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Effectiveness APMOL Integrated With JMOL As Technology Media Learning Based On Augmented Reality In The Subject Of Geometry Molecule

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ABSTRACT

Education quality is affected by how students' creativity works on creating innovation and also by character of the teacher itself. Therefore, indifference to one of the conditions bring in education problem. Chemistry gives anxiety to students especially senior high school students because of many abstract illustrations used, moreover learning about geometry molecule. High-school students cannot understand how to create the form of the molecule, and also be required to remember all of the formula Valence Shell Electron Pair Repulsion (VSEPR). The type of research is Research and Development (R&D) method, which produces application based on Augmented Reality and integrated with JMOL (computer software for molecular modelling chemical structures) that operate by showing three dimensions structure of molecule. APMOL is designed for android users, and it will be expanded for IOS and PC. Studies on practicing in four Indonesian senior high schools indicate that APMOL utilization gives a significant impact on student comprehension. The result shows that impact at sig < 0.05, which it proves that APMOL can be used as technology media learning to increase the quality of education

Key words: Geometry Molecule, Augmented Reality, JMOL

Introduction

The science growth and technology amid education growth (2005-2010) based on UNESCO Science Report 2010, state that key to the success of a country depends on how human resources practice science in their daily life (Sari, 2012). This knowledge creates creative human, also critical, logically, and take initiative that present as vessel to get deep into nature and self-understanding to overcome every issue in society (Permanasari, 2016). Study results of PISA (Program of International Student Assessment) in 2018, indicate that Indonesia's science education occupies 70th of 78 countries participated.

Indonesia needs improvement in many aspects of education, with the implementation Visual Thinking method that mainly implements on high thinking of chemistry as one of modernize step. Students that study STEM (Science, Technology, Engineering, and Mathematics) consider that chemistry direct demands high thinking, and expresses chemistry as most difficult lesson to understand (Johnstone, 2000). The difficulty on study chemistry related on main features of chemistry itself: demonstrate many abstract illustration, indeterminate nature, and rapid development of

science, and is a simplification of various other sciences (Sirhan, 2007). The comprehension of science is not getting just by laboratory experimental or sitting in classroom, but sophisticated technology utilization by providing animation 2D or 3D can describe the molecular phenomenon (Irwansyah et al, 2018). There are limitations in imagination so that, students feel distressed on imagining about microparticles such as atoms without any device supported (Cai, Wang, and Chiang, 2014).

Geometry molecule concept offers many advantages to get into another sub-theme related, like a chemical bond, stereochemistry, and biochemistry. On chemical bond, carbon dioxide (CO_2) is linear shape, this is mean that CO_2 cannot soluble in oxidane (H_2O, polar solvent) and can be confirmed that CO_2 is non-polar. Other molecules have each structure depending on bonding, water (H_2O) molecule has bent arrangement of electron pairs. This is one reason why water is polar and has properties such as cohesion, surface tension, and hydrogen bond. In biochemistry, the concept of geometry molecule plays an important role in protein synthesis, especially in translation stage. Where the transcript results, mRNA goes out nucleus which eventually binds with small ribosomal subunit. When it has met start codon (AUG), thus tRNA with amino acid methionine and anticodon (UAC) would attach on mRNA. It shows that 3D animation on chemistry learning is needed. Three-dimension structure of protein can determines appropriately what amino acid will bind with mRNA in translation stage. In the wave of fourth revolution in the midst of life bequeaths a new kind of technology, the idea on combining reality and virtual reality simultaneously. Augmented Reality (AR) is an extension to Virtual Reality (VR). Camera has important role to ensure that AR works well, camera is needed as bridge between reality and virtual reality. By using markers, camera will detect the marker and show the object that matches the marker (Cai, Wang, and Chiang, 2014).

Augmented Reality can be used to facilitate students' comprehension of abstract science mainly to understand geometry molecules or even to understand the properties of matter. In chemistry, there are a bunch of models to define molecule structure, such as 2-D drawing, dash-wedge drawings, handheld models, and computer models. And found that most effective models are augmented reality and computer models (Setiahadi, Setyati, and Setiawan, 2017). The three-dimension chemical structure is developed by using Unity 3D. Unity 3D is a software that has multifunction properties and supports various platforms to develop video games, computer simulation, virtual reality, and also augmented reality (Buyuksalih et al., 2017).

Apart from using unity, APMOL design is integrated with JMOL as well. JMOL is a open-public software to visualize molecule structure, by JMOL as source of molecule structure model and Unity 3D to create a three-dimension shape. JMOL has been developed in several versions, starting from Xmol, – is software same as JMOL that developed by Minnesota Supercomputer Center. However, Xmol is closed and users are forbidden to access the code source, but after that new software is launched. Dan Gazelter initiates JMOL as one of an open-science project that dedicate to scientific research, and released for free (Herráez, 2006). All problems explained present one solution that is APMOL Integrated with JMOL as Technology Media Learning Based on Augmented Reality in The Subject of Geometry Molecule.

Methodology

This kind of research belongs to development that focus on education, or Education Research and Development (R&D). R&D method is a method to create a new media learning and gain students' understanding in chemistry. The research method of APMOL is based on augmented reality, integrated

to JMOL, implemented the development theory of Born and Grill, by carrying out the validity, practicality and effectiveness of the product

Development Style

This research uses a modification model of development theory by Borg and Grill. The method has ten stages of work: (1) carry out previous research by gathering information related; (2) make a research planning; (3) take out a prototype of product; (4) then, do primary limit testing the prototype to create the product (Preliminary field test); (5) from trial and error done, take out the problem exist and do some revision for product; (6) retest to latest version of product after did revision; (7) do revision again to latest version of product to get the final version product that can be used by public; (8) operational field test; (9) maintenance for final product; (10) the last stage is to disseminate and implement the product (Bord and Gall, 1983).

Development Procedure

Application development method used is waterfall model. This method uses a sequential approach which consists of several processes that will be carried out sequentially (Youlia, Muhammad & Wahyu, 2013). This is the development research flowchart taken as figure 1.
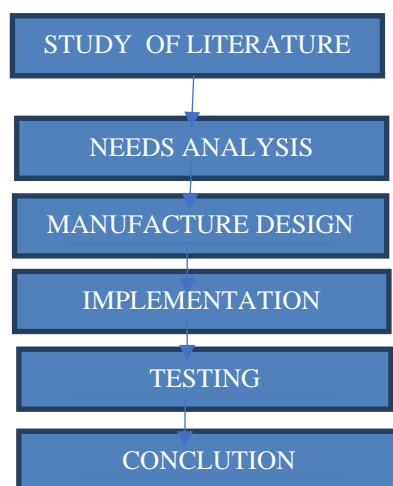

Figure 1. Development Research Flowchart

Result and Discussion

Product Trial

The next step on develop teaching material is product trial. Assessment instrument of teaching material have to be validated first by IT expert, material expert, and linguist. Afterward, the instrument is used to evaluate quality of application and consideration to learning module to be published. After being assessed by experts, the results of the assessment are converted into data on product quality aspects (APMOL) and the modules developed. Then suggestions, criticisms and comments from experts are used for revision.

Table 1. Procedure for Using APMOL

Description of Molecule

Output result of three-dimension molecule structure by APMOL follows

1. 3D shape of water molecule (H_2O) is bent or seems like a planar V, if seen from counting number of bonded electron pairs (PE) and lone pairs (EB). Atomic number O = 8 and H = 1, electron configuration O = 2 6, electron valence O = 2, and bonded electrons are 4 electron or 2 pairs. It can be seen that there are two pairs of unbonded electrons. Two bonded electron pairs and two lone pairs, by theory VSEPR claim to AX_2E_2. (A = Central Atom, X = Bonding Electron Pairs, E = Lone Pair Electron)
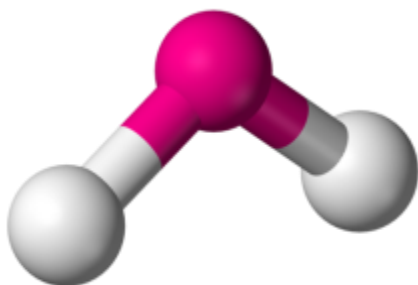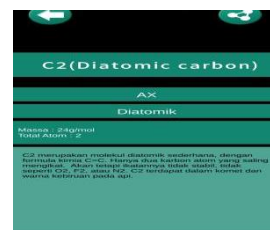

$$AX_2E_2 = \text{Bent (Planar V)}$$

2. NH_3, molecule shape and three-dimension model. N is central atom that has atomic number = 7, contain electron configuration with order 2, 5. Three electrons are bonded with H that has 3 electrons. In this case, 2 electrons are lone, or one lone pair electron. By theory VSEPR claim it to AX_3E (Pyramid Trigonal).
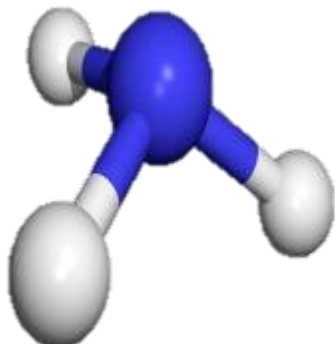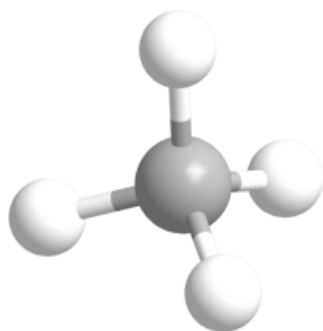

$$AX_3E = \text{Pyramid Trigonal}$$
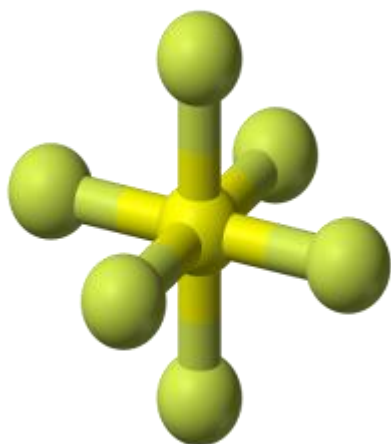

3. CH_4 molecule shape

C as central atom that contains atomic number = 6, by configuration 2 4, and four of electrons are bonded to 4 atoms of H. This means, there is no atom that lone pair.

$AX_4 = $ tetrahendral

4. S as the central atom with central atomic = 16, electron configuration 2 8 6, valence electrons = 6 is shared with F, so the S atom does not have a lone pair of electrons.

$AX_6 = $ octahedral

VSPER theory require some conditions that have to be fulfilled, in consideration on central atom (A), bonded electron pair (X), and lone pair of electron (E).

Product Effectiveness in SMUN 4 Depok, SMU Batang Angkola, MAN 2 Medan dan SMU Nurul Ilmi Average Pre-test Scores follows.
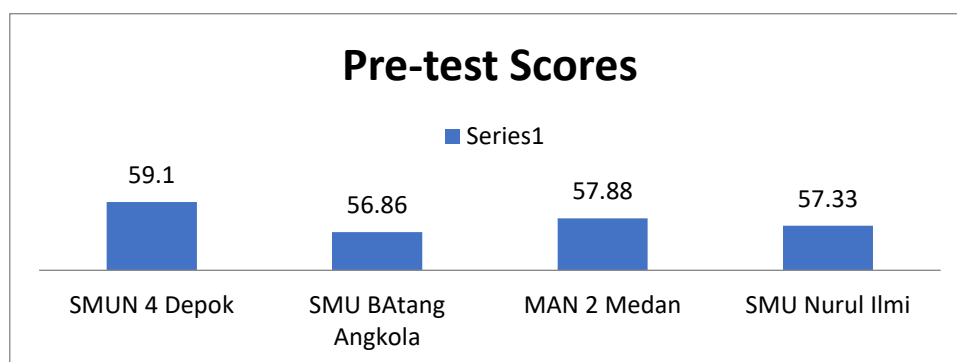
Pre-test Scores

■ Series1

SMUN 4 Depok	SMU BAtang Angkola	MAN 2 Medan	SMU Nurul Ilmi
59.1	56.86	57.88	57.33

Figure1. Pretest Scores

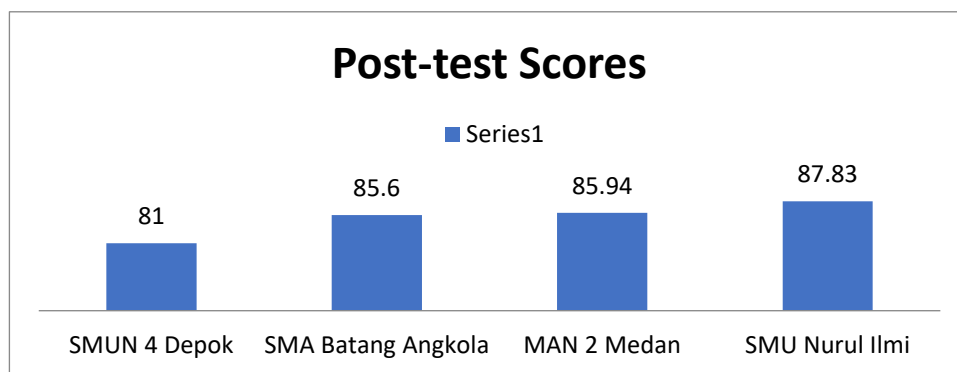Product Effectiveness in SMUN 4 Depok, SMU Batang Angkola, MAN 2 Medan dan SMU Nurul Ilmi Average Post-test Scores
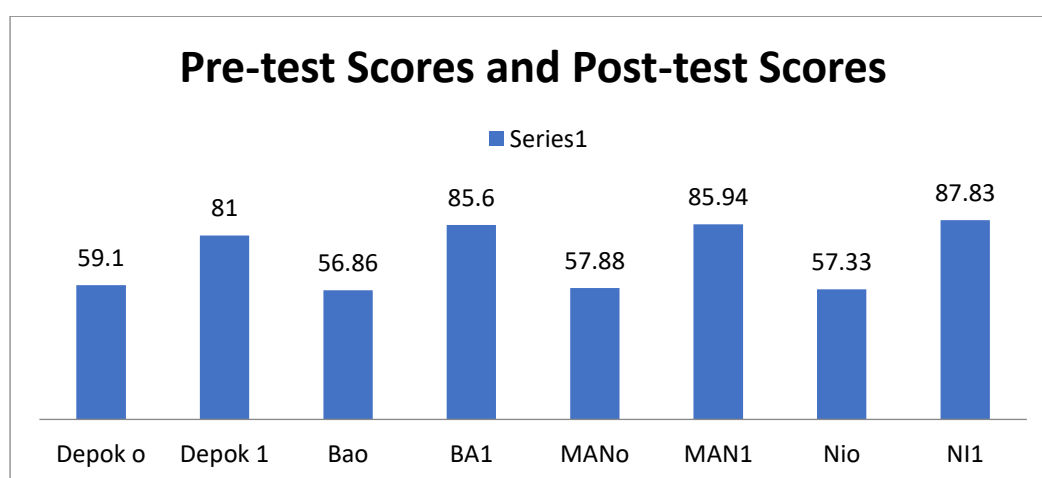

Figure 2. Post-test Scores

Figure 3. Pre-test Scores and Post-test Scores

Paired Sample Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Depok1	85.4211	19	4.14080	.94996
	Depoko	59.1053	19	4.05373	.92999
Pair 2	BA1	85.6000	15	5.23450	1.35154
	BAo	56.8667	15	3.85202	.99459
Pair 3	MAN1	85.9412	17	5.10478	1.23809
	MANo	57.8824	17	4.34284	1.05329
Pair 4	NI1	87.8333	18	3.34752	.78902
	NIo	57.3333	18	4.18681	.98684

Paired Sample Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	Depok1 – Depoko	26.31579	6.28095	1.44095	23.28847	29.34311	18.263	18	.000
Pair 2	BA1 – Bao	28.73333	6.23889	1.61088	25.27835	32.18832	17.837	14	.000
Pair 3	MAN1 – MANo	28.05882	7.45378	1.80781	24.22644	31.89120	15.521	16	.000
Pair 4	NI1 – NIo	30.50000	4.75580	1.12095	28.13500	32.86500	27.209	17	.000

Statistics calculation result by T-test formula points on significant different happened between learning media with Augmented Reality and traditional learning media; t hit score (SMU 4 Depok) = 18.263, sig 0.00 < 0.05; T hit (SMU 1 Batang Angkola) = 17.837, sig 0.00 < 0.05; T hit (MAN 2 Medan) = 15.521, sig 0.00 < 0.05; and T hit (SMU Nurul Ilmi) = 21.209, sig 0.00 < 0.05.

Discussion

This research generates an android application called APMOL that is based on Augmented Reality with Unity 3D as three-dimension maker and integrated to JMOL. Augmented Reality (AR) shows the three-dimension shape as real-time or indicating marker from reality and create it in visual form. AR is interactive that can make 3D visual on cell phone from combining the real world and the visual. The same research was done by (Irwansyah et al., 2018b) about Augmented Reality (AR) as one of the most advanced and effective technologies as learning media, especially in chemistry. The result of this research intends to describe the steps on making learning media based on AR technology in geometry molecule subject.

3D objects are shown real-time with AR technology. This represent the visualization has been explored. Augmented Reality system is effective on summarize effort to overcome future education problem by information and technology. Research from R.M. Aulawi (2019) produces technology media of augmented reality with an Interactive Multimedia System Design Development (IMSDD). Environment can influence people, and so technology do. Technology influences student to study actively and can motivates in streamlining the learning process. Augmented Reality has proven that had a potential to get student to study more active, effective, and having mean. On the other hand, AR recently attracts researchers and teachers to innovate new technique on learning, to give student a new realistic experience in education. And augmented reality has all kind of stuff to get students drawn into new study experiences (Saidin et al., 2015).

APMOL produced apart from giving information about molecules in three-dimension way, also show the description of molecules. APMOL is developed for android users. Simple to use, just have to

scan the text and the 3D structure pops up. But APMOL has some shortcomings including the result is not same as what the users want in odd moments. However, APMOL has been provided searching column.

Development results have been validated by validator, practicalities, teachers, and students, and also to count effectiveness before, the students have to do a test with variable before using APMOL and variable after using APMOL. The results of the three tests gave very good results so that APMOL media could be used very well in supporting learning by increasing student learning outcomes, creativity and innovation. The research result of (Fuhrmann & Encarnac, n.d.), tell that using augmented reality in geometry molecule can be effective because reach presentation $\geq 61\%$ from the maximum scores for each criterions whether it's content, appearance, language, and others from the results obtained from lecturers, teachers and students. The research by Irwansyah et al (2018b) indicates product that learning media based on AR in android system was successfully developed. Test result also show that AR in geometry molecule is very worthy to used in class with pretty great presentation 70.83% - 92.50%. These results imply that AR-based learning media on the android system has the potential to be applied to chemistry learning, especially in molecular geometry.

In addition, the results of research conducted Adami & Budihartanti (2016) show that the application of augmented reality in digestive learning seen from the managerial aspect makes it easier and attracts students' interest in studying the digestive system. Meanwhile, viewed from the aspect of the augmented reality media system, this is a good medium because it is based on Android and can be accessed by everyone.

The result of research from (Van Laar et al., 2017) introduced AR to learning chemistry for high school students. Cheap camera used and software as a source to whip up collaborative environment to support students that is studying chemistry or pertaining to compounds. VSEPR theory also has explained relation for every bond, and that from each bonding creates other structure. Research result augmented reality application that is used from every aspect, one of them functional aspect (Supriono & Rozi, 2018). This application obtains portability test result as 96,7% and can be used for every kind smartphone except high screen resolution such as tablet. Marker good scanned and including periodic table are advantages of this application.

Conclusion

Effectiveness of APMOL as learning media based on augmented reality in molecular geometry subject is effective, by measuring pre-test average scores to post-test average scores and comparing both. SMU 4 Depok [59.81 to 81], SMU 1 Batang Angkola [56.85 to 85.61], MAN 2 Medan [57.88 to 85.94], and SMU Nurul Ilmi Padangsidimpuan [57.33 to 87.83]. The results of statistical measurements show that there is a significant effect of using augmented reality-based APMOL technology media on molecular geometry learning using Unity 3D and JMOL.

References

dami, F. Z., & Budihartanti, C. (2016). Penerapan Teknologi Augmented Reality Pada Media Pembelajaran Sistem Pencernaan Berbasis Android. Teknik Komputer AMIK BSI, 2(1), 122–131. http://ejournal.bsi.ac.id/ejurnal/index.php/jtk/article/viewFile/370/279.

Ananda, R. (2017). Perkembangan Teknologi Pembelajaran dan Pengaruhnya Terhadap Perkembangan Peserta Didik. HIJRI - Jurnal Manajemen Pendidikan Dan Keislaman, 6(1), 69–83.

Ananda, T. A., Safriadi, N., & Sukamto, A. S. (2015). Penerapan Augmented Reality Sebagai Planet-Planet Di Tata Surya. Jurnal Sistem Dan Teknologi Informasi, 1(1), 1–6.

Billinghurst, M., Clark, A., & Lee, G. (2014). A survey of augmented reality. Foundations and Trends in Human-Computer Interaction, 8(2–3), 73–272. https://doi.org/10.1561/1100000049.

Borg, W. R & M.D. Gall. (1983). Educational Research: On Introduction. (4th ed.) , New York: Longman Inc, 1983.

Blaschke, L. M. (2014). Using social media to engage and develop the online learner in self-determined learning. Research in Learning Technology, 22(1063519). https://doi.org/10.3402/rlt.v22.21635.

Buyuksalih, I., Bayburt, S., Buyuksalih, G., Baskaraca, A. P., Karim, H., & Rahman, A. A. (2017). 3D MODELLING and VISUALIZATION BASED on the UNITY GAME ENGINE - ADVANTAGES and CHALLENGES. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 4(4W4), 161–166. https://doi.org/10.5194/isprs-annals-IV-4-W4-161-2017.

Cai, S., Wang, X., & Chiang, F. K. (2014). A case study of Augmented Reality simulation system application in a chemistry course. Computers in Human Behavior, 37(June), 31–40. https://doi.org/10.1016/j.chb.2014.04.018.

Carmigniani, J., & Furht, B. (2011). Handbook of Augmented Reality. In Handbook of Augmented Reality. https://doi.org/10.1007/978-1-4614-0064-6.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. Multimedia Tools and Applications, 51(1), 341–377. https://doi.org/10.1007/s11042-010-0660-6.

Chiarle, A. (2017). The 21st Century Skills. Key Competencies and Contemporary Skill Development in Education, 562–1065. https://doi.org/10.4018/978-1-4666-9823-9.les2.

Fedosky, E. W., & Coleman, W. F. (2006). Using Jmol To Help Students Better Understand Fluxional Processes. Journal of Chemical Education, 83(2), 336. https://doi.org/10.1021/ed083p336.1.

Fuhrmann, A., & Encarnac, L. M. (n.d.). The Studierstube Augmented. 33–54.

Herráez, A. (2006). Biomolecules in the Computer. Biochemistry and Molecular Biology Education : A Bimonthly Publication of the International Union of Biochemistry and Molecular Biology (2006), 34(4), 255–261.

Hilda, L. (2016). Revitalisasi Kearifan Lokal Dalihan Na Tolu Masyarakat.

Irwansyah, F. S., Yusuf, Y. M., Farida, I., & Ramdhani, M. A. (2018a). Augmented Reality (AR) Technology on the Android Operating System in Chemistry Learning. IOP Conference Series: Materials Science and Engineering, 288(1). https://doi.org/10.1088/1757-899X/288/1/012068.

Irwansyah, F. S., Yusuf, Y. M., Farida, I., & Ramdhani, M. A. (2018b). Augmented Reality (AR) Technology on the Android Operating System in Chemistry Learning. IOP Conference Series: Materials Science and Engineering, 288(1). https://doi.org/10.1088/1757-899X/288/1/012068.

Johnstone, A. H. (2000). Teaching of Chemistry - Logical or Psychological? Chem. Educ. Res. Pract., 1(1), 9–15. https://doi.org/10.1039/a9rp90001b.

Joyce, B., & Calhoun, E. (2014). The 21st-Century Skills. Realizing the Promise of 21st-Century Education: An Owner's Manual, 46–66. https://doi.org/10.4135/9781483387451.n6.

Kesim, M., & Ozarslan, Y. (2012). Augmented Reality in Education: Current Technologies and the Potential for Education. Procedia - Social and Behavioral Sciences, 47(222), 297–302. https://doi.org/10.1016/j.sbspro.2012.06.654.

Lee, K. (2012). Augmented Reality in Education and Training. TechTrends, 56(2), 13–21. https://doi.org/10.1007/s11528-012-0559-3.

Muslim Mandailing Dalam Menjaga Harmonisasi Lingkungan Hidup. MIQOT: Jurnal Ilmu-Ilmu Keislaman, 40(1), 175–192. https://doi.org/10.30821/miqot.v40i1.218.

Adami, F. Z., & Budihartanti, C. (2016). Penerapan Teknologi Augmented Reality Pada Media Pembelajaran Sistem Pencernaan Berbasis Android. Teknik Komputer AMIK BSI, 2(1), 122–131. http://ejournal.bsi.ac.id/ejurnal/index.php/jtk/article/viewFile/370/279.

Ananda, R. (2017). Perkembangan Teknologi Pembelajaran dan Pengaruhnya Terhadap Perkembangan Peserta Didik. HIJRI - Jurnal Manajemen Pendidikan Dan Keislaman, 6(1), 69–83.

Ananda, T. A., Safriadi, N., & Sukamto, A. S. (2015). Penerapan Augmented Reality Sebagai Planet-Planet Di Tata Surya. Jurnal Sistem Dan Teknologi Informasi, 1(1), 1–6.

Billinghurst, M., Clark, A., & Lee, G. (2014). A survey of augmented reality. Foundations and Trends in Human-Computer Interaction, 8(2–3), 73–272. https://doi.org/10.1561/1100000049.

Borg, W. R & M.D. Gall. (1983). Educational Research: On Introduction. (4th ed.) , New York: Longman Inc, 1983.

Blaschke, L. M. (2014). Using social media to engage and develop the online learner in self-determined learning. Research in Learning Technology, 22(1063519). https://doi.org/10.3402/rlt.v22.21635.

Buyuksalih, I., Bayburt, S., Buyuksalih, G., Baskaraca, A. P., Karim, H., & Rahman, A. A. (2017). 3D MODELLING and VISUALIZATION BASED on the UNITY GAME ENGINE - ADVANTAGES and CHALLENGES. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 4(4W4), 161–166. https://doi.org/10.5194/isprs-annals-IV-4-W4-161-2017.

Cai, S., Wang, X., & Chiang, F. K. (2014). A case study of Augmented Reality simulation system application in a chemistry course. Computers in Human Behavior, 37(June), 31–40. https://doi.org/10.1016/j.chb.2014.04.018.

Carmigniani, J., & Furht, B. (2011). Handbook of Augmented Reality. In Handbook of Augmented Reality. https://doi.org/10.1007/978-1-4614-0064-6.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. Multimedia Tools and Applications, 51(1), 341–377. https://doi.org/10.1007/s11042-010-0660-6.

Chiarle, A. (2017). The 21st Century Skills. Key Competencies and Contemporary Skill Development in Education, 562–1065. https://doi.org/10.4018/978-1-4666-9823-9.les2.

Fedosky, E. W., & Coleman, W. F. (2006). Using Jmol To Help Students Better Understand Fluxional Processes. Journal of Chemical Education, 83(2), 336. https://doi.org/10.1021/ed083p336.1.

Fuhrmann, A., & Encarnac, L. M. (n.d.). The Studierstube Augmented. 33–54.

Herráez, A. (2006). Biomolecules in the Computer. Biochemistry and Molecular Biology Education : A Bimonthly Publication of the International Union of Biochemistry and Molecular Biology (2006), 34(4), 255–261.

Hilda, L. (2016). Revitalisasi Kearifan Lokal Dalihan Na Tolu Masyarakat.

Irwansyah, F. S., Yusuf, Y. M., Farida, I., & Ramdhani, M. A. (2018a). Augmented Reality (AR) Technology on the Android Operating System in Chemistry Learning. IOP Conference Series: Materials Science and Engineering, 288(1). https://doi.org/10.1088/1757-899X/288/1/012068.

Irwansyah, F. S., Yusuf, Y. M., Farida, I., & Ramdhani, M. A. (2018b). Augmented Reality (AR) Technology on the Android Operating System in Chemistry Learning. IOP Conference Series: Materials Science and Engineering, 288(1). https://doi.org/10.1088/1757-899X/288/1/012068.

Johnstone, A. H. (2000). Teaching of Chemistry - Logical or Psychological? Chem. Educ. Res. Pract., 1(1), 9–15. https://doi.org/10.1039/a9rp90001b.

Joyce, B., & Calhoun, E. (2014). The 21st-Century Skills. Realizing the Promise of 21st-Century Education: An Owner's Manual, 46–66. https://doi.org/10.4135/9781483387451.n6.

Kesim, M., & Ozarslan, Y. (2012). Augmented Reality in Education: Current Technologies and the Potential for Education. Procedia - Social and Behavioral Sciences, 47(222), 297–302. https://doi.org/10.1016/j.sbspro.2012.06.654.

Lee, K. (2012). Augmented Reality in Education and Training. TechTrends, 56(2), 13–21. https://doi.org/10.1007/s11528-012-0559-3.

Muslim Mandailing Dalam Menjaga Harmonisasi Lingkungan Hidup. MIQOT: Jurnal Ilmu-Ilmu Keislaman, 40(1), 175–192. https://doi.org/10.30821/miqot.v40i1.218.

Nobuyasu, R. S., Ward, J. S., Gibson, J., Laidlaw, B. A., Ren, Z., Data, P., Batsanov, A. S., Penfold, T. J., Bryce, M. R., & Dias, F. B. (2019). The influence of molecular geometry on the efficiency of thermally activated delayed fluorescence. Journal of Materials Chemistry C, 7(22), 6672–6684. https://doi.org/10.1039/c9tc00720b.

Pascasarjana, P., & Negeri, U. (2014). Pemodelan Real Berbasis Penemuan Terbimbing Untuk. 3(2), 332–339.

Permanasari, A. (2016). STEM Education: Inovasi dalam Pembelajaran Sains. Seminar Nasional

Pendidikan Sains, 23–34.

Prayogi, R. D., & Estetika, R. (2019). Kecakapan abad 21 : kompetensi digital pendidik masa depan. Jurnal Manajemen Pendidikan, 14(2), 148. http://journals.ums.ac.id/index.php/jmp/article/view/9486.

Redhana, I. W. (2019). Mengembangkan Keterampilan Abad Ke-21 Dalam Pembelajaran Kimia. Jurnal Inovasi Pendidikan Kimia, 13(1).

Saidin, N. F., Halim, N. D. A., & Yahaya, N. (2015). A review of research on augmented reality in education: Advantages and applications. International Education Studies, 13, 1–8. https://doi.org/10.5539/ies.v8n13p1.

Sari, M. (2012). Usaha Mengatasi Problematika Pendidikan Sains Di Sekolah Dan Perguruan Tinggi. Al-Ta Lim Journal, 19(1), 74–86. https://doi.org/10.15548/jt.v19i1.9.

Setiahadi, H., Setyati, E., & Setiawan, E. I. (2017). Pembelajaran Ikatan Molekul Dalam Pelajaran Kimia Menggunakan Augmented Reality. Jurnal Ilmiah JICTE, 1(2), 80–86.

Singhal, S., Bagga, S., Goyal, P., & Saxena, V. (2012). Augmented Chemistry: Interactive Education System. International Journal of Computer Applications, 49(15), 1–5. https://doi.org/10.5120/7700-1041.

Sirhan, G. (2007). Sirhan / TÜFED-TUSED / 4(2) 2007 2 Learning Difficulties in Chemistry: An Overview. Journal of Turkish Science Education., 4(2), 2–20.

Supriono, N., & Rozi, F. (2018). Pengembangan Media Pembelajaran Bentuk Molekul Kimia Menggunakan Augmented Reality Berbasis Android. JIPI (Jurnal Ilmiah Penelitian Dan Pembelajaran Informatika), 3(1), 53–61. https://doi.org/10.29100/jipi.v3i1.652

Tay, E., & Allen, M. (2011). Designing social media into university learning: Technology of collaboration or collaboration for technology? Educational Media International, 48(3), 151–163. https://doi.org/10.1080/09523987.2011.607319.

Van Krevelen, D. W. F., & Poelman, R. (2010). A Survey of Augmented Reality Technologies, Applications and Limitations. International Journal of Virtual Reality, 9(2), 1–20. https://doi.org/10.20870/ijvr.2010.9.2.2767.

Van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. Computers in Human Behavior, 72, 577–588. https://doi.org/10.1016/j.chb.2017.03.010.

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. Computers and Education, 62, 41–49. https://doi.org/10.1016/j.compedu.2012.10.024.