



Augmented Reality in Chemistry Education: A Literature Review of Advantages on Learners

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ABSTRACT

Education moves forward together with technology. In recent years, application of modern technology known as Augmented Reality (AR) has significantly shifted the paradigm of learning process in education, including Chemistry education. Many researchers have explored the potential of AR in education. Unfortunately, literatures on its benefits for learners in Chemistry education are limited and inaccessible. This research-based paper manifests underlying usefulness of AR in teaching and learning process of chemistry education in terms of (i) Mastering chemistry content and (ii) motivation, interest and attitude. The researchers aspired that with the contents of this paper, other researchers and interested parties could use them for their literature and as incentive to improve current available AR software or develop further advance technology program of AR in chemistry.

Keywords: augmented reality, chemistry, education, technology, advantages.

INTRODUCTION

Evolution of education has impacted greatly with technology. Technology is needed in education because technology promotes active learning and self-dependent and indirectly cause the development of children intellectual (Papert, 1980; Lamanaskas 2006). Similarly, technology creates more active, drives students' interest, and safe learning process (Singhal, Bagga, Goyal, & Saxena, 2012). For instance, the use of typical PowerPoint presentations has created a more attractive learning process. Yet, such formulated technology is stagnant and limited to illustrate dimensions of a substance causing learning become passive. In this regard, modern technology is built to combat such obvious issue. Virtual reality (VR) and Augmented Reality (AR) are examples of modern technology. Therefore, VR and AR are expected to provide dynamic and dimensional solution to the problems.

According to Cai, Wang, and Chiang (2014), Virtual reality and Augmented Reality have gained popularity in recent years due to their ability as tools for microstructure learning. Virtual Reality (AR) is praised due to its effectiveness in providing almost similar environment with real world context. However, there is no significant difference in accuracy of completing experiments due to its unnatural and restricted movement in the virtual environment. Augmented Reality (AR) is an extension of VR. AR fixes weaknesses of VR such as providing seamless interface to users that merge virtual and real world together at a same time (Cai et al., 2014). Similarly, with the current improvement of AR, creating a virtual world by using AR features have become easier and

it only requires tools such as computer and camera or simply by just using a smartphone (Irwansyah, Yusuf, Farida, & Ramdhani, 2018).

Augmented Reality (AR) was firstly introduced since 1990s and brought into education in the 21st century as both teaching aid and teaching material. This modern technology has shown great potential in education and assist students mastering subject content that requires visualization. Comai and Mazza (2010) mentioned that application of AR in chemistry was first introduced in 2001 by Wu et. al (2001) to help students in order to apprehend the abstractness of chemistry concepts. Since then, studies on AR and Chemistry education have become popular. According to Lamanauskas (2006) stated that chemistry is an experimental science, and it requires visual to explain its abstractness. Singhal et al. (2012) support such emerging statement because they observed that many students experiencing difficulties in visualizing molecular structures and this is due to learning of molecular structure through two-dimensional representation such as books, whiteboard or any other two dimensional (2D) molecular tools.

Numerous research and studies have shown great potential of AR in learning chemistry. A study conducted by Singhal et al. (2012) disclosed that mastering chemistry content depends on the learner's ability on understanding the spatial structure and dynamic structure which will help the learner to understand better theory occurring in chemical process and other chemistry contents. Aside from that, Ibanez and Delgado-Kloos (2018) believed that AR currently has achieved fame in education because it does not necessarily need overpriced hardware and futuristic equipment. In fact, Wu, Lee, Chang, and Liang (2013) has supported this statement because AR requires least additional tools compared to other modern technology. Despite countless findings of AR in chemistry, literatures done on advantages of Augmented Reality and Chemistry education is barely available. Therefore, the main purpose of this paper is to highlight the usefulness of Augmented Reality (AR) application in chemistry education.

Despite the greatness and potentiality of AR revealed by the previous researchers, the literature is still inadequate as many issues regarding how AR manifests underlying usefulness of AR in teaching and learning process of chemistry education most specically on learners mastering chemistry content, their motivation, interest and attitude toward learning. Hence this study aimed at presenting these significances of AR.

METHODOLOGY

This research is included in the parameters of the content analysis theme. The data and information in this study were obtained from literature reviews from various journals and articles about Augmented Reality (AR) in chemistry learning. The analysis was carried out on the information and data obtained from these various sources.

This study uses a review of the definition of Augmented Reality (AR), the Augmented Reality (AR) and education, Augmented Reality (AR) in chemistry education, advantages of Augmented Reality (AR) in chemistry on learner which contain how to master chemistry content and motivation, interest and attitude. This study explores what Augmented Reality (AR) is, why Augmented Reality (AR) is important, what the advantages of Augmented Reality (AR) in chemistry education, and how Augmented Reality (AR) can motivate students to learn in chemistry.

RESULT AND DISCUSSION

Augmented Reality

Technology has progressively grown and has helped humankind to complete their daily tasks. Augmented Reality (AR) is one of the advance technologies that combines both virtual and real world together with assistance of equipment such as camera and computer. Nachairit and Srisawasdi (2015) stated that AR is a connecting technology that infuse real-world environment with virtual dimensional objects. AR is different from Virtual Reality (VR), yet they are similar in terms of providing virtual experience to their users (Tuli & Mantri, 2015). Compared to VR, AR provides seamless interaction with virtual objects in an actual real environment (Wu et al., 2013) and it only requires a computer software and a camera (Ibanez & Delgado-Kloos, 2018). Hence, it keeps evolving from year to year.

Many individuals and related parties define Augmented Reality (AR) based on their perspective expertise. Wu et al. (2013) mentioned that researchers have provided various meaning of AR respectively to their own yield, especially in computer sciences and educational technology. This statement is supported by literature found in Kesim and Ozarslan (2012) as well. Kesim and Ozarslan (2012) argued that some researchers restricted the meaning of AR, where these researchers define AR as another form of VR but with a transparent head-mounted display. Plus, there are also that definition of AR based solely on its features or characteristics such as statement on Azuma (1990). This may be because AR was not fully understood back then (Irwansyah et al., 2018). Wu et al. (2013) believes that AR should be define as a system that has three essential features; fusion of worlds in virtual and reality, real-time interaction and precise three-dimensional forms of virtual objects integrated with real objects and environment. Thus, this definition should be used as it marks a clear line between features of Virtual Reality (VR) and Augmented Reality (AR).

Dave, Chaudhary, and Upla (2019) believe that AR has potential to any working field that aims to create and see three-dimensional form of an object virtually due to the limiting factors as human beings. This is statement is applicable to education field as well. AR technologies were often taken as a burden by public due to its inaccurate association with sophisticated and overpriced tools. Bronack (2011) in Dave et al. (2019), convinced that true educational researchers are more interested on the impact of AR on supporting and providing meaningful learning to learners or users rather than the cost of a technology. Therefore, applications of AR into classroom were made possible due to these dedicated educational researchers that keep exploring AR potential.

Augmented Reality and Education

Augmented Reality (AR) was initially used as training tool for aviation purposes such as airline and military Air Force pilots in the 1990s (Akçayır & Akçayır, 2017; Pence, Williams, & Belford, 2015). Since its introduction, multiple industries and study fields have shown great interest in applying AR in their own over the past decades. According to Nachairit and Srisawasdi (2015), AR accessibility causes growth of employment in the fields such as marketing, entertainment, or social activities. Thus, it is also inevitable to merge AR with education field.

Similarly, Wu et al. (2013) found that educators and designers define AR in general meaning, and this has helped other interested parties in education line to create and apply AR in diverse technologies, such as desktop computers, mobile computer, head-mounted displays and so on. Through this, AR has widened its potential to be taken as teaching materials and teaching aids, yet not limiting application of AR to any kind of technology. In addition, Akçayır and Akçayır (2017) mentioned that AR becoming more popular nowadays since AR is no longer requires costly hardware nor complicated tools such as head-mounted displays (HMD). In fact, it can be used with

portable computers or mobile devices such as smartphones and computer-embedded electronic devices that equipped with camera. Consequently, bring AR technology is no longer a burden to educators to apply it to their teaching and learning process.

Many researchers believed that we could learn more by doing hands-on experiences rather than using conventional verbal learning approach. Fortunately, AR assists learners to experience hands-on activity through immersion of reality and virtual worlds (Ibanez & Delgado-Kloos, 2018). AR is now relevant to apply to all level of education level (Yu, Jin, Luo, Lai, & Huang, 2009). There are many variations of AR technology in education, however, these alterations must consist of these fundamental features of AR (Cai et al., 2014; Maier & Klinker, 2013a; Naud, Richard, & Ferrier, 2009; Shelton, 2002; Soares et al., 2018; Zepeda, 2018):

- 1) AR promotes continuous interaction during application within real environment and virtual world.
- 2) AR enables object manipulation through use of additional physical interface tools as subject to interact with the virtual objects
- 3) AR provides ability of effortless bridging users' experience of both worlds in real world and virtual world.

With clear clarification on essential features of Augmented Reality (AR), many educational researchers were interested to experiment AR into their own fields. Observation on literature of education fields that implementation of AR has tremendously gaining spotlight on the research stage due to the flexibility of AR. Application of AR into education varies from science to art fields (Balazs & Attila, 2006; Yu et al., 2009). Besides, Yu et al. (2009), has illustrated purposes of AR into different education fields and their uses. Table 1 displays the findings found.

Table 1: Uses of augmented reality application into education

Education Fields	Purpose of using AR	Author (Year)
Mathematic	A mathematical education game was developed to teach kindergarten and elementary students.	(Lee & Lee, 2008)
Geography	ARToolKit helped undergraduate geography students virtually observe relationship of Sun and Earth.	(Shelton & Hedley, 2002)
Biology	AR technology to teach students about human digestive system.	(Vilkoniene, 2009)
Engineering	- AR technology infused with computer-aided design (CAD) as visualization tool.	(Alves Fernandes & Fernández Sánchez, 2010)
	- AR technology used to design and develop multimedia content in e-learning environment.	(Olabe, Basogain, Espinosa, Rouèche, & Olabe, 2007)

After more than two decades, effectiveness of integrating Augmented Reality (AR) into education has shown great impact to their users. Together with the developments of technology, improvement on AR technology into classroom has increased to assist learning effectively. Akçayır and Akçayır (2017) and Lamanauskas (2006) discussed the advantages of AR in education. Table 2 shows certain advantages of AR in multiple education fields.

Table 2. Advantages of augmented reality (ar) in education

Author (Year)	Statement
Nunez, Quiros, Nunez, Carda, Camahort, (2008)	Spatial intuition can be development with the assistance of 3Dmodels in AR.
Chen (2006)	Augmented Reality merges three-dimensional (3D) objects with real objects simultaneously.
Shelton (2002)	Content of a subject that involves illustration can be mastered with help of Augmented Reality
Kaufmann and Meyer (2008)	Students can create their own experiments and manipulate variables in a 3D virtual laboratory
(Lu & Liu, 2015)	Learner can increase their learning achievement

Augmented Reality in Chemistry Education

Countless studies have shown that students are having trouble in gasping content in chemistry especially young learners. Students' difficulty comes from the nature of chemistry concepts because students must integrate each content in chemistry through domains of macroscopic, microscopic and symbolic (Johnstone, 1991, 2000). Behmke et al. (2018) believed that educators or instructors are obligated to teach chemistry students to build their own mental models of microscopic interactions and associating the interactions through microscopic, so that, students will successfully master chemistry. Therefore, Augmented Reality (AR) technology could help instructors in fortuitously teaching chemistry to their students.

According to Pence et al. (2015) the first usage of AR technology into chemistry education was in 2001. They stated that Wu, Krajcik, and Soloway (2001) build chemistry animation to assist students in understanding the abstractness of Chemistry concepts. Since then, educational researchers in chemistry education began to show interest in integrating AR technology with Chemistry content. Nechypurenko, Starova, Selivanova, Tomilina, and Uchitel (2018) also believed that technology is needed to increase students' imagination on illustrating structure of particles such as atoms and molecules, because not every student could create accurate virtual forms through their limited imagination. They then added that AR is capable in helping this issue. Hence, AR technology is needed to assist chemistry learning dueto its ability to increase visibility of virtual objects into reality.

Years has passed since AR technology enters the world of chemistry education. There have been many variations of technology equipment used together with AR technology. For instance, Taçgin, Uluçay, and Özüağ (2016) developed and designed Augmented Reality platform to study periodic table and the elements in each group. They developed an equipment that acts as hand motion control by using users' fingers and hands. Moreover, supporting tools in teaching chemistry through Augmented Reality has increased these recent years. For examples, Augmented Chemical Reactions, Arloon Chemistry, and Atomic Structure AR Learning Gear. Augmented Chemical Reactions is a supporting tool created by Patrick Maier, Marcus Tönnis, and Gudrun Klinker (2009b) that provides visualization in a three-dimensional form, and interaction and changes among molecules. Many supporting tools has emerged into the public eyes. For these reasons, researchers should take in account of the potential of these variations of Augmented Reality technology bring into Chemistry education.

Advantages of Augmented Reality in Chemistry on Learner

Mastering Chemistry Content

Many researchers found that application of AR into learning chemistry has tremendously improve students acquiring content and concepts of chemistry. For instance, Singhal et al. (2012) stated that students understanding in chemistry due to increasing apprehension on spatial relations between molecules and relating them with Valence Shell Electron Pair Repulsion (VSEPR) theory. This statement can be supported Cai et al. (2014), where they discovered that students mark is higher comparing to traditional learning method of lecturing due to increase of students spatial thinking. Hence, AR technologies improved users' understandings through spatial skills to relate microscopic domain, macroscopic domain, and symbolic domain in chemistry.

Nechypurenko et al. (2018) strongly believed that full potential of AR technologies as teaching tool to help students in mastery content of chemistry could be possible if it is implemented correctly. In addition, Boonterng and Srisawasdi (2015) stated that after integrating AR technologies into learning acid-base, the students' conceptual understand has tremendously increased. This observation is experienced by Hou and Lin (2017) as well. After infusion of AR game technology, they observed that the students' understanding on laboratory related matter has remarkably elevated. Furthermore, students could experience possibilities if some variables are manipulated because experimenting different manipulation of variable in real world would be costly and dangerous

Moreover, Behmke et al. (2018) found that learners understanding of stereochemistry was enhanced due to the development of AR technologies. This is because teaching students to manipulate molecular structures and seeing them from different view through AR technologies, has increased their understanding interactions that happened between particles (Medina, Chen, & Weghorst, 2007; Musio et al., 2016). Plus, Wu et al. (2001) found that users' understandings increased together with the time consumed in using AR technologies in learning concepts in chemistry with the infusion of real world and virtual world. Whereby, the longer the experience, the higher the mastery of content gained by the users. Henceforth, students' understanding increased through visible observation of the molecule interactions. Table 3 display some findings of previous research that showed increase of chemistry content through AR technologies

Table 3: Findings on advantages of AR technologies in mastering chemistry content

Content	Statement	Researchers
VSEPR Theory	AR prosper deeper understanding in learning the topic	(Singhal et al., 2012)
Molecule interaction	AR developed students' spatial skills to imagine possible interaction between molecules.	(Cai et al., 2014)
Acid-Base	AR improved students' understanding on theoretical concepts of acid-base.	(Boonterng & Srisawasdi, 2015)
Laboratory practices	Students understanding of laboratory related matter greatly	(Hou & Lin, 2017)
Chemical representations	Intensity of knowledge gained increased as the time consumed using the technology is also increased	(Wu et al., 2001)
Inorganic chemistry	The students have shown increase in understanding of inorganic chemistry	(Núñez et al., 2008)

Motivation, Interest and Attitude

Multiple studies of investigating the benefits on learners such as motivation, interest, and attitude, due to implementation of AR technologies in chemistry have received positive feedbacks from their findings. Most researchers have shown positive effect on the learners' perception and lead to a more successful learning and teaching process. Indirectly, this increases the students' performance in learning chemistry through AR technologies. Table 4 has displayed the categories, and findings found by previous researchers based on their categories.

In terms of attitude, most of the researchers have disclosed that learning chemistry through AR technologies shown positive indication (Cai et al., 2014; Sirakaya & Kiliç Çakmak, 2018). Their findings showed that positive attitude in learning chemistry were adopted while they were using the AR technologies. Cai et al. (2014) mentioned that the students were enjoying themselves and did not realize they were actually learning. This statement is supported by the findings of Chang et al. (2014). In addition, Sirakaya and Kiliç Çakmak (2018) also have found that positive attitudes among the students were developed regardless the gender of the students. They claimed that the results were due to the advantages of applying AR technologies in education. Thus, AR technologies significantly enhance and develop positive attitude in learning chemistry among all students.

In terms of interest, Cai et al. (2014), Núñez et al. (2008), Maier and Klinker (2013c) and Fjeld et al. (2007) found that students have shown great interest in learning chemistry and their interest improved as well. The study conducted by Núñez et al. (2008) on university students, they disclosed that the students were more interested in learning inorganic chemistry due to visibility of molecules interacting among them. The students gave response of they were able to acquire more knowledge because of the interesting visible molecular structure in three-dimensional projection. This is corresponded to study conducted by (Zhang, Sung, Hou, & Chang, 2014) where they discovered that the students gave higher concentration in learning topic when applying AR. Hence, students' performance in learning chemistry will be enhanced due to higher attention given in the learning process.

Lastly, numerous researchers have found that AR technologies motivated their researcher samples to learn more about respective contents in chemistry. Nachairit and Srisawasdi (2015) and Boonterng and Srisawasdi (2015) applied AR technologies into chemistry content of acid-base, and both studies found that the motivation among their research samples has increased because the students were able to see the interaction happened in acid and base reactions. According to Zhang et al. (2014), the students motivation increased because they were triggered and excited to find additional information on their learning contents. AR technology gave immediate feedback once they are interacted with users, and this indirectly motivates students to learn.

Table 4: Advantages of AR technologies in chemistry in terms of motivation, interest and attitude

Categories	Findings	Sample research
Attitude	The results shown that students displayed a positive attitude in learning chemistry through AR technologies	(Cai et al., 2014)
Interest	Shown positive effect on the level of interest in studying chemistry among the learners.	
Interest	Students' interest was increased in acquiring chemistry content.	(Núñez et al., 2008)

Categories	Findings	Sample research
Motivation	The undergraduate students were motivated to learn more in foodchemistry through game-based learning approach of AR technologies	(Crandall et al., 2015)
Interest	The students gave positive feedbacks and interested of using in classroom.	(Maier & Klinker, 2013b)
Motivation	The result shown that the students haspositively increase their motivation to study chemistry of acid-base concept.	(Nachairit & Srisawasdi, 2015)
Motivation	Students were motivated to explore more on augmented laboratory technologies	(Huwer & Seibert, 2018)
Motivation	Students have positive perceptions after they have experience learning acid-base through AR technologies	(Boonterng & Srisawasdi, 2015)
Attitude	The students that used AR application shown positive attitudes.	(Sirakaya & Kiliç Çakmak, 2018)
Interest	Teaching chemistry through AR application has positive effect on the users' interest.	(Fjeld et al., 2007)

There should not be excuse of implementing AR into Chemistry because according to Nechypurenko et al. (2018), mobile devices nowadays are equipped with camera, and it only requires certain software to permit the functionality of Augmented Reality.

According to Nechypurenko et al. (2018), current AR-technologies are solely aiming aspect of visualization such as atom's structure, crystal structure and molecular structure. With the presented advantages of implying multiple AR technologies on Chemistry, it is hoped that educational researchers would feel motivated in conducting various studies on the implementation of AR.

Besides that, Nechypurenko et al. (2018) were determined to make their own AR technologies in Chemistry education with their own language of Ukrainian. The same thing happened as well for Nachairit and Srisawasdi (2015). The researchers were passionate in building and creating their own platform of AR technologies and their papers mostly contained a promising underdeveloped software in their own languages. Hence, other educational researchers shall learn to build their own AR technologies based on their own mother tongue language as it assists in smooth understanding both learning and contents instructions.

In addition, through this literature, there were many new platforms of AR technologies that are using Chemistry as their content (Behmke et al., 2018; Maier & Klinker, 2013a, 2013c; Patrick Maier, Marcus Tönnes, & Gudron Klinker, 2009a; Maier et al., 2009b). These platforms served multiple functions, for both learners and instructors. Therefore, this opens many possible opportunities to create even more diverse function and improved version on the current technologies. For instance, Luis, Mellado, and Diaz (2013) has created a Project Based Learning (PBL) approach using AR technologies in Chemistry education. These researchers built potential pedagogical to shift the learning nature to a more student-centred learning. Maier and Klinker (2013c)

With the current new technology, windows of opportunities to experiment and research on the effect of the application in class have significantly increased. Crandall et al. (2015) created a game-based learning approach in learning Food chemistry through application of AR technologies

in learning food chemistry. Similarly, there were other researchers created game-based learning approach as well like Hou and Lin (2017). As stated by Chen and Hwang (2014), a game-based learning has proven to improve students' motivation and performance. Hence, researchers should investigate more on the other effects of implementing a game-based learning through different chemistry content

CONCLUSION

There is now considerable evidence that it is undeniably that Augmented Reality (AR) technology is useful in teaching and learning chemistry. Learners or users experience a lot of benefits offered by the application of AR in learning chemistry such increasing in motivation, attention in learning process due to deep interest, enhancing positive attitudes during the application of AR technologies and directly affect their performance in mastering the content of chemistry. Usefulness of AR technology in Chemistry education affect all directions, from the learning institutions, students, pedagogy, to environment factors. Through the rapid technology advancement, AR technology has tremendously increased and indirectly affect its credibility. In sum, learning chemistry should be fun, however, due to limited virtual media, students experience pain instead of joy and AR addresses to make it fun and pleasure.

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