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Augmented reality learning media based on tetrahedral chemical representation: How effective in learning process?

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Abstract

The implementation of technology in the era of Society 5.0 runs massively in the world of education. One of them is in the form of augmented reality (AR) learning media. AR technology that can visualize abstract chemical topics in line with the concept of tetrahedral chemical representation. Therefore, this study aims to design and test the effectiveness of AR learning media based on tetrahedral chemical representation. This study used research and development methods with ADDIE (analysis, design, development, implementation, and evaluation) model. The topic of chemical equilibrium chemistry was chosen in this study to develop AR media. This research was conducted in three representative schools in Surakarta, Central Java, Indonesia. A total of 168 students from three representative schools (66 male and 102 female) participated as subjects in the Implementation stage. In addition, a multiple-choice instrument with 24 parallel questions on the pre- and post-test was used to determine the effect of the developed media on the experimental and control classes. The results showed that the design of AR learning media based on tetrahedral chemical representations was successfully developed and proved effective in improving learning outcomes. Student response sheets are given after using the media to find user experience regarding the strength and weaknesses of AR media.

Keywords: augmented reality, chemical tetrahedral representation, chemical equilibrium

INTRODUCTION

Society 5.0, proposed in the 5th basic science and technology plan by Japan's national government for a technology-based, human-centered society emerging from the 4th industrial revolution, is a new chapter in changing human life (Hitachi-UTokyo Laboratory, 2020). This era is marked by merging technology and human life by applying data processing schemes from the real world with computers to produce output that is utilized for the benefit of human life (Hitachi-UTokyo Laboratory, 2020). All lines of human life today are inseparable from existence of technology. The education sector is one sector that has a significant impact from the presence of technology. The conversion of education from traditional to digital formats is an example of a great need for technology (Hitachi-UTokyo Laboratory, 2020; Takakuwa et al., 2018). Use of this technology is common in various fields of education to help teach concepts that are abstract and considered complex by students, including chemistry (Andrejevic & Selwyn, 2020; Berendt et al., 2020; Ilyasa & Dwiningsih, 2020a).

Chemistry is considered difficult to understand due to the characteristics of its abstract concepts (Câmara Olim et al., 2022; Ewais & de Troyer, 2019; Yamtinah et al., 2022). This is because students need to visualize complete chemical concepts even though chemical reaction processes often cannot be observed directly (Ilyasa & Dwiningsih, 2020b; Nechypurenko et al., 2018). Difficulties in visualizing chemistry concept especially arise in submicroscopic representations (Mahanan et al., 2021). On the other hand, visualizing an abstract concept at level of submicroscopic representation is a necessary

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Contribution to the literature

- This research provides an alternative to developing Augmented Reality learning media based on tetrahedral chemical representations.
- Augmented reality can continuously represent the level of a human element, macroscopic, submicroscopic, and symbolic representation.
- Augmented reality learning media based on tetrahedral chemical representations has proven to be effective in the topic of chemical equilibrium.

skill in chemistry lessons (Abdinejad et al., 2020; Kartimi et al., 2022; Ripsam & Nerdel, 2022).

Previous studies have used various technology-based learning media to visualize chemical concepts with their respective successes (Brunnert et al., 2018; Rayan & Rayan, 2017; Sang et al., 2004). In addition, other research related to the use of animation technology (Yanarates, 2022), virtual laboratory for learning organic chemistry (Eljack et al., 2020), online platform for chemistry learning during COVID-19 (Guo et al., 2020; Huang, 2020; Sunasee, 2020) and the used of other technologies in chemistry learning (Annetta & Shapiro, 2019; Shidiq et al., 2021, 2022) have also been carried out successfully.

Besides that, there have also been many previous studies that have developed visualization media for the representation of chemical concepts (Liu et al., 2022; Pradani et al., 2020; Ripsam & Nerdel, 2022). Among that, augmented reality (AR) is the technology-based learning media that is being developed to visualize chemistry concepts (Karnishyna et al., 2022; Wong et al., 2021). However, AR and other media's development still focuses on the triangle chemical representation. A tetrahedral chemical representation is needed in line with the concept of Society 5.0, which represents aspects of human life (Mahaffy, 2004, 2006; Sjöström, 2013). The tetrahedral chemical representation adds a human element to help students think holistically by knowing the impacts, sources, and uses of chemicals in human life (Mahaffy et al., 2018, 2019; Shidiq et al., 2020, 2022). This opens up research opportunities to develop AR learning media based on tetrahedral chemical representation (human element, macroscopic, submicroscopic, and symbolic).

This study aims to design AR learning media based on tetrahedral chemical representations and examine their impact on student learning outcomes. The topic of chemical equilibrium was chosen in this implementation because it has many abstract concepts and is considered difficult by students (Ganaras et al., 2008; Yamtinah et al., 2019). This research is expected to be a reference for researchers and chemistry teachers to use AR media based on tetrahedral chemical representation on similar or other chemical topics.

Conceptual Framework

Augmented reality

Technology-based learning media has the advantage of being more easily accepted by students (Antee, 2021; Inquimbert et al., 2019). One type of learning media is AR. AR is a current technique representing the natural world in virtual form with contextual information assisted by computer technology (Cai et al., 2014; Chen & Liu, 2020). AR is an emerging new technology with potential applications in education. The number of studies on AR continues to grow due to the effectiveness of this technology in recent years. In particular, AR provides an efficient way to represent models that require visualization (Saidin et al., 2015).

AR has three main features:

(1) combining real and virtual objects,

(2) providing opportunities for real-time interaction, and

(3) providing three-dimensional virtual and real objects (Annetta & Shapiro, 2019).

AR has gained attention in education for its potential to improve learning and teaching (Annetta & Shapiro, 2019). AR can help bridge gaps and incorporate contextual approaches to learning. AR can be used in various ways, including with computers, laptops, mobile devices, and smartphones. This allows for technological flexibility in its use. Since AR is an emerging technology, it is essential to get an overview of its benefits in an educational setting and some of the challenges that come with it (Annetta & Shapiro, 2019; Saidin et al., 2015; Wu et al., 2013).

AR technology can be used without expensive equipment, strengthening its application in educational environments. With AR applications, the subject matter can provide a different dimension and enhance interaction between individuals and materials. When used effectively, AR increases students' willingness and concentration in learning (Kaya & Bicen, 2019; Zhang et al., 2014). At the same time, AR applications allow students to carry out their learning process so that teachers can save time that would be used to explain the subject repeatedly. Students welcome AR technology, so well-organized AR applications ensure the learning process is carried out successfully (Kaya & Bicen, 2019; Martín-Gutiérrez et al., 2015).

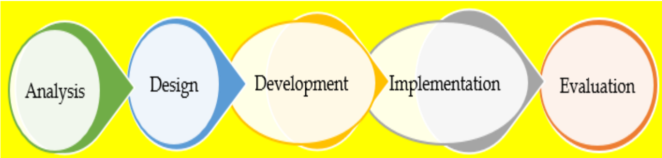

Figure 1. Stages of the research (Source: Authors' own elaboration)

Chemical tetrahedral representation

Various ways have been done to overcome abstractness in chemistry. Meanwhile, chemistry can be explained through three levels of representation, namely the macroscopic, submicroscopic, and symbolic levels (Treagust et al., 2003). Furthermore, the chemical representation is developed into four dimensions by adding human elements into multiple representations, called a chemical tetrahedral representation (Mahaffy, 2006). These four dimensions can help students understand chemistry concepts during the learning process.

Chemists refer to chemical phenomena at three different levels of representation–macroscopic, symbolic, and submicroscopic–that are directly related to each other (Gilbert & Treagust, 2009b; Lewthwaite et al., 2014). However, Mahaffy (2004, 2006) suggests that the three-level model eliminates the essential dimension, namely *the human element* (Lewthwaite, 2014; Mahaffy et al., 2014). Therefore, chemistry education must move beyond a three-tier model focusing only on conceptual understanding and content acquisition. This chemical positioning movement incorporates further investigative and communication experience dimensions, thus turning the model into a tetrahedron.

As Mahaffy (2006) argues, this change emphasizes the need to place chemical concepts, symbolic representations, and chemical substances and processes in the authentic context of the human beings who create substances, the cultures that use them, and the students who try to understand chemistry. Mahaffy (2006) explained the need to develop public understanding and trust by exploring contemporary chemical applications and social and environmental issues related to the production and use of chemicals (Lewthwaite, 2014; Lewthwaite, 2014; Mahaffy et al., 2014).

This 'tetrahedral' approach includes explicit learning of chemistry and about chemistry as a contextual reality in society (Burmeister et al., 2012; Shidiq et al., 2020). Furthermore, it ensures that the chemistry learning process is directed to support continuing education (Burmeister et al., 2013; Shidiq et al., 2020). As Taber (2013) dealing with the 'complexity' of chemistry requires teachers to 'slow down' to provide sufficient opportunities through various contexts, including macroscopic, submicroscopic, symbolic, and human element representations.

Related Research

Chemistry learning using AR has been carried out on several materials, including analytical chemistry (Dave et al., 2019), organic chemistry (Midak et al., 2021), physical chemistry (Lam et al., 2020), and inorganic chemistry (Fombona-Pascual et al., 2022; Nuñez et al., 2008; Schmid et al., 2020). The learning process using AR can be used to increase student motivation (Kaur et al., 2020). In addition, AR is also helpful in improving students' cognitive test performance on chemistry content (Cai et al., 2014).

In learning chemistry, many students still have misconceptions about chemical representations (Gudyanga & Madambi, 2014; Satriana et al., 2018; Yamtinah et al., 2019). Several learning media have been combined with chemical representation to make it easier for students to understand (Pradani et al., 2020; Widarti et al., 2021). The chemical tetrahedral representation in learning must be applied in a comprehensive and interconnected manner to be able to train the skills needed by students (Mahaffy, 2006).

Purpose of the Study

This study aims to design AR learning media based on tetrahedral chemical representations and examine their impact on student learning outcomes. This study also included AR media's strengths and weaknesses, which were developed to determine the user experience when using the media.

METHOD AND MATERIALS

Research Model

This study used research and development method with ADDIE (analysis, design, development, implementation, and evaluation) model. This model provides five phases for developing AR, namely: analysis, design, development, implementation, and evaluation (Mahanan et al., 2021). This study involved three purposefully selected representative schools in the city of Surakarta, Central Java, Indonesia. This research has received approval from the local education office. In addition, all school principals and students involved in this study were permitted to collect research data. The stages of research are presented in **Figure 1**.

The analysis stage was carried out to capture needs of teachers and students for AR media based on chemical tetrahedral representations on chemical equilibrium materials. At the stage, questionnaires were distributed to 16 chemistry teachers and 35 students as a basis for analysis of development needs. Teachers and students are purposively selected from representative schools.

Design stage is carried out by developing initial form products of AR media based on chemical tetrahedral representations on chemical equilibrium materials. In

Table 1. Pre-/post-test group design

Class	School	n		Pre-test	Treatment	Post-test
		Male	Female			
Experiment	A	11	17	O_1	AR media	O_2
	B	11	17	O_1	AR media	O_2
	C	11	17	O_1	AR media	O_2
Control	A	11	17	O_1	Students' book	O_2
	B	11	17	O_1	Students' book	O_2
	C	11	17	O_1	Students' book	O_2

addition, a focus group discussion (FGD) was conducted with six teachers who were purposively selected to get input on the development of the initial form of the product.

Development stage begins with validating the content of the product that has been developed to experts. In this study, nine experts were used as validators, namely one lecturer in chemistry, one lecturer in learning technology, one lecturer in AR learning media, and six senior teacher practitioners. Content validity is done to find out how the attributes measured by an instrument match the performance developed. In this study, the validity of the content was determined using Aiken's formula, namely:

$$V = \frac{S\sum n_i(r-lo)}{n\times(c-1)}, \quad (1)$$

where V is validity index of Aiken, n_i is number of raters who choose criteria, iC is number of categories/criteria, r is i's criteria, ℓo is the lowest category, and n is the sum of all validators.

V values range from zero to one, the value of the criteria used to declare a product valid in content is determined by how many validators and scale are used. In this study using nine validators and five categories, the threshold or validity criteria are 0.78 (Aiken, 1980; Aiken et al., 1985; Sari et al., 2022). After producing a valid product, then a preliminary field test was carried out to obtain readability information, which was carried out to six students and one chemistry teacher from each representative school in Surakarta. The data obtained in the preliminary field test was used to improve AR media products based on chemical tetrahedral representations on chemical equilibrium materials before entering the implementation stage.

The implementation stage is carried out to determine whether AR media has a significant influence or has a positive impact on student learning outcomes. The test was conducted in the form of a quasi-experimental design in three representative schools in the city of Surakarta, Central Java, Indonesia. The design used is pre-/post-test group design. First, both classes were given a pre-test, then the experimental group learned using AR media that had been developed, while the control group learned using teaching materials that are usually used in schools. After the learning process is complete, students are given a post-test. Pre- and post-test tests are used to test the effectiveness of the developed media. Before testing effectiveness, pre- and post-test results are first tested for normality and homogeneity. Pre-/post-test group design are presented in the **Table 1**.

The evaluation stage is carried out by analyzing the results of the effectiveness test of AR media products. At this stage, reflection with interview will also be carried out on the development process and analysis of user satisfaction questionnaire results.

Data Collection Tools

The instruments used in this study were initial analysis questionnaires for teachers and students, user satisfaction questionnaires, and pre- and post-test questions. The initial analysis questionnaire for teachers contains questions about

(1) commonly used learning conditions,

(2) characteristics of chemical equilibrium material, and

(3) learning using AR media based on chemical tetrahedral representations.

As for the initial analysis of students, among others, it contains

(1) the use of commonly used learning media,

(2) the way students learn to understand the material, and

(3) students' opinions on chemical equilibrium material in chemistry learning.

User satisfaction questionnaires that have been used contain 10 statements with yes and no options related to the use of AR media. The pre- and post-test instruments contain 24 multiple-choice questions. This instrument was developed in parallel to ensure improved learning outcomes after treatment. All instruments used are first validated to experts with validation criteria from Aiken. As a result, all instruments and devices used for research are valid (V>0.78) and can be used after several revisions according to comments and suggestions from validators.

Data Analysis

Media validity analysis was carried out through the Aiken test, which scored 0.78 in the valid category. The effectiveness of the use of AR media that has been developed is carried out by t-test using IBM SPSS statistics 22.

Table 2. Results of teacher questionnaire needs analysis

No	Statement	Percentage (%)
1	The obstacle in chemistry learning is the limited learning media available.	43.8
2	Teachers rarely use *AR* as a learning medium.	81.3
3	Teachers rarely use learning media that are oriented to the four levels of chemical representation.	75.0
4	Teachers rarely link submicroscopic aspects to the media created.	56.3

Table 3. Results of student questionnaire needs analysis

No	Statement	Percentage (%)
1	Chemistry is a difficult subject.	77.1
2	The way students learn about chemistry is memorization.	48.6
3	Students do not know the application of chemical concepts in everyday life.	57.1
4	Students do not know the molecular processes that occur in chemical reactions.	74.3

Table 4. Recap of FGD results with high school chemistry teacher

No	Teacher	Suggestion
1	Teacher A	AR media should emphasize on collaboration between students.
2	Teacher B	Add descriptions to images that will appear in AR.
3	Teacher C	Add smartphone specifications used to install AR.
4	Teacher D	Media needs to meet material criteria.
5	Teacher E	Blood pH equilibrium material needs to be added buffer compounds to reaction mechanism. Material for making ammonia, reaction is not equivalent, & necessary to add number of molecules to be proportional.
6	Teacher F	All four levels of chemical tetrahedral representation need to appear in AR.

RESULTS AND DISCUSSION

Analysis Stage

At this stage, a needs analysis is carried out by providing questionnaires to teachers and students, the results of teacher and student questionnaires are presented in **Table 2** and **Table 3**.

Based on **Table 2** and **Table 3**, it is known that the overall development of *AR* media based on chemical tetrahedral representations is a need for teachers and students. Teachers rarely use *AR* as a learning medium. In addition, the learning media that are usually used still do not contain the four levels of chemical representation, especially in sub-microscopic level.

To understand chemistry holistically requires mastery the multiple representations of chemistry. Multiple representations arise because of the need for students to explore and perform many diverse tasks involving various abstract information (Bucat & Mocerino, 2009; Liu et al., 2022; Shidiq et al., 2020; Wong et al., 2021). In fact, chemistry learning in general emphasizes on the macroscopic and symbolic levels. Meanwhile, submicroscopic level is also an important thing to teach to students (Gilbert & Treagust, 2009a; Herga et al., 2016; Ilyasa & Dwiningsih, 2020a; Mahanan et al., 2021). **Table 3** shows that 74.3% of students do not know the molecular processes in a chemical reaction. In line with the data from teacher questionnaires, as many as 56.3% of teachers rarely link submicroscopic aspects in making learning media. This further shows that the submicroscopic level is becoming a necessity to be taught to students. On the other hand, the use of AR technology to provide explanations about the submicroscopic level is one of the biggest obstacles for teachers. This is evidenced by the results of teacher questionnaires, which stated that as many as 81.3% of teachers have never used AR as a learning medium. Therefore, AR can be an alternative solution for adequate learning media for tetrahedral chemical representation (Merino et al., 2022; Sari et al., 2022; Yamtinah et al., 2021).

Design Stage

Focus group discussion results

At this stage, FGD and preliminary form of the product development are carried out. FGD is carried out to determine materials, indicators, basic competencies and solicit input related to AR media design to be developed. The results of the FGD are presented in **Table 4**.

Table 4 shows the input given by chemistry teachers to pay attention to in the development of AR media. In addition, at this stage the suitability of basic competencies and the material to be taught is discussed. The results of this analysis are presented in **Table 5**.

Based on the concept analysis that has been carried out, the chemical equilibrium in the developed AR media includes dynamic equilibrium and the four factors that affect the shift in the direction of equilibrium. Examples of dynamic equilibrium subprincipal are divided into homogeneous equilibrium (such as the reaction in the ammonia manufacturing process) and heterogeneous equilibrium (such as the reaction in photosynthesis). The four factors that affect the shift will be arranged based on examples of chemical equilibrium

Table 5. Basic competencies, indicators, & learning objectives

Basic competencies	Competency achievement indicators	Learning objectives
Analyze process of equilibrium occurrence & factors affecting shift in equilibrium direction	Analyze process of dynamic equilibrium occurrence	Students can analyze process of dynamic equilibrium in a chemical reaction through 3D illustration correctly
	Analyze process of shifting direction of chemical equilibrium	Students can analyze process of shifting direction of chemical equilibrium through 3D illustrations correctly
Design & conclude & present data on results of classification of factors that affect shifts in direction of equilibrium	Present conclusions on factors that can affect equilibrium shifts	Students can present conclusions on factors that can affect equilibrium shifts through questions on student worksheets that are provided appropriately

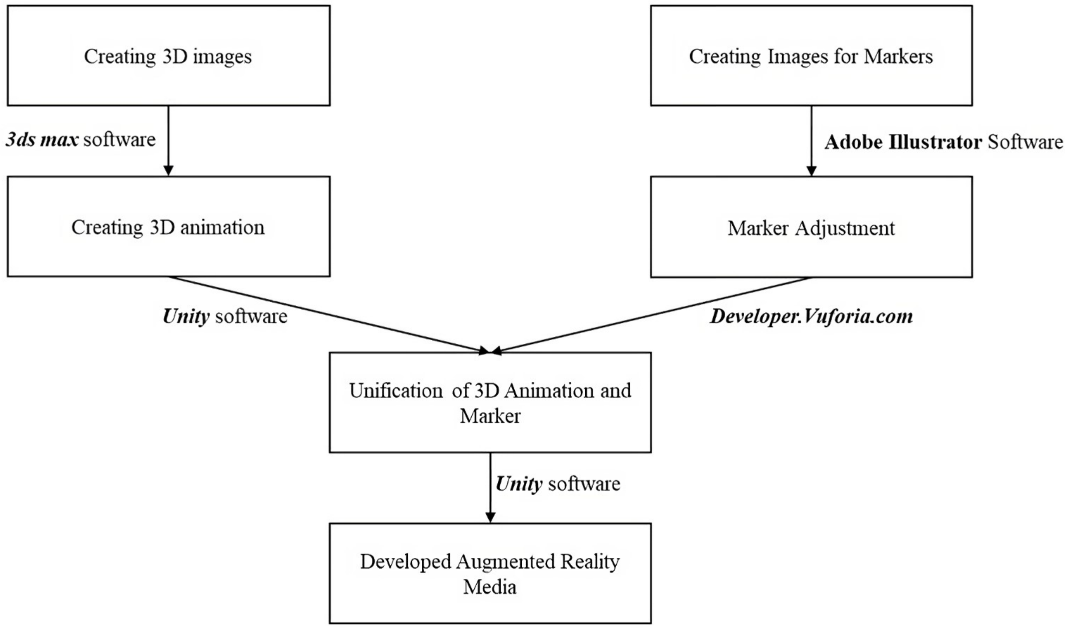

Figure 2. AR media creation flow (Source: Authors' own elaboration)

in everyday life. As in the process of photosynthesis, blood pH equilibrium, and the process of making ammonia.

AR media design

AR media that was developed was made using the main software in the form of Unity with the C# programming language. Other additional supporting software is the Vuforia engine (developer.vuforia.com) to create markers and 3Ds max to create three-dimensional images. This AR media is designed to be used only on Android smartphones, with a minimum specification of Android Pie 9.0 with 2GB of RAM. The flow of AR media creation is briefly shown in **Figure 2**.

The developed AR media is based on a chemical tetrahedral representation approach, which consists of four aspects, namely:

(1) human element,

(2) macroscopic,

(3) sub-microscopic, and

(4) symbolic.

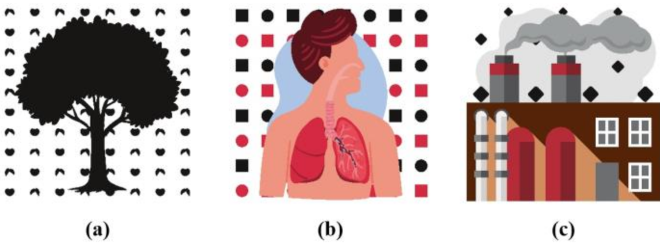

Figure 3. Markers for each of following themes: (a) photosynthesis, (b) blood pH balance, & (c) manufacture of ammonia (Source: Authors' own elaboration)

AR media developed in the topic of chemical equilibrium consisted of three main themes, namely

(1) photosynthesis,

(2) blood pH balance, and

(3) the manufacture of ammonia.

The three themes are simple descriptions of the chemical equilibrium material, each of which is represented by a different marker, as shown in **Figure 3**. The chemical tetrahedral representation is represented by a different button for each theme, as shown in **Figure 4**.

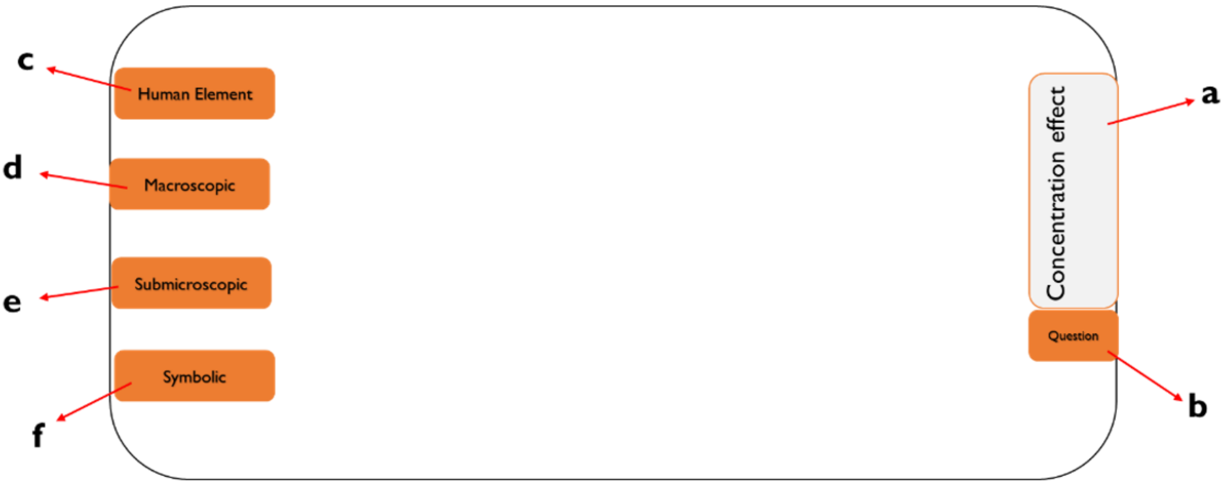

Figure 4. Chemical tetrahedral representation sketch (Source: Authors' own elaboration)

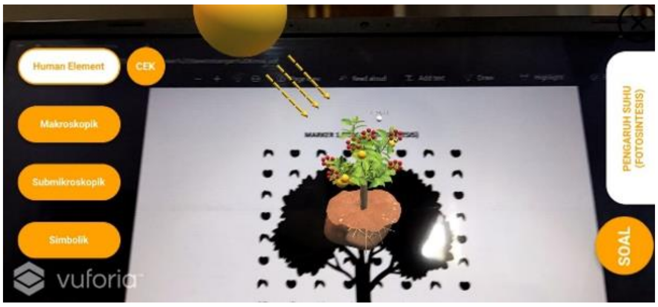

Figure 5. Human element aspect in AR media (Source: Authors' own elaboration)

Figure 6. Macroscopic aspects of AR media (Source: Authors' own elaboration)

After students access the material, they can test their understanding by pressing the question button. The questions are in the form of multiple-choice questions whose answers can only be found implicitly or explicitly in the material in the theme. After answering several questions, students will know how many scores were received from the correct answers. From these results, students are expected to be able to self-measure how much they understand chemical equilibrium material.

The following is a description of the developed AR media data arranged based on the chemical tetrahedral representation as an example of a brief description that will be discussed on photosynthesis.

Human element

The human element is a level of representation that represents chemical events in real life (Mahaffy, 2006). In this viewpoint, understudies know the relationship between chemistry and some phenomena in their environment (Talanquer, 2011). The description of AR media on human element aspect is shown in **Figure 5**.

In **Figure 5**, it can be seen the process of photosynthesis with the entry of CO_2 and H_2O into the plant to produce $C_6H_{12}O_6$ and O_2 gas. The depiction of these compounds uses the analogy of a simple spherical sphere. This simple spherical image is used to ensure that students understand the basic model first before moving on to complex modeling in submicroscopic aspects (Coll, 2006).

Macroscopic

Macroscopic is the level of representation in the form of real phenomena and can be seen or observed directly (Treagust et al., 2003). The description of AR media on the macroscopic aspect is in **Figure 6**. Based on **Figure 6**, macroscopic is described as the phenomenon of the release of water during the respiration process at night. These phenomena meet the macroscopic level requirements, including actual phenomena experienced and observed in everyday life (Gabel, 1999).

Submicroscopic

The submicroscopic level is the level of representation based on real observations but still requires theory to explain what happens at the molecular level (Treagust et al., 2003). The description of AR media on the submicroscopic aspect is shown in **Figure 7**. Submicroscopic is described by the molecular shape of compounds that react on the theme of photosynthesis. The molecule's shape is one embodiment of the submicroscopic aspect (Nicoll, 2003). The process of molecular movement in the submicroscopic aspect is used to explain the macroscopic aspect (Treagust et al., 2003).

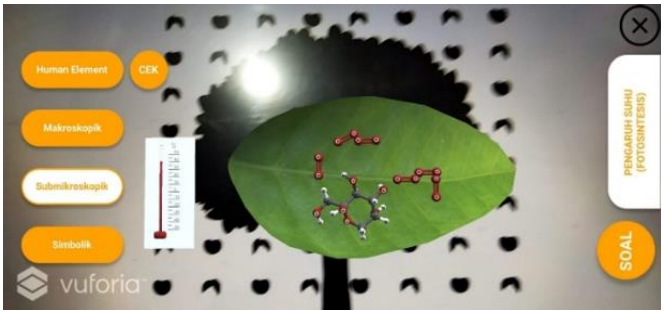

Figure 7. Submicroscopic aspects of AR media (Source: Authors' own elaboration)

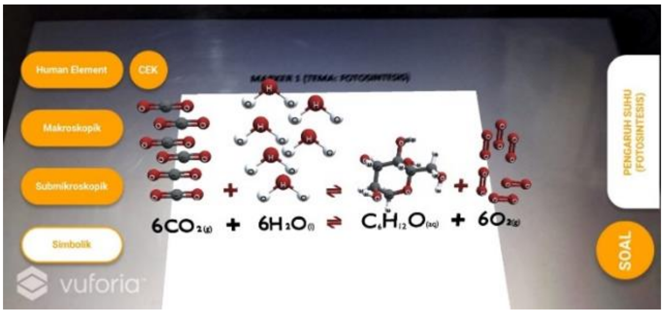

Figure 8. Symbolic aspects of AR media (Source: Authors' own elaboration)

Table 6. AR media design

No	Media components	Content draft	Information
1	Initial view	AR camera	The camera is on for the marker scan process.
		AR markers	It contains a marker in the form of a code to bring up the material.
		About media	Contains name of application creator & purpose of application is created.
		Go out	Button to exit the application.
2	Core	Marker 1 (Photosynthesis)	
		- Human element	3D animation about the process of photosynthesis that uses sunlight.
		- Macroscopic	Animation of photosynthesis at night, shown by presence of water spots on leaves.
		- Submicroscopic	Movement of molecules that are reacting to photosynthesis.
		- Symbolic	Chemical reactions & molecular shape of substances that make up reaction.
		Question	The question is at the end of material in the form of a multiple choice.
		Score	Score results when the questions are done.
		Marker 2 (Blood pH balance)	
		- Human element	3D animation of people getting ready to dive into the water.
		- Macroscopic	Bubbles appear when people are holding and exhaling water.
		- Submicroscopic	Movement of the reacting molecules and their analogy when holding your breath and exhaling on the pH balance of the blood.
		- Symbolic	Chemical reactions & molecular shape of substances that make up reaction.
		Question	The question is at the end of material in the form of a multiple choice.
		Score	Score results when the questions are done.
		Marker 3 (Ammonia production)	
		- Human element	3D animation of making ammonia through the Haber-Bosch process.
		- Macroscopic	The final product of ammonia on the market.
		- Submicroscopic	Changes & movement of molecules when there is a change in pressure.
		- Symbolic	Chemical reactions & molecular shape of substances that make up reaction.
		Question	The question is at the end of material in the form of a multiple choice.
		Score	Score results when the questions are done.

Symbolic

The symbolic level is the level of symbolic representation of atoms, molecules, and compounds that are usually depicted in a chemical reaction (Treagust et al., 2003). Some things that can be categorized as symbolic aspects are chemical equations, molecular formulas, molecular models, Fischer projections, stoichiometry, and mathematics (Gkitzia et al., 2020). However, in the developed AR learning media, the symbolic aspects used were molecular formulas and chemical equations. This is adjusted to the chemical equilibrium material in the sub-materials in AR learning media in the form of dynamic equilibrium and factors that affect chemical equilibrium. The description of AR media on the symbolic aspect is in **Figure 8**.

The symbolic aspect can be used to communicate the human element and macroscopic aspects. Limitations on the submicroscopic aspect when observed directly, make the symbolic aspect the only way to describe the characteristics and properties of these compounds to construct mental images (Treagust et al., 2003).

Briefly, the design of AR learning media developed is summarized in **Table 6**. With the addition of questions at the end of each theme, it is hoped that students will not only see animations on the media and match visualization forms with chemical formulas on the developed learning media, but also be able to bridge information based on chemical tetrahedral representations obtained from the media to complete their knowledge about the surrounding phenomena to get meaningful chemistry learning (Talanquer, 2011).

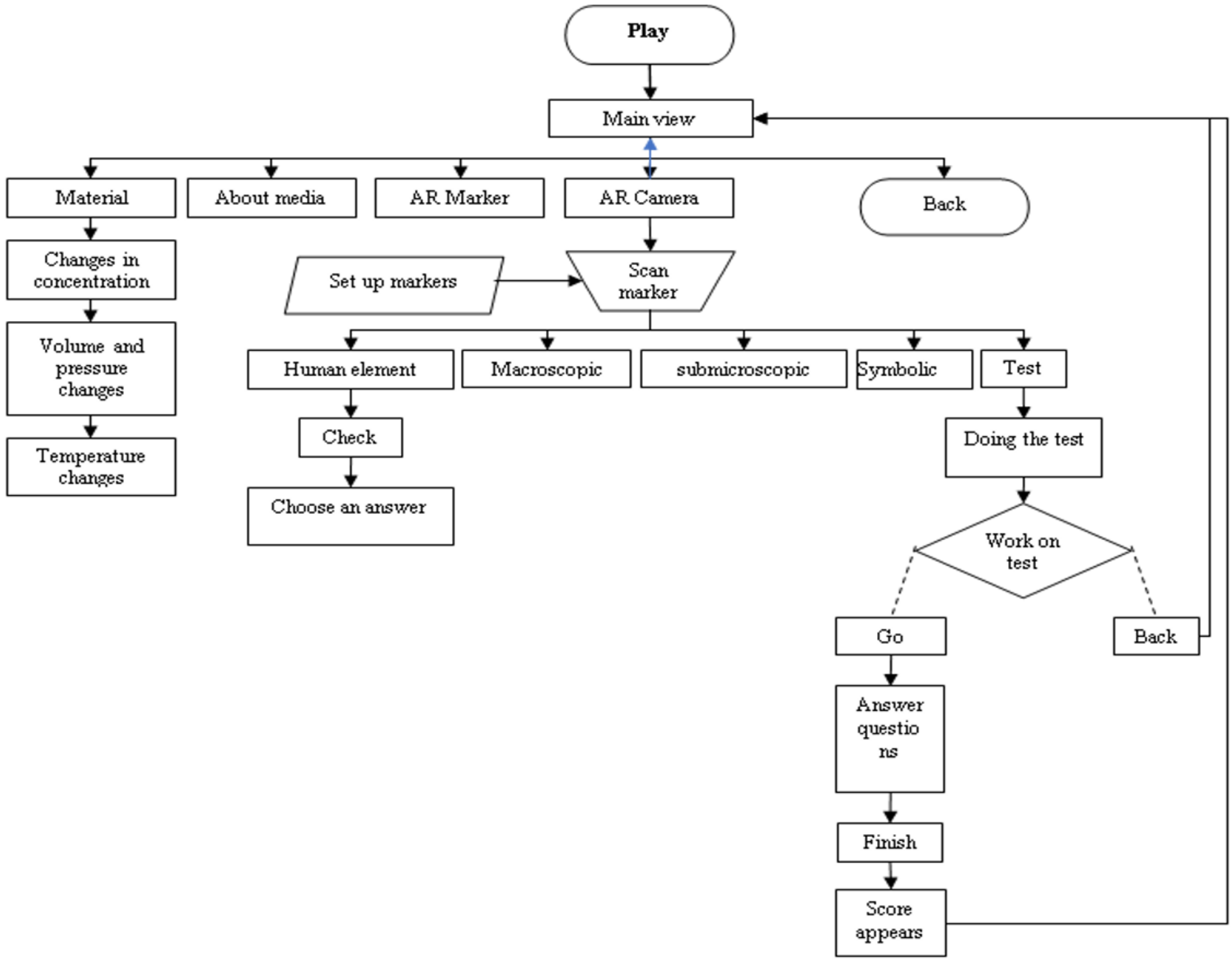

Figure 9. Flow of using AR media (Source: Authors' own elaboration)

Development and Implementation Stage

The development stage is carried out by validating the initial product that has been created. Content validation with the Aiken formula involving six validators from senior teachers and three validators from expert lecturers was used in this study. There are four aspects that are validated, aspects of content suitability on the theme of photosynthesis, blood pH balance, and ammonia preparation, aspects of the language used, aspects of presentation, and graphic aspects. After going through several revisions according to the advice of validators, valid media and research instruments were obtained in content with criteria of V>0.78. This criterion is obtained based on the Aiken validity table by considering the number of validators and the scale used. The flow of using AR media after the validation stage is shown in **Figure 9**.

The implementation of learning in this study uses the discussion learning method, with the following stages:

(1) clarify aims and establish set,

(2) focus the discussion/ask students to use AR media,

(3) hold the discussion,

(4) end the discussion, and

(5) debrief the discussion.

The questions used have passed the normality test (Shapiro-Wilk test) and homogeneity test (Levene's test). Each test got a significance value of more than 0.05, meaning the data is normal and homogeneous. After the data obtained were normally distributed and homogeneous, the statistical test used was the independent sample t-test with a significance level of 5% using SPSS software. The decision criteria taken is if the significance value (1-tailed)<(α=0.05), then H_0 is rejected. The provisions of the hypothesis are, as follows:

H_0. There is no significant difference in learning outcomes between groups of students who use AR media and groups of students who do not use AR media.

H_1. The average increase in learning outcomes for the group of students who use AR media is higher than the group of students who do not use AR media.

Based on the results of the study shown in **Table 7**, obtained a significance score 0.000 in all schools, meaning sig. (p)<0.05. So that **H_0** is rejected or **H_1** is accepted, which means that the average increase in learning outcomes in the class of students who use AR media is higher than students who do not use AR media.

AR media has a role in students' cognitive learning outcomes. This is because AR provides a clear

Table 7. Results of independent sample t-test significance score

No	Representative schools	Sig. (p)
1	High category	0.000
2	Medium category	0.000
3	Low category	0.000

submicroscopic visualization that students do not get from books or print media. Students can see the composition of the material in real life (Cai et al., 2014). So that students get a new learning experience. This experience increases students' confidence in the concepts they have. This is like previous research by Cai et al. (2021), which states that the use of AR can significantly increase students' self-efficacy, so that it has a positive impact on student learning outcomes.

Students' cognitive learning objectives are measured through Bloom's taxonomy (Furst, 1981). The learning outcomes obtained after using AR media are supported by the ability of students who master lower-order cognitive skills (remembering, understanding, and applying) as well as one of higher-order cognitive skills in the form of analyzing in Bloom's taxonomy. In this study, it was explained that in the remembering level, students were able to remember chemical equilibrium in real life in different ways. The understanding level, students can and are able to understand the factors that affect chemical equilibrium. The applying level, students were able to solve the problems given by the teacher by applying AR media. The analyzing level, students are able to discuss with friends and also the teacher in organizing the problem into the correct parts.

Several studies say that in addition to improving cognitive abilities, AR can be used to improve student learning outcomes in several subjects (Ling et al., 2021; Pochtoviuk et al., 2020; Sahabuzan, 2012; Saidin et al., 2015; Tarng et al., 2022; Wan et al., 2018), to improve thinking skills (Aliyu & Talib, 2020; Astuti et al., 2020; Cheng et al., 2022), to improve class completeness score (Cen et al., 2020; Smith & Friel, 2021), and to interest and understanding of certain material concepts (Kuit & Osman, 2021; Mayilyan et al., 2018).

Evaluation Stage

The evaluation process is carried out in two ways, interviews and filling out questionnaires. These results are used as an evaluation to consider the strengths and weaknesses of the developed AR media. The results of the questionnaire are presented in **Table 8**.

Strength

Student responses to the excellence of AR focus on three things: engaging, enabling exploration, motivating. This is in accordance with previous research, which stated that AR media is a fun and interesting medium for young people (Al-Azawi et al., 2019). AR provides more information than in the teaching materials (Wallace, 2018), thus allowing students to explore more in 3D illustration in AR. In addition, AR is also proven to increase students' motivation to learn on certain subject matter (Khan et al., 2019), and promote better learning opportunities for students with different learning styles (Wallace, 2018).

The teacher who was given a response questionnaire added that AR media developed for the material in chemistry was able to shorten class learning time. This is because students can easily understand 3D images and animations on developed AR media instead of having to read several pages of books on chemistry. The use of 3D is considered to be able to shorten learning time and even provide higher satisfaction to students if providing material using AR technology compared to providing material traditionally (Clements et al., 2013; Marsh et al., 2008).

Table 8. User satisfaction questionnaires results per school

No	Question	Positive answers (%)		
		A	B	C
1	Is the appearance of AR media on chemical equilibrium material interesting?	92.8	85.7	89.2
2	Are languages & symbols used in chemical equilibrium material AR media easy to understand?	67.8	71.4	78.5
3	Does the illustration contained in the AR media of chemical equilibrium material make it easier for you to understand chemical equilibrium material?	96.4	92.8	85.7
4	Does the AR media of chemical equilibrium material help make it easier for you to strengthen your understanding of chemical equilibrium material taught in school?	96.4	96.4	92.8
5	Is the concept of material contained in AR media, chemical equilibrium material in accordance with the material taught in schools?	89.2	85.7	96.4
6	Are you having difficulty defining chemical equilibrium material after using AR media?	67.8	64.2	71.0
7	Is AR media on chemical equilibrium material difficult to operate?	75.0	78.5	75.0
8	Does the AR media on chemical equilibrium material motivate you to learn more about chemical equilibrium material?	89.2	92.8	96.4
9	Does the AR media on chemical equilibrium material motivate you to find out the relationship of chemical equilibrium material with other materials?	89.2	89.2	92.8
10	Does the AR media of chemical equilibrium matter motivate you to find out the uses of chemical equilibrium materials and their examples in everyday life?	92.8	85.7	85.7

Weakness

Student responses to AR weaknesses focus on three things: AR media is new, so students need to adapt, need at least two devices to run AR, and challenging to use when learning online. This is in accordance with previous research that the general public is ignorant of AR technology, and only some have equipment as AR supporting materials (Wallace, 2018). When in class, which is done offline, students will have no difficulty due to the many devices used, especially if they are used in a group. Each group member will collaborate by providing markers, opening applications, and discussion. This cannot be done when online learning (using zoom, google meet, etc.) even though the learning method is carried out by discussion. This is because online learning cannot provide a maximum pedagogical process.

The teacher who was given a questionnaire stated that AR media developed had two weaknesses: a camera angle that could not be used to see as much as 360o and required a large smartphone memory to install the application. The camera scan angle that cannot access 3D images is 360o because the marker is on 2D objects (paper, other smartphone screens, laptop screens, etc.). Meanwhile, the position of the smartphone camera when scanning must remain on the marker so that it does not allow students to see the whole from various sides. On the other hand, the weakness of AR is the large size of the software that must be installed on the smartphone. AR media on the chemical equilibrium material developed has a size of 93 megabytes. Therefore, some smartphones that lack storage memory cannot install this software.

CONCLUSIONS & RECOMMENDATIONS

Conclusions

AR media is designed in a structured manner based on the four components of the chemical tetrahedral representation. Each marker has the same portion of the tetrahedral representation. The implementation of AR media is proven effective in improving learning outcomes. The most dominant strength of AR media in this study is its ability to facilitate students in exploring chemical material, while the most dominant weakness of AR learning media in this study lies in the inability of AR to play a leading role in the online learning process.

Recommendations

AR learning media is proven to be effective in learning. Therefore, the author recommends that similar research be carried out on other learning materials by adding a combination of 3D images, videos and even interactive animations.

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