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Development of Augmented Reality on Molecule Geometry to Improve Mental Models of High School Students

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Abstract

This research aims to produce augmented reality learning media for molecular form materials and improve the mental model of high school students. This research is a type of research and development using a 4D model (define, design, develop and, disseminate). The media that has been developed is validated by five validators consisting of 2 media experts and 3 material experts. In addition, feasibility tests and effectiveness tests are carried out through trials. The results of the research that have been carried out were obtained: 1) In the validity criteria obtained an average score of 94.8 in the very valid category for the material aspect and a score of 95.8 with the very valid category for the media aspect. 2) The results of the teacher's response obtained an average score of 95.3 with the very good category, while in the students' response obtained 80.1 with the good category. 3) Most students experience improved synthetic mental models. Thus, it can be concluded that augmented reality learning media molecular form material is feasible to be used to improve students' mental models. The mental model of the student increases to the synthetic category in most students who were originally in the initials category.

How to Cite

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INTRODUCTION

Chemistry is a branch of science that studies matter, its properties, and how it behaves and interacts with other substances (Ardi et al, 2017). Chemistry students need to be able to represent chemical problems in macroscopic, submicroscopic, and symbolic forms to develop a comprehensive understanding of chemistry (Darmiyanti et al, 2017, Safitri et al, 2019). Integrating multiple representations in chemistry can aid student learning and improve reasoning skills (Suyono et al, 2015).

One of the abstract chemistry concepts that includes all three representations is molecule geometry. The visualization of 3D molecular shapes is the main obstacle for students in learning atomic and molecular structures (Pratama, 2018). Due to inadequate representation, students often misunderstand molecular shapes while studying (Nazar et al, 2020; Esselman & Block, 2018). For some students, the representation of molecules is intuitive and lacks a systematic approach (Karonen et al, 2021). Islami et al (2018) said that there are many misconceptions about the molecule concept. Additionally, there are sub-concepts with the highest misconceptions, namely Lewis structures, octet rules, and the influence of intermolecular forces on boiling and melting points. Visualizing the structure of the material can help students overcome difficulties in connecting the three representations (Darmiyanti et al, 2017).

Understanding multiple representations is often termed a mental model. Some experts convey that mental models are representations of internal scale models of external reality, or representations of students' mind concepts to explain ongoing situations or processes (Greca and Moreira, 2000; Prayekti, 2018). Mental models refer to internal representations of students' understanding, (Batlolona et al, 2020) built from perception, imagination, or comprehension (Albaiti et al, 2022). There are three types of student mental models: initial models, synthetic models, and scientific models. The initial model is a perception that does not align with scientific knowledge. A synthetic model is a perception that partly corresponds or partially does not correspond to scientific knowledge. The scientific model is a perception that corresponds to scientific knowledge (Vosniadou &; Brewer, 1994; Kurnaz & Eksi, 2015). The learning outcome of a student is directly proportional to their level of mental model. In simpler terms, the higher the mental model a student has, the better their learning outcome.

Students who possess initial mental models often have misconceptions and can only explain scientific phenomena at the macroscopic level. On the other hand, students with scientific mental models have the ability to explain phenomena at the submicroscopic level by integrating both macroscopic and symbolic levels of understanding. During the learning process, students develop their own mental models as they attempt to grasp scientific concepts.

The results of research by Supriadi et al (2018) stated that mental models can affect learning outcomes, even though students' mental models are also influenced by the learning process. Therefore, it is necessary to identify student mental models from an early age, so that teachers can design learning in accordance with student mental models both in terms of model selection, approach, and learning media used (Fratiwi *et al*, 2020).

Utilizing technology to present learning material through words, images, and animations can help overcome student misunderstandings. (Putri &; Sukarmin, 2020). One technology-based media that is increasingly developed and appropriate to describe the shape of molecules is Augmented Reality. Augmented reality media is the integration of three-dimensional virtual objects into a real-life environment, displayed in real time. The use of augmented reality can be leveraged through smartphone applications to create engaging educational content (Kamelia, 2015), training abstract thinking skills on atomic models to enhance practicality and learning effectiveness (Nandyansah &; Suprapto, 2019; Irwansyah et al, 2018). Augmented reality (AR) applications are versatile and user-friendly, making them accessible in any setting. These apps can be used without difficulty, regardless of your level of technical expertise (Nazar et al, 2020).

Based on the issues that have been described, it is considered important to provide learning media to overcome learning problems in the era of the industrial revolution 4.0 that can help teachers improve students' mental models. This research study was conducted to answer the following research questions: 1) What is the feasibility of using augmented reality media to represent developed molecule geometry, according to both experts and users? 2) How effective is the use of augmented reality media in improving students' mental models on molecule geometry?

METHOD

This type of research uses research and

development methods or Research and Development (R & D) with reference to Thiagarajan's 4D development model (define, design, development, and dissemination). In this R&D, augmented reality-based learning media has been developed on molecular form material. The development of augmented reality-based learning media refers to 4D models which include Define, Design, Develop, Disseminate.

The development of this media starts from the defining stage. Define is a stage that aims to determine and define learning requirements. The activities at this stage are analysis of media needs that are suitable for use and material analysis. The results of the analysis are then used as guidelines for carrying out the design stage. The second stage is design which aims to design augmented reality media. Things that are done at this stage, including making storyboards and compiling material that will be included in learning media. Augmented reality is made in the form of the formation of molecular shapes in the form of animations based on lone electron pairs and bonding electron pairs. Devices used in making media are laptops, smartphones, and some software used in making Augmented Reality-based learning media , namely: Vuforia sdk, Android sdk and unity 3D. The third stage of development aims to produce augmented reality learning media that have been revised based on input from experts. At this stage, a limited-scale trial was also carried out to potential users. The effectiveness test of the use of AR media in improving students' mental models was conducted on 30 grade XI students of Senior High School 15 Semarang in the form of a one-shot case study.

RESULT AND DISCUSSION

Through a series of stages that have been carried out in research and development, 13 types of molecular shapes have been produced *in augmented reality* learning media, namely Linear, Trigonal Planar, V Shape, Tetrahedral, Trigonal Pyramid, V Shape, Trigonal Bipyramid, Scale Shape, T Shape, Linear, Octahedral, Pyramid Quadrilateral, Square. The *augmented reality media* has characteristics in the form of animation of the formation of molecular shapes and buttons to determine the desired molecular shape based on Free Electron Pairs (PEB) and Bonding Electron Pairs (PEI). When the marker is scanned and pressed the desired PEB and PEI buttons, a 3D animation of the corresponding molecular shape will appear. In addition, on the screen display of molecular shapes there is information in the form of molecular geometry, molecular formulas and molecular examples. The markers used are only one for 13 types of molecules. The resulting 3D object can be rotated 360o and can be enlarged and reduced. *This augmented reality* learning media also has a menu of materials, evaluations, learning objectives and instructions for using media.

In the process of making this AR media, it has gone through a series of stages including at the design stage, researchers prepare material to be included in augmented reality learning media.Researchers also animated molecular shapes using 3D blender software and markers. In addition, several other software at the media production stage are also used such as Vuforia sdk, Android sdk and unity 3D. Figure 1-6 presents the display of Augmented Reality-based media content developed.

Figure 1-6 Augmented reality learning media

Figure 1. Main Menu Display

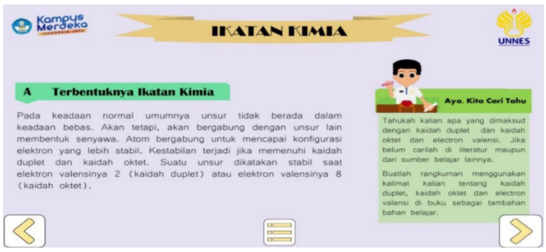

Figure 2. Material Display

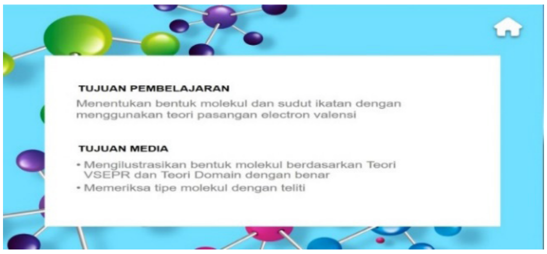

Figure 3. Learning Objectives Display

Figure 4. User Guide

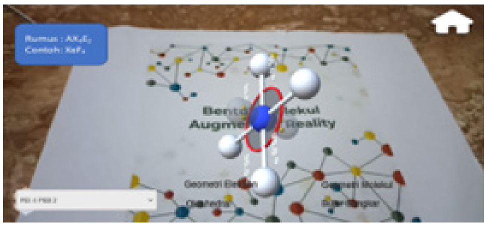

Figure 5. Augmented Reality Display

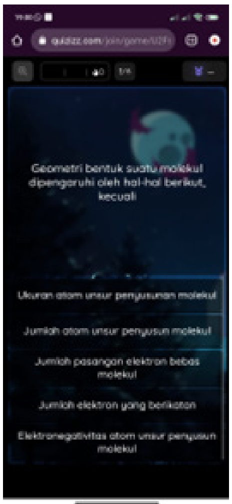

Figure 6. Competency Test Display

At the development stage, validation is carried out by experts to determine the validity of the content of learning media. A total of 3 material and media experts were involved in this stage. Table 1 presents the results of expert validation of the developed media.

Table 1. Results of Instrument Validation by Content Experts

No.	Aspects	Scores obtained			Maximum score
		V1	V 2	V 3	
1	Fill credentials	36	33	34	36
2	Content	7	7	8	8
3	Instructional	8	7	8	8
Average		94,8			
Criterion		Very Valid			

Based on Table 1, it can be known that the results of augmented reality learning media molecular form material are declared very valid by experts. Assessments and suggestions for improvement have been given, and some revisions have also been made. These revisions include, among others: 1) providing reference writing on the AXmEn formula; 2) the writing of the electron configuration is determined using the shell electron configuration or aufbau configuration after which it is equalized from beginning to end; 3) add examples of problems containing lone electron pairs. In Figure 7-11 material changes in media based on material expert input.

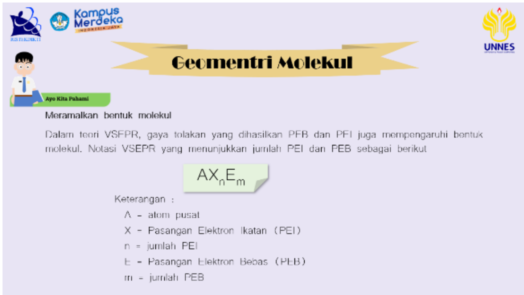

Figure 8. Before adding a reference to the AX_mE_n formula

Figure 9. After adding a reference to the AX_mE_n formula

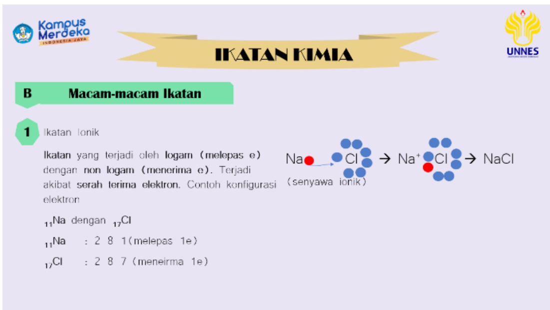

Figure 10. Before changing the writing of the electron configuration of the shell

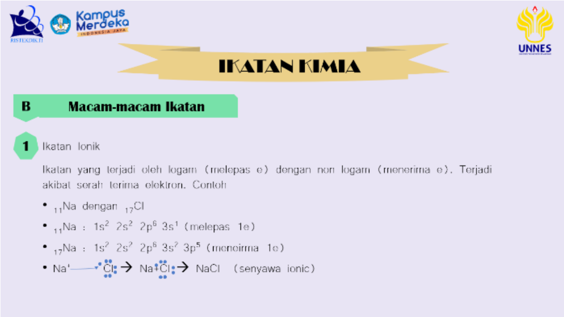

Figure 11. After changing the writing of the electron configuration of the shell

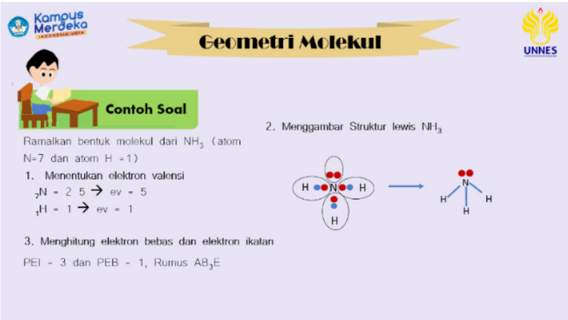

Figure 12. Addition of Sample Questions

Validation of learning media by media experts covers several aspects, namely technical quality and interface design. Technical quality includes the type, size, and color of the text, the size and quality of the image, and the accuracy, suitability, and selection of the animation is appropriate. Aspects of interface design include symbol size, symbol placement, button use, user instructions, ease and flexibility of media. The results of media expert validation of augmented reality learning media are shown in Table 2.

Table 2. Results of Assessment for Augmented Reality Media Expert.

No	Aspects	V1	V 2	Max Score
1	Technical Quality	33	35	36
2	Interface Design	23	24	24
Average		95,8		
Criterion		Valid		

The results of the assessment of media experts show that augmented reality learning media on molecular form material has been declared very valid. Suggestions and inputs related to the media include, 1) the molecular model needs to be equated with the original one so that the molecules are appropriate; 2) Let's understand writing font needs to be enlarged so that it can be read clearly.

Design changes based on media expert input can be seen in Figure 13 - Figure 16.

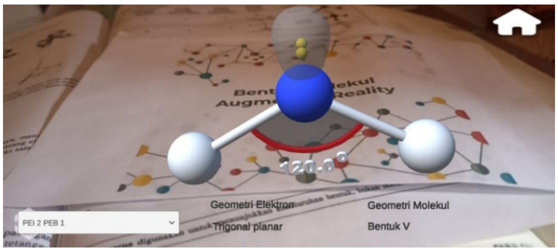

Figure 13. Before changing the binding angle writing

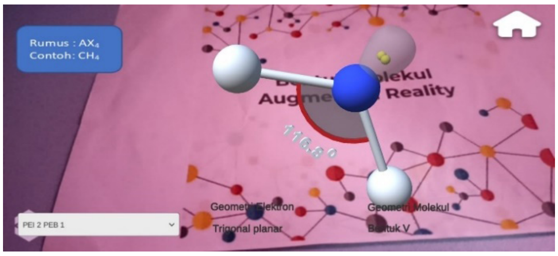

Figure 14. After Changing the binding angle writing

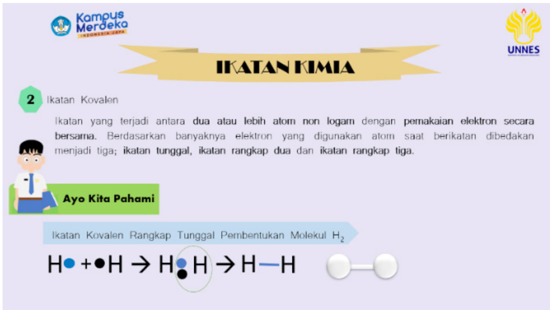

Figure 15. Before the design change

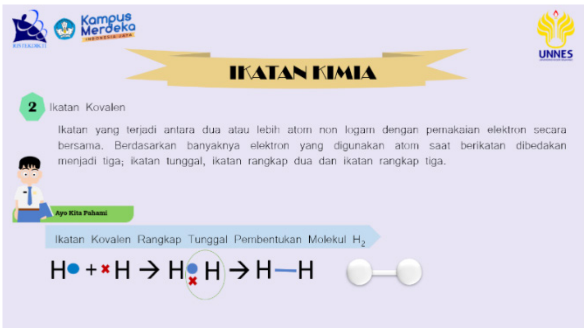

Figure 16. After Design Changes

Augmented Reality-based learning media that have been declared valid/suitable for use are then tested on prospective users, namely students and teachers at SMA N 15 Semarang. This trial aims to determine user response to augmented reality learning media. Input and suggestions from teachers and students are used as a reference for media improvement. Data from student and teacher response questionnaires were obtained using questionnaires and interview sheets. The teacher's assessment of the media was given by 2 teachers of class XI high school chemistry subjects. The assessment results from teachers can be seen in Table 3.

Table 3. Results of Teacher Response

Assessment Aspect	Value	Category
Media Display	95,8	Excellent
Presentation of Content	95,8	Excellent
Implementation	95	Excellent
Average	95,3	Excellent

Based on the results of teacher responses in Table 3. shows that augmented reality learning media is so good that it is suitable to be used as an aid in learning as an effort to improve students' mental models. After being declared worthy of the teacher, it is then tested on students. The data on the results of student responses at the trial stage can be seen in Table 4.

Table 4. Results of the student responses

Assessment Aspect	Value	Category
Learning Design	79,1	Good
Media Display	81,6	Good
Software	76,9	Good
Content	82,9	Good
Average	80,1	Good

The average percentage of student responses to learning media is included in the good category. There are several obstacles faced when using the application, namely; (1) after installing the application cannot be opened because it always exits to the home; (2) old marker scans (3) quite draining the battery (4) the camera is not clear (5) it still frames a bit when entering the augmented reality page.

After improvements, learning media are implemented in real classroom learning to test effectiveness. The subjects of research in the real class were 30 grade XI students of SMA N 15 Semarang. The improvement of students' mental models can be known by analyzing student learning outcomes obtained through pretest and posttest scores. The results of the analysis of each question item were used to determine the improvement of students' mental models on molecular form material as presented in Table 5.

Table 5. Student Mental Models on Molecule Geometry

No Soal	Initial		Synthetic		Scientific	
	Pre	Post	Pre	Post	Pre	Post
1	30	3	-	25	-	2
2	29	9	1	3	-	18
3	28	7	2	22	-	1

In Table 5 it can be known, for pretest question number 1 all students are in the initial category, after the post-test as many as 3 students are still in the initial category, 25 students are in the synthetic category and 2 students are in the scientific category. In pretest question number 2 there are 29 students classified as the initials category and 1 student in the synthetic category, after the posttest there are 9 students classified as the initials category, 3 students in the synthetic category, and 18 students classified as the scientific category. In question number 3 the pretest results showed 28 students in the initial category and 2 students in the synthetic category, while the posttest results showed that there were 7 students in the initials category, 22 students in the synthetic category, and 1 student in the scientific category. Based on these results, it can be seen that students who were originally in the initial category, after learning with augmented reality learning media aids, at the end of learning increased to the synthetic category and slightly increased in the scientific category.

The results of the study above are in line with the results of research by Supriadi et al (2023) which found that augmented reality media is effective and practical to be used to develop students' mental models into the synthetic category. Likewise, Ningrum's (2021) findings that augmented reality learning media have the potential to improve students' mental models, in addition to being able to increase students' understanding and motivation of learning (Liu et al, 2022). This increase in mental models is due to Augmented reality can facilitate the visualization of virtual objects in 3D view to match each molecular shape to the student's imagination (Kudale &; Buktar, 2022). This is also reinforced by Nandyansah &; Suprapto (2019) said that augmented reality learning media can train abstract thinking skills in molecular form.

The results showed that augmented reality learning media molecular form material is feasible for use in the learning process. The results also prove that augmented reality learning media has the potential to improve students' mental models. Various things that can build students' mental models to form the concept of student understanding according to what has been taught, can also be caused by the existence of media that have a positive effect on the learning process, as Tekedere & Goker (2016) conveyed that the use of augmented reality learning media has a positive effect on the learning process, and can increase student learning motivation (Khan et al, 2018) because augmented reality learning media makes the learning process fun, interactive and easy to understand (Liu et al., 2022). Explaining topics and providing additional information using augmented reality in the learning process becomes more interesting (Dutta, 2015)

Based on the results of this description, it is proven that Augmented reality also has the potential to overcome chemistry learning problems in the era of the Industrial Revolution 4.0 (Maulana et al, 2019) and can help teachers and students in learning activities (Feri &; Zulherman, 2021).

CONCLUSION

Based on the analysis of research data, it can be concluded that augmented reality learning media molecular form material to improve students' mental models is declared feasible because it has met the criteria for validity according to experts and received a positive response from teachers and students. The use of augmented reality learning media has also proven effective for improving students' mental models into synthetic categories in most students who were originally in the initial category.

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