Application of Augmented Reality on Chemistry Learning: A Systematic Review

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Abstract: The rapid development of technology in the world of education has many positive impacts, namely facilitating the learning process. Technological sophistication can be felt, one of which is augmented reality. This Augmented Reality concept collaborates the real world with the virtual world which can display more detailed information in 3D visuals. This review systematic analysis study was conducted to classify the application of augmented reality in chemistry learning. The main criteria for the selections of journals the implementation of augmented reality in the field of chemistry education with a period ranging from 2015 to 2022 from an international database. There were 74 journals were obtained that fit into the criteria. Journal studies focused on the application of AR chemistry materials at the high school and university levels. The studies analyzed focused on the form of applying AR in chemistry learning, applied chemistry, chemical material, and sample level. The results of the study show that the application of AR in chemistry learning is often presented in the form of android-based learning, organic chemistry is widely applied using AR. In addition, an explanation of the application of chemical concepts and sample groups is also discussed here.

Keywords: Augmented reality; Chemical concepts; Chemistry learning

Introduction

The rapid development of technology in the world of education has many positive impacts that is facilitating the learning process. Technological sophistication can be felt, one of which is augmented reality. The concept of Augmented Reality collaborates the real world with the virtual world which can display more detailed information in 3D visuals (Abuhammad et al., 2021; Ayoub et al., 2019). The advantage of this AR technology is that it can enter information into the virtual world and then it can be displayed in the real world with the help of special tools (An et al., 2020; Elford et al., 2022), usually in the form of cameras, computers webcams and even using special AR glasses.

The use of media in learning can improve memory (Botella et al., 2018; Martín-Gutiérrez et al., 2017; Untari, 2017), improve the effectiveness and quality of learning (Frevert et al., 2019; Winda et al., 2021). Therefore, the nature of learning media is very important to help students in the learning process with or without educators in the educational process (Naese et al., 2019; Risabethe et al., 2017). Learning media is becoming more interesting and more concise even though it does not reduce the essence of the material. Utilization of educational media with Augmented Reality can directly provide learning wherever and whenever students want to carry out the learning process (Lam et al., 2020; Sahida et al., 2020; Zhang et al., 2022).

Connecting learning with the real world is one of the objectives of implementing augmented reality which is focused on attracting students' interest in learning. Moreover, when it comes to understanding chemistry, often students are less motivated in learning it. Chemical material is often avoided because it is labeled as material that is abstract and complex, so it requires high-level reasoning and thinking which causes learning difficulties for students (Chen et al., 2020; Extremera et al., 2020; Sarabi et al., 2018). Therefore, almost all chemistry lessons are difficult, abstract, and complex so

they require high-level reasoning and thinking (Rahman et al., 2016; Rodríguez et al., 2021; Wright et al., 2021).

Additionally, the main cause of the lack of student learning motivation is the use of less effective learning media; less involving students in the learning process; (Keller et al., 2021; Nazar et al., 2020; Supriono et al., 2018), lack of skills to apply knowledge; lack of teacher's ability to convey scientific information effectively using various media. Several things that the teacher must pay attention to are the application of learning media according to the needs of the subjects and the needs of students (Abriata, 2020; Nuraini et al., 2021; Suleman et al., 2019), learning media must be able to facilitate students to develop their ability to solve problems optimally (Chiu et al., 2019; Ovens et al., 2020; Puspitarini et al., 2019; Smith et al., 2021) so that students can be creative and not get bored in the process of solving problems and understanding learning material.

Based on several studies, the application of augmented reality is quite popular in chemistry learning. The explanation of Chuang et al. (2023) regarding the proper use of augmented reality in the learning process can increase learning motivation, learning achievement and effectiveness in learning. Therefore, this practicality can increase the level of use of augmented reality so that its application is popular in education. Currently, popularity and application in chemistry learning, the forms and models of augmented reality that are offered are quite diverse. Recently, there have been quite a number of systematic literature reviews (SLR) investigating the use of AR in education.

For example, the SLR presented by Garzón et al. (2019) analyzed the impact of AR on learning effectiveness. Other SLR have a more specific purpose, as was done by da Silva et al. (2019) where the authors try to show how AR has been evaluated in education. Akçayır et al. (2017) highlight which AR technologies are most often used for educational purposes, while Radu (2014) analyzed articles comparing applications with or without AR use. However, there is no research that focuses on the SLR application of AR in chemistry learning. Most AR SLR provide general educational explanations. Therefore, there is a need for systematic research related to the application of AR in chemistry learning to analyze what chemical concepts are commonly applied using AR, so that it can be used as a reference for teachers, prospective teachers, and others.

The purpose of this research is to synthesize the application of augmented reality focusing on chemistry learning from 2015 to 2022. The issues raised in this research are: How is the application of augmented reality in chemistry learning, what fields of chemistry can augmented reality apply to, how is the distribution of augmented reality studies based on chemistry

concepts and who are the samples involved in this study.

Method

Research Design

This study using a systematic review analysis. This is done to synthesize and find studies that explain related to Augmented Reality in chemistry learning. The procedure is to determine the topic, then determine the inclusion and exclusion criteria and do content analysis, then do the coding (coding), then synthesize and present findings based on literature that is relevant to the research topic.

Data Collection

The researcher determines the topic and looks for the keywords of the journal to be synthesized. This research focuses on the application of AR in chemistry learning. The journals used are international journals that have been indexed by Scopus through the Google Scholar database and Research gate with the keywords used namely "Augmented Reality in chemistry learning", "Augmented Reality in high school chemistry learning", "Augmented Reality in university chemistry learning". During the search process, certain data ranges are applied in the years 2015-2022.

The journals used in the synthesis were searched based on inclusion criteria, 1) chemistry-based AR, 2) concentrated on cognitive, affective and psychomotor aspects, 3) dealing with chemistry topics at the university level, such as organic chemistry, inorganic chemistry, pharmaceuticals, 4) dealing with chemistry topics at the high school level, 5) journals explaining in English, 6) indexed journals or proceedings. For example Tee et al. (2018) who describes the development and application of AR based on chemistry in colorimetric titration material in learning or Plunkett (2019) who discusses AR on the topic of organic chemistry in English.

Meanwhile, the exceptions used are matters that do not discuss the application of AR in chemistry learning (in the fields of mechanical engineering, interior design, learning mathematics, biology, physics and others), do not apply AR in chemistry learning at high school and university levels. For example, Scaravetti et al. (2019) who apply AR in learning, but the material taught is in the form of mechanical design material, or Yilmaz (2016) which discusses the application of AR in early childhood education which is not the focus of research.

Data Analysis

Journals included in the criteria will be identified and analyzed to be presented in a systematic review. A systematic review method is carried out to examine

relevant research topics in various journals. This journal review is focused on the application of AR in chemistry learning, to see which chemical materials are often applied using AR. In addition, to see the form of applying AR in learning, whether in the form of games, virtual laboratories and others. Coding is done by assigning numbers in sequence along with file names to make it easier for researchers to classify and analyze the journals to be synthesized.

Research Validity and Reliability

In ensuring the journal used meets the inclusion criteria, two peer assessments were carried out to check the suitability of the journal with the existing criteria. There were 290 journals whose content the researchers analyzed and found 74 journals that met the criteria according to peer assessment. Next, the author continues coding all journals that have passed the criteria. Coding is done by focusing on the abstract, if the abstract has met the criteria, then it will continue with full attention to the entire contents of the journal. Coding results are conceptualized, listed and grouped based on the problems and information needed.

Result and Discussion

Results of the Application of AR

The form of applying Augmented Reality in chemistry learning is divided into five codes. The form of applying AR in Android-based chemistry learning gets the highest frequency consisting of thirty-seven articles that apply this form. The computer-based implementation form consists of seventeen articles, then the virtual laboratory-based application consists of fourteen articles, there are other forms of application such as web-based which consists of three articles, and the last is the game-based AR implementation form which consists of three articles. The frequency codes for applying AR in chemistry learning are presented in Table 1.

Table 1. The Frequency of the Application of Augmented Reality in Chemistry Learning

Code	f
Web based learning	3
Game based learning	3
Android based learning	37
Computer based learning	17
Laboratory based learning	14
Total	74

Results of the Application of AR in Chemistry

The field of chemistry that is applied using Augmented Reality is divided into six codes, the field of organic chemistry has the highest frequency consisting of twenty-six articles that apply AR. The biochemistry code consists of fifteen articles, the inorganic chemistry code consists of eleven articles, the analytical chemistry code consists of nine articles, the basic chemistry code consists of nine articles, and finally the physical chemistry code consists of four articles that apply AR. The frequency of chemical field codes applied using AR is presented in Table 2.

Table 2. Frequency of Chemical Fields Applied using AR

Code	f
AR integration on analytical chemistry subjects	9
AR integration on organic chemistry subjects	26
AR integration on general chemistry subjects	9
AR integration on biochemistry subjects	15
AR integration on physical chemistry subjects	4
AR integration on inorganic chemistry subjects	11
Total	74

Results of Chemistry Concept

The study of the frequency of augmented reality distribution codes based on chemicals is presented in Table 3. Based on the results of Table 3 it can be seen that there are 137 chemical concepts discussed in the 74 journals analyzed. The distribution of AR in chemical concepts is divided into twenty-one codes. The highest frequency is the concept of molecular structure which consists of twenty-eight articles. The stereochemistry code consists of twenty- two articles. The molecular geometry code consists of seventeen articles. The code of molecular orbital theory consists of fourteen articles. The macromolecular code consists of thirteen articles.

The chemical reaction code consists of eleven articles. The VSEPR code consists of five articles. The carbon code consists of four articles. The acid-base code, NMR spectroscopy, and crystal structure each consist of three articles. Titration codes, pH meters, laboratory safety, and redox reactions each consist of two articles. Codes of chemical indicators, enzyme kinetics, medicinal chemistry, electrochemistry, reaction rates, and polymerization each consist of one journal. Overall, a total of 137 chemistry concepts were discussed in the 74 journals analyzed.

Table 3. Frequency Distribution of AR in Chemistry Concept

Code	f
Acid-Base	3
VSEPR	5
Stereochemistry	22
Titration	2
Chemical Indicators	1
pH meter	2
Molecular Structures	28
Chemical Reaction	11

Code	f
Geometry of Molecules	17
Hidrocarbon	4
Laboratory Safety	2
Enzyme Kinetics	1
Medicinal Chemistry	1
Redox Reaction	2
Electrochemistry	1
Reaction Rate	1
Molecular Orbital Theory	14
Polymerization	1
Macromolecules	13
NMR Spectroscopy	3
Crystal Structure	3
Total	137

Results of Sample Levels

The frequency of coding at the sample level of applying AR in chemistry learning is presented in Table 4. Based on the results of the table it can be seen that there were seventy-nine samples obtained from seventy-four journals because several journals applied AR to two different samples in one journal. Thus, a total of thirty-four journals used a university-level sample. This is because most journals discuss material at the university level. Then as many as thirty-three journals used the high school level sample, six journals used the chemistry teacher sample. The lecturer sample code consists of two journals and the last four journals are not known using the sample level because the journals analyzed do not mention samples.

Table 4. Sample Rate Frequency of Applying AR in Chemistry Learning

Code		f
Students	University	34
	Senior high school	33
Chemistry teacher		6
Lecturer		2
Not mentioned		4
Total		79

Discussion

The results of the analysis carried out explain the form of application, distribution of chemical fields, the concept of distribution of chemicals, and the level of samples used. The most widely used frequency of AR application in chemistry learning is android-based (see Table 1). Generally, the application of AR is mostly in the industrial machinery and interior design fields which are designed through computer programs. The development of AR can now be used with special AR glasses, and the web, and it's even more practical to use Android. Sahida et al. (2020) in his journal explains the purpose of implementing AR in learning is to improve the learning process and students' interest in learning because AR itself has entertainment aspects that can increase students' interest in learning and playing and projecting it in real terms and involving the interaction of all the five senses of students with this AR technology.

In addition, An et al. (2020) used AR in learning to cultivate students' general attitudes about working with instruments in chemical laboratories. Therefore, students' interest and scientific attitude can increase in studying chemistry. Apart from being skilled in chemistry concepts, students can also be skilled at getting to know the instruments in the laboratory virtually. For example, Alfaro et al. (2022) discussed the application of Android-based AR with acid-base titration chemicals in the form of a virtual laboratory. In these learning activities, students conduct virtual acid-base titration experiments. Even if you only use Android, it doesn't take away the essence of learning like in a real laboratory.

The virtual laboratory is designed the same as the real laboratory, as well as the tools and materials used are adapted to the tools and materials needed for acid-base titration experiments. This is by Tee et al. (2018) where the application of AR using android is more practical and does not eliminate the essence of learning as in a real laboratory. In addition, Tarng et al. (2021) (2021) explained the application of AR with inquiry-based learning in electrochemical material to acquire chemical knowledge and concepts during the learning process and is very helpful for improving scientific thinking and learning.

The highest frequency of chemistry applied to AR is found in the organic chemistry code (see Table 2). Research by Aw et al. (2020) shows that students find organic chemistry a challenging material because it is difficult to imagine abstract concepts without seeing atoms, molecules, and ions in an invisible 3D world and it is difficult to see their dynamic motion, interactions, and kinetics. Therefore, the application of virtual experiments in the field of organic chemistry is the most widely applied. In line with that Whatoni et al. (2022) explained that the application of AR in the field of organic chemistry allows students to observe the shapes of molecular structures and see the movement of electrons and ions which are useful for understanding abstract concepts and principles in molecular structures. For example, Broman et al. (2019) students view molecules in 3D through AR glasses and then draw the Lewis structure of the molecule. Most students find it very helpful to visualize molecules and to understand organic chemistry more deeply. In addition, Dunnagan et al. (2020) explained the use of AR as a virtual organic chemistry laboratory can make students experience understanding organic chemistry material virtually.

The most widely used frequency in the code for applying AR in chemical concepts is found in the

molecular structure code (see Table 3). Based on the results of Table 3, it can be seen that there are 137 chemical concepts discussed in the 74 journals analyzed. The distribution of AR in chemical concepts is divided into twenty-one codes. What's more, there are three highest chemical concept codes in the molecular structure code consisting of twenty-eight journals, the second stereochemical code consisting of twenty-two journals, and the third code of molecular geometry consisting of seventeen journals.

This explanation by Hilda et al. (2022) that most chemical material is abstract and difficult to understand without practice. In addition, Ewais et al. (2019) explained that AR can display possible reactions between two atoms and will present the formed molecule as a 3D object by placing the two markers close together and will display whether there is a possibility of interaction between the two atoms. The concept codes for chemical indicators, enzyme kinetics, medicinal chemistry, electrochemistry, reaction rates, and polymerization each consisting of one journal. This means, there is still little research that applies AR to the chemical concept.

The sample level code frequencies are presented in Table 4. Based on the results of the table it can be seen that there were seventy-nine samples obtained from seventy-four journals, because some journals apply AR to two different samples in one journal. Meanwhile, the sample level consists of five different codes. The first code is a student, the second code is a high school student, the third code is a chemistry teacher, the fourth code is a lecturer and the last is a sample code that is not mentioned in the journal. The highest frequency of the student code consisted of thirty-four journals, the high school student code consisted of thirty-three journals, the chemistry teacher code consisted of six journals, the lecturer code consisted of two journals and as many as four journals did not mention the level and were coded without mentioning it.

Research Gant et al. (2018) showed similar results where research using AR was more widely used at the level of students who had a higher level of difficulty understanding chemical concepts, so it was very necessary to apply AR in their learning. Besides this, the application of AR has also developed a lot at the high school level. For example, Rahmawati et al. (2021) applied AR at the high school level explaining stereochemical material to improve students' cognitive levels, attitudes and spatial abilities. Besides that, the application of AR to chemistry teachers at Astuti et al. (2020) to improve chemistry teachers' technological literacy.

According to this study, the form of application in the field of chemistry that is used must be in accordance with the needs and facilities that support the learning process of chemistry. Besides that, whatever form of application of AR in chemistry learning, it must be adapted to the material and chemistry concepts to be taught. For example, the need for experiments in a laboratory that is not yet possible due to limited materials and tools, AR can be used in the form of a virtual laboratory. The possibility of research that can be carried out to be analyzed in future research is related to the field of chemistry and chemical concepts applied by AR in more detail and depth, because this is still very little discussed in this journal.

Conclusion

Augmented reality is a popular technology in various fields, especially in education. Its application in chemistry learning is considered appropriate because it can increase learning motivation, learning achievement and effectiveness in the learning process. Along with its popularity and application in chemistry learning, the forms and models of augmented reality that are offered are quite diverse. According to this study, the application of AR in chemistry learning is often presented in the form of android-based learning, this is in accordance with the advantages in practicality. In addition, AR is often applied to the field of organic chemistry with the concept of molecular structure at the university level. This research can be used as a reference for other researchers, teachers and prospective teachers in choosing and estimating chemical material that will be applied using augmented reality appropriately in learning.

Conflicts of Interest
No conflicts of interest.

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