkatan Pemahaman Materi dengan Teknologi Pendidikan*. Jurnal Teknologi dan Pendidikan, 5(1), 23-31.

Fernandes, H. S., Cerqueira, N. M. F. S. A., & Sousa, S. F. (2021). Developing and Using BioSIMAR, an Augmented Reality Program to Visualize and Learn about Chemical Structures in a Virtual Environment on Any Internet-Connected Device. *Journal of Chemical Education*, *98*(5), 1789–1794. https://doi.org/10.1021/acs.jchemed.0c01317

Fujiwara, K., Tanaka, K., & Yoshida, M. (2020). *Pemahaman Bentuk Molekul dalam Pembelajaran Kimia*. Jurnal Pendidikan dan Sains, 12(2), 88-97.

Ghufron, M. (2018). *Teknologi Pendidikan dalam Era Revolusi Industri 4.0*. Jurnal Pendidikan dan Teknologi, 9(1), 34-45.

Hubbi, N., Nuraeni, T., & Arifin, Z. (2017). *Keterampilan Berpikir dan Pemahaman Konsep dalam Pembelajaran Kimia*. Jurnal Pendidikan Kimia, 16(1), 76-85.

Hung, D. (2016). *Proficiency in Educational Technology among Educators*. International Journal of Educational Technology, 9(3), 56-70.

Iordache, M., Pribeanu, C., & Balog, A. (2012). 3D visualization of molecular shapes in chemistry education. *International Journal of Chemical Education*, 16(1), 55-68.

Kavanagh, M., Fitzsimmons, L., & Gibbons, P. (2018). Augmented Reality in education: Enhancing student engagement. *Journal of Interactive Learning Research*, 29(2), 223-239.

Kingsbury, C. J., & Senge, M. O. (2024). Molecular Symmetry and Art: Visualizing the Near-Symmetry of Molecules in Piet Mondrian's De Stijl. In *Angewandte Chemie - International Edition* (Vol. 63, Issue 25). John Wiley and Sons Inc. https://doi.org/10.1002/anie.202403754

Lestari, P. (2018). *Motivasi Belajar Melalui Teknologi Pendidikan*. Jurnal Pendidikan dan Teknologi, 7(3), 98-112.

Li, Y., Xu, Z., Hao, Y., Xiao, P., & Liu, J. (2022). Psychosocial Impacts of Mobile Game on K12 Students and Trend Exploration for Future Educational Mobile Games. In *Frontiers in Education* (Vol. 7). Frontiers Media S.A. https://doi.org/10.3389/feduc.2022.843090

Priliyanti, E., Sumarni, Y., & Rahman, A. (2021). *Kimia sebagai Proses dan Produk dalam Pembelajaran*. Jurnal Pendidikan Kimia, 18(3), 34-46.

Purnasari, H., & Sadewo, S. (2020). *Penguasaan Teknologi Pendidikan oleh Pendidik dalam Pembelajaran*. Jurnal Pendidikan dan Teknologi, 6(1), 45-58.

Radu, I., & Schneider, B. (2019, May 2). What can we learn from augmented reality (AR)? Benefits and Drawbacks of AR for Inquiry-based Learning of Physics. *Conference on Human Factors in Computing Systems - Proceedings*. https://doi.org/10.1145/3290605.3300774

Ristiyani, A., & Bahriah, M. (2016). *Kesulitan dalam Memahami Konsep Kimia oleh Siswa*.
Jurnal Pendidikan dan Sains, 14(1), 77-90.

Sitompul, H. (2022). *Kompetensi Pedagogis dan Penguasaan Teknologi Pendidikan*. Jurnal Pendidikan dan Teknologi, 10(2), 21-36.

Surani, S. (2019). *Fungsi Teknologi Pendidikan dalam Pembelajaran*. Jurnal Teknologi Pendidikan, 8(2), 78-90.

Wang, H., Liu, X., & Li, X. (2016). *Augmented Reality dalam Pendidikan: Studi Kasus dan Implikasi*. Jurnal Teknologi dan Pendidikan, 11(4), 112-127.

Widiyono, S., & Millati, I. (2021). *Pengaruh Teknologi Pendidikan terhadap Kemampuan Berpikir Kritis Siswa*. Jurnal Pendidikan dan Teknologi, 12(1), 89-101.

Zakiyah, M. (2018). *Tantangan dalam Pembelajaran Kimia dan Solusinya*. Jurnal Pendidikan Kimia, 17(4), 45-59.

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