eS²MART Teaching and learning material in chemistry: Enhancing spatial skills thru augmented reality technology

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ABSTRACT

This study developed a teaching and learning material (TLM) in chemistry entitled eS²MART TLM with integrated augmented reality (AR) technology and assessed its effect on students' learning gains in terms of spatial skills and students' learning experience on the use of augmented reality as a tool in understanding atomic theory, chemical bonding and molecular structure. The present study utilized the design-based research paradigm in the development of AR-enabled teaching and learning material while the assessment of the effect of using the developed material on learners' spatial skills employed the pre-experimental single group design. To provide the AR component of the TLM, this study also developed a database of intuitive virtual 3D objects and animations that can be manipulated by tactile controls, a dedicated mobile application software called eS²MART TLM designed to retrieve, display, and control the virtual 3D objects, and unique trackers for each virtual 3D object and animation that were printed in eS²MART TLM. A pretest and posttest using standardized spatial skills test composed of seven Purdue Spatial Visualization Test (PSVT) items and 13 content-specific items were administered to the participants before and after using eS²MART TLM. Using Hake factor test, the study found out that student participants obtained a normalized gain value of 0.50 on the PSVT spatial visualization test which signifies medium learning gain and a normalized gain value of 0.76 on the Content Specific Spatial Skills Test which indicates high learning gain. In terms of learning experience, there is an overall very positive learning experience on the use of augmented reality in eS²MART TLM as implied by the composite mean value of 3.54.

Keywords: educational technology, virtual molecules, mobile learning, chemical education, STEM

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INTRODUCTION

Augmented Reality (AR), an emergent technology with great possibilities for its use is slowly being adapted as an effective tool in education which results to enhanced learning achievement and positive attitudes toward learning activities (Akçayir and Akçayir 2017). Augmented Reality is defined as “a situation in which a real world context is dynamically overlaid with coherent location or context sensitive virtual” (Klopfer and Squire 2008) and combines digital and physical information in real time through different technological formats such as tablets or smartphones to create this new reality (Fombona et al. 2018). When compared with other technological pedagogical resources like multimedia resources and traditional teaching tools, there is higher learning gains when AR is used (Garzon and Acevedo 2019).

Augmented Reality is a cost-effective technology for providing students with more attractive contents than paper alone and that learners are comfortable in using AR for practical and theoretical content (Martín-Gutiérrez et al. 2015b). According to Cabero-Almenara et al. (2019), future research should focus on the creation of instructional materials with AR technology and should investigate how AR objects should be utilized and developed for their use. Furthermore, Garzon and Acevedo (2019) suggested that there should be an assessment of knowledge or skill that could specifically be attributed to AR.

Spatial skills are one of the student attributes that has long been identified as an essential skill in the science, technology, engineering and mathematics (STEM) disciplines. (Stieff 2007; Sorby 2009; Davidowitz and Rollnick 2011). In the field of chemistry, spatial skills is important in visualizing abstract concepts like atomic and molecular structure, Valence Shell Electron Pair Repulsion theory and hybridization of molecular orbitals, to name a few. It is an important skill that must be developed among students in introductory chemistry course because of its application in advanced chemistry courses like organic chemistry, biochemistry and physical chemistry. However, studies have shown that only a few percentage of students have the spatial skills necessary to succeed in early STEM coursework (Wai et al. 2009; Uttal and Cohen 2012), making the teaching of spatial skills important in chemistry education and STEM disciplines in general.

Based on the premises discussed above, the researcher considers the need to develop a teaching and learning material that incorporates the use of augmented reality. Furthermore, the researcher also believes that augmented reality can be used to enhance the students’ spatial skills, an important student attribute in the STEM discipline, because of its capability to rescale virtual images and provide real-time visualization of molecules, atoms and other chemical species through tactile manipulations of their virtual 3D images.

Hence, this study intended to measure the effect of using Augmented Reality in eS²MART Teaching and Learning Material on the students' spatial skills and assess the students' learning experience in the use of eS²MART Teaching and Learning Material.

METHODS

Study Site

This study was conducted at Batangas State University (BatStateU) Integrated School–Senior High School Department, Main Campus I, located at Rizal Avenue, Batangas City. Batangas State University only offers STEM discipline in its Senior High School curriculum to prepare students for the STEM programs in the university.

Research Design

The development of the eS²MART teaching and learning material utilized the design-based research paradigm while the assessment of the impact of the developed material on learners' spatial skills used the pre-experimental single group design utilizing one intact class.

The goal of the design-based research is to "offer the relationship between theory-design-implementation through embodying the principles about teaching and learning" (Cengizhan 2007) "to address complex problems in educational settings" (Sari and Lim 2012) while "supporting design and development of prototypical products to solve complex authentic context-specific problem" (Lai et al. 2009). The prototypical product in this study refers to eS²MART TLM.

Participants of the Study

The participants of the study were composed of Grade 11 STEM students who were taking up General Chemistry 1. The result of Kolmogorov-Smirnov (K-S) statistical test on their spatial skills pretest revealed that the data set is well modeled by a normal distribution as evidenced by the *P*-values which were greater than the alpha value of 0.05.

Research Instrument

To determine the level of spatial skills among the participants, the researcher adapted the Spatial Reasoning Test developed by Carlisle (2012). This test was designed to measure spatial skills in chemistry and was measured to have Cronbach's alpha of 0.65, signifying an acceptable internal consistency and reliability. The first part of the test consists of seven items that were lifted from Purdue Spatial Visualization Test (PSVT) - a standardized test that was usually administered to measure cognitive spatial skills (Bodner and Guay 1997; Brownlow et al. 2003; Morgil et al. 2005). A sample of this test question is presented in Figure 1A.

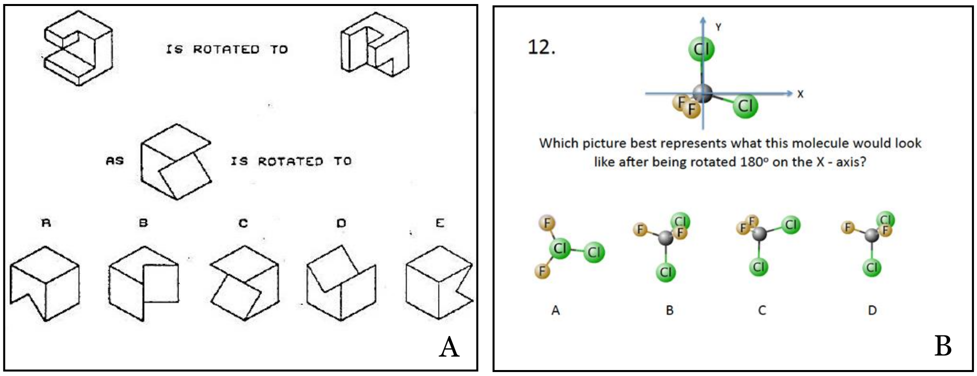


Figure 1. Example of Purdue Spatial Visualization Test (PSVT) item in the Spatial Skills Test (A); and example of content-specific item in the Spatial Skills Test (B).

The second part consists of thirteen content-specific questions on chemistry that were related to spatial skills (Figure 1B). The questions on the content-specific test of spatial skills covered the topics of chemical bonding and VSEPR theory. These contents were selected because of their relevance to spatial skills in chemistry, like mental rotations of three-dimensional molecular structures, and visualization of molecular structures from different perspectives that requires spatial orientation and spatial relations.

Research Procedure

The present study was conducted in five successive phases. The first phase was the analysis of the instructional problem which involved a review of literature in order to understand the problem and setting of research objective.

The second phase was designing the features of eS²MART TLM which incorporated the instructional approach of using innovative technology through AR. This phase also involved reviewing the Department of Education's (DepEd) K to 12 chemistry curriculum for senior high school. From this, the topics that will be included in eS²MART TLM were selected and an outline was made.

The third phase was the development of eS²MART TLM which implemented the design features crafted in the second phase. Concurrent with the development of the printed teaching and learning material was the design and development of original AR database of virtual 3D objects and a dedicated mobile application software called eS²MART TLM for the retrieval, display and manipulation of intuitive 3D objects and animations. The augmented reality component of the teaching and learning material was designed and specified by the researcher based on the need and suitability of the lesson.

However, its development was consigned to a computer programmer who built the prototype needed in this study. Each of the AR virtual object and animation has a unique tracker that was strategically placed in the accompanying teaching and learning material. The mobile application software called eS²MART TLM was used to retrieve and display the AR objects and animations in the teaching and learning material.

Examples of AR objects that were included in the database are 3D images of molecules (Figure 2A). These AR objects are intuitively designed and can be rotated and zoomed through tactile manipulations on the screen of smartphones (Figure 2B). Because of this, students can view the molecule from any angle by just simple hand controls, strengthening the mind and hand coordination in learning. Likewise, the rotation of 3D molecules in real time gave the students a visual perspective of the actual orientation of molecules.

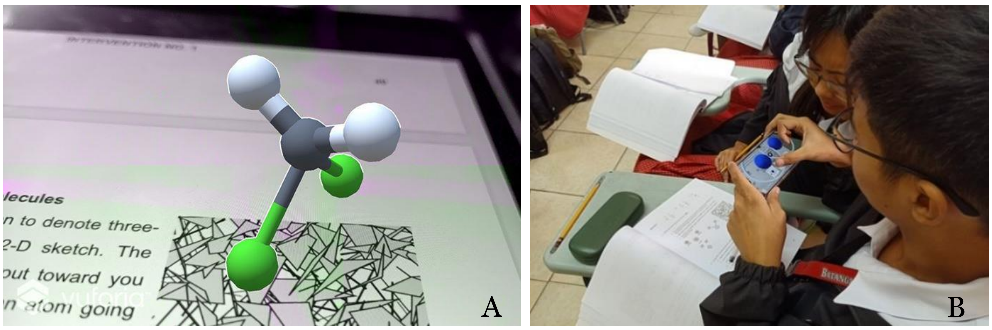


Figure 2. Augmented Reality virtual image of dichloromethane (CH_2Cl_2) molecule (A); and a student controlling the Augmented Reality virtual animation of covalent bonding through tactile manipulations on their smartphones (B).

To further maximize the augmented reality component of eS²MART TLM and provide exercises that can develop spatial skills, four intervention activities were also included in the developed material. The intervention activities include guided instructions that required observing and manipulating AR molecules from their mobile phones and then sketching and drawing these molecules from different angles. Prior to the utilization of eS²MART TLM, five chemistry professors evaluated the material using DepEd's Learning Resources Management and Development System (LRMDS) Evaluation Rating Sheet for Print Resources. Results revealed a mean score of 27.4 in terms of content, 71.6 in terms of format, 19.4 in terms of presentation and organization, and 24 in terms of accuracy and up-to-datedness of information. A score of 21, 54, 15 and 24 are needed in order to pass the criteria for content, format, presentation and organization, and accuracy and up-to-datedness. Thus, eS²MART TLM passed the standard evaluation for print resources set by the Department of Education and was approved for use as a resource material for chemistry course.

The fourth phase was the utilization of eS²MART TLM in the teaching and learning of General Chemistry 1 course. Student participants were given free copies of eS²MART TLM and the accompanying mobile application software that they have downloaded and installed in their mobile phones.

To establish rapport between the researcher and the participants, and to make the students knowledgeable and confident on the use of augmented reality, the researcher handled the participants and used eS²MART TLM one month prior to the actual study. During this period, the students were immersed on the use of eS²MART TLM in the discussion of atomic theory and quantum numbers. These topics were outside the scope of the present study. The spatial skills pretest was administered during the first week of the study while the posttest was administered at the conclusion of the study.

The fifth phase was the evaluation of eS²MART TLM in terms of its effect on the spatial skills of students, its level of acceptability and the overall learning experience of the students. Results of the spatial skills pretest and posttest provided data for calculating the average normalized gain, g. This test was used to evaluate the effectiveness of using AR in eS²MART TLM on enhancing students' spatial skills. The following coefficient range for g was utilized: a value between 0.10–0.30 denotes low gain, 0.31–0.70 signifies medium gain and 0.71–1.0 equates to high gain.

To further investigate where the students showed the most improved skill area, the learning gains in the three attributes of spatial skills which are visualization (VZ), spatial orientation (SO) and spatial relations (SR) were also measured. The test items in the standardized test were categorized based on which skill area/s was/were used in answering the question. Ten items that include numbers 1–7, 11, 13, and 15 fall under Visualization Skills, five items that include numbers 9, 12, 14, 16, and 18 fall under Visualization and Spatial Orientation, and lastly, five items including numbers 8, 10, 17, 19, and 20 falls under visualization, spatial orientation, and spatial relations. Figure 3 shows a test item that requires all these three skill areas.

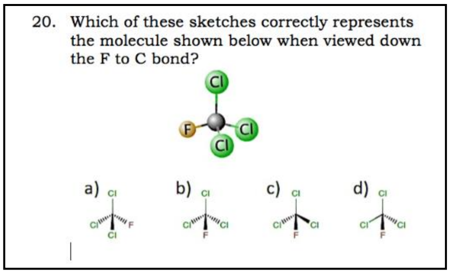


Figure 3. Test item that requires VZ-SO-SR skill area.

Finally, the mean and standard deviation (±SD) were the statistical tools utilized in assessing the students' learning experience on the use of eS²MART teaching and learning material.

RESULTS

Effect of AR Component of eS²MART TLM on Students' Spatial Skills

The spatial skills had medium gain in the Purdue Spatial Visualization Test (PSVT) and high gain in the Content-Specific Test Items. The medium gain in the PSVT component may be attributed to the high pretest scores of the students (Table 1).

Table 1. Average normalized gains (g) and standard deviation (±SD) for spatial skills of student participants.

Test Component	Pretest	Posttest	g	(±SD)	Interpretation
Purdue Spatial Visualization Test (PSVT)	0.84	0.92	0.50	(±0.26)	Medium Gain
Content-Specific Test	0.71	0.93	0.76	(±0.18)	High Gain

In terms of frequency distribution, majority (75%) of the students obtained medium learning gains under the PSVT component. On the other hand, 68% of the students obtained high gains under the content-specific spatial skills test (Table 2).

Table 2. Frequency distribution of Hake Factor interpretation of results in terms of test component. F-frequency.

Hake Interpretation	Test Component			
	Purdue Spatial Visualization Test (PSVT)		Content Specific Spatial Skills Test	
	F	%	F	%
High Gain	5	11.36	30	68.18
Medium Gain	33	75.00	1	2.27
Low Gain	6	13.64	13	29.55
Total	44	100.00	44	100.00

It can be deduced that the intervention activities designed to enhance spatial skills are effective in terms of content specific spatial skills as evidenced by the percentage of students that obtained high gains in this particular test.

All of the students recorded medium gains in all three spatial skill areas (Table 3). From the pretest scores, test items that require visualization skills (VZ) only, obtained the highest average scores while test items that require an interplay of all three spatial skill areas of visualization (VZ), spatial orientation (SO) and spatial relations (SR) obtained the lowest scores. Visualization skills require an ability to imagine molecules from different perspectives by mentally changing their point of view or reference. It is understandable that without exposure to any learning intervention, students can demonstrate higher spatial skills that require only one skill area than one that requires two or more skill areas.

Table 3. Average normalized gains (g) and standard deviation (±SD) for spatial skills of student participants. VZ-visualization; SO-spation orientation; SR–spatial relations.

Skill	Pretest	Posttest	g	(±SD)	Interpretation
VZ	0.76	0.88	0.50	(±0.19)	Medium Gain
VZ-SO	0.73	0.83	0.37	(±0.15)	Medium Gain
VZ-SO-SR	0.64	0.85	0.58	(±0.39)	Medium Gain

However, after using augmented reality technology in depicting virtual molecular models in the intervention exercises, test items that require all spatial skills area (VZ-SO-SR) registered the highest normalized gain value of 0.58 (±0.39). It was followed by test items that require visualization (VZ) skills and lastly, those that require visualization and spatial orientation (VZ-

SO) skills. This only shows that AR is an effective tool in improving all of the spatial skill areas (Table 3).

Majority of the students obtained low learning gain in the test items that require visualization skills only. This is not to say that they performed poorly, but rather the low gain was attributed to the high pretest scores in these type of test items, which mostly consists of the PSVT items. The effectiveness of using AR in the developed material could be seen in the VZ-SO skill area where majority of the students fall under medium learning gain and most especially in the VZ-SO-SR skill area where the students registered medium and high learning gains. This further corroborates the result in Table 3 which shows that the highest average normalized gain value among the three spatial skill areas belong to VZ-SO-SR category (Table 4).

Table 4. Frequency distribution of Hake Factor interpretation of results in terms of spatial skills area. VZ-visualization; SO-spatial orientation; SR-spatial relation; F-frequency

Hake Interpretation	Spatial Skills Area					
	VZ		VZ-SO		VZ-SO-SR	
	F	%	F	%	F	%
High Gain	6	13.64	0	0.00	15	34.09
Medium Gain	5	11.36	35	79.55	22	50.00
Low Gain	33	75.00	9	20.45	7	15.90
Total	44	100.00	44	100.00	44	100.00

When students were asked if they feel it's important to be able to imagine or visualize molecules in 3D, all of them provided affirmative answers as they reason that it is critical to understand the structure of molecules. It can be deduced that students have an understanding of the importance of spatial skills in understanding and making mental visualizations of molecules in chemistry. Figure 4 shows a student's actual response to the question.

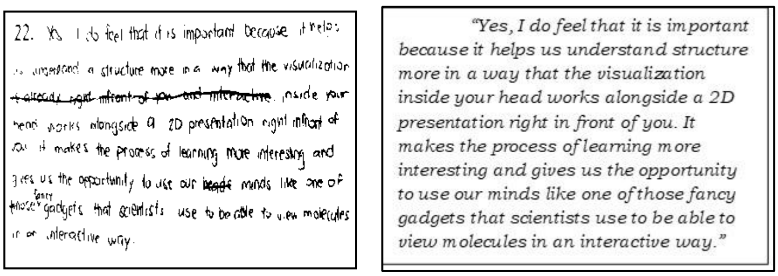
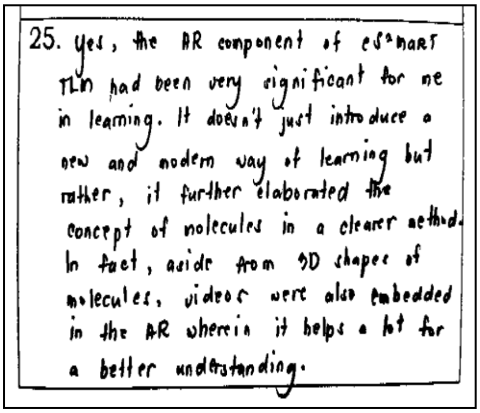


Figure 4. A sample of a Student's actual response about visualization of molecules.

Likewise, when students were asked whether the use and manipulation of AR molecular models helped them enhance their spatial skills, all of them again gave a positive response. Majority of them stated that they have a better understanding of the 3D shape of molecules because AR made it a lot easier and faster to visualize the structure (Figure 5). One specific response of a student is presented in Figure 5.



25. Yes, the AR component of eS²MART TLM had been very significant for me in learning. It doesn't just introduce a new and modern way of learning but rather, it further elaborated the concept of molecules in a clearer method. In fact, aside from 3D shapes of molecules, videos were also embedded in the AR wherein it helps a lot for a better understanding.

"Yes, the AR component of eS²MART TLM had been very significant for me in learning. It doesn't just introduce a new and modern way of learning but rather, it elaborated the concept of molecules in a clearer method. In fact, aside from 3D shapes of molecules, videos were also embedded in the AR wherein it helps a lot for better understanding."

Figure 5. A sample of a student's actual response on the effect of AR.

Another student shared that they can "feel or view the molecules from their preferred perspective, and with the ability to rotate, zoom and view from different angles, better learning is already ensured when studying using AR". The student further elaborated that they felt like they're chemists or scientists that can manipulate a certain molecule.

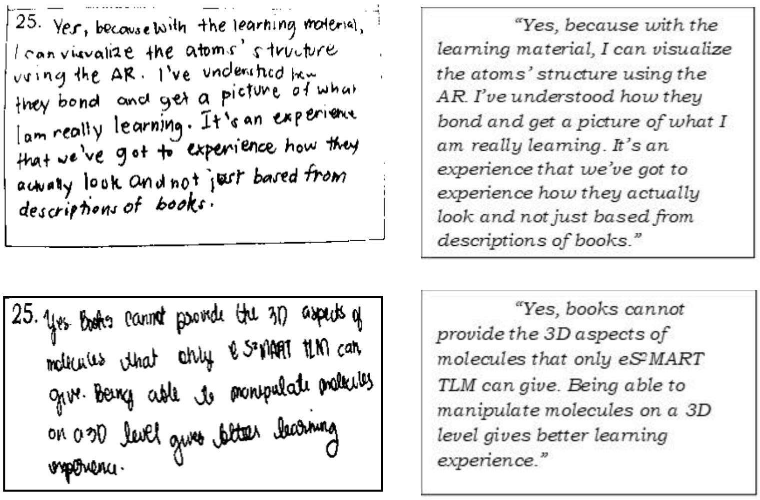
Students' Learning Experience on the Use of eS²MART TLM

There is an overall very positive learning experience on the use of eS²MART TLM in terms of augmented reality component as implied by the composite mean value of 3.54 (±0.57) (Table 5). Eight out of ten experiences obtained mean values that were interpreted as very positive and only two have mean values that correspond to a positive experience. Among the very positive experiences, the statement "The AR objects and animations of eS²MART TLM made me visualize molecules and other chemical concepts more clearly than mere pictures in textbooks" got the highest mean value of 3.73 (±0.54). Figure 6 shows samples of students' actual statements when asked about their learning experience.

Table 5. Students' learning experience on the use of eS²MART TLM.

Statements	Mean	±SD	Adjectival Rating	Interpretation
1. I enjoyed learning chemistry using augmented reality-enabled eS²MART TLM.	3.39	0.54	Strongly Agree	Very Positive
2. The AR animations and actual manipulations of AR objects in eS²MART TLM helped me understand the concepts faster.	3.52	0.55	Strongly Agree	Very Positive
3. The AR objects and animations in eS²MART TLM made learning chemistry more interesting.	3.68	0.56	Strongly Agree	Very Positive
4. The AR objects and animations of eS²MART TLM made me visualize molecules and other chemical concepts more clearly than mere pictures in textbooks.	3.73	0.54	Strongly Agree	Very Positive
5. The intervention activities using AR objects in eS²MART TLM enabled me to visualize and make mental rotations of molecules.	3.66	0.57	Strongly Agree	Very Positive
6. I became more engaged in class because of the AR component of eS²MART TLM.	3.00	0.68	Agree	Positive
7. It is easy for me to operate the dedicated mobile app needed to manipulate the AR objects embedded in eS²MART TLM.	3.36	0.57	Strongly Agree	Very Positive
8. I find AR as a useful tool in learning chemistry.	3.57	0.59	Strongly Agree	Very Positive
9. I prefer to use learning materials/textbooks with AR component than traditional learning materials/textbooks.	3.25	0.54	Agree	Very Positive
10. I want to continue using teaching and learning materials with AR component.	3.32	0.56	Strongly Agree	Very Positive
Composite Mean	**3.45**	**0.57**	**Strongly Agree**	**Very Positive**

It is to be noted that the question here is in general whether AR helped them understand the lesson or not, and not specifically asking for comparison between eS²MART TLM and regular textbooks. As a response, some of the students compared their experience on AR-enabled eS²MART TLM with that of ordinary books and recognize the role of AR in seeing and understanding how molecules really look like as opposed to ordinary pictures or descriptions in regular textbooks.


25. Yes, because with the learning material, I can visualize the atoms' structure using the AR. I've understood how they bond and get a picture of what I am really learning. It's an experience that we've got to experience how they actually look and not just based from descriptions of books.

"Yes, because with the learning material, I can visualize the atoms' structure using the AR. I've understood how they bond and get a picture of what I am really learning. It's an experience that we've got to experience how they actually look and not just based from descriptions of books."

25. Yes. Books cannot provide the 3D aspects of molecules that only eS²MART TLM can give. Being able to manipulate molecules on a 3D level gives better learning experience.

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Figure 6. Sample of actual statements of students on Augmented Reality (AR) Learning experience.

The next experience with the second highest mean value of 3.68±0.56 relates to how AR objects and animations in eS²MART TLM made learning chemistry more interesting. Moreover, during the pilot meeting when the researcher oriented the class about the study and demonstrated the mobile application software and its use in scanning the trackers in eS²MART TLM to reveal the intuitive AR objects, the class erupted into loud applause and cheers. They were really amazed by the features of eS²MART TLM and they were all eager to download the mobile application software in their individual smartphones and experience AR technology.

The third highest mean value equivalent to 3.66±0.57 interpreted as very positive pertains to their experience on the intervention activities that uses AR objects designed to enhance their spatial skills.

On the other end of the spectrum, the learning experiences that obtained the lowest mean scores of 3.25±0.54 and 3.00±0.68 pertains to the statements "I prefer to use learning materials/textbooks with AR component than traditional learning materials/textbooks" and "I became more engaged in class because of the AR component of eS²MART TLM". Nevertheless, these experiences were still identified as positive learning experiences based on the adjectival rating and interpretation.

DISCUSSION

Effect of AR on Students' Spatial Skills

The study revealed that the students acquired medium learning gains in the PSVT component of spatial skills test and high learning gains in the content-specific test items. The medium gain in PSVT which requires visualization skills, was due to the fact that students already got high scores in the pretest in the PSVT component as compared to content-specific spatial skills pretest. This is similar to the results obtained by Carlisle (2012) in her study about development of spatial skills where 80 to 90 percent of STEM students correctly answered the PSVT component of spatial skills pretest. Since the participants in the study are STEM students, they may already have good visualization skills.

However, the normalized high learning gains in content specific test items that require visualization, spatial orientation and spatial relations signify that using augmented reality as a component in teaching and learning material can enhance spatial skills of students, a trait that is very important for academic success in chemistry and in STEM discipline in general. Furthermore, the normalized high learning gain in the content-specific test items may be the effect of the four intervention activities in eS²MART TLM where students were directed to view the molecules from different perspectives or views, have a grasp of identifying planes of symmetry and learned how to illustrate 3D objects in two-dimensional surface in their paper through the wedge and dash notation of Lewis structures. This result is consistent with the result obtained by Martín-Gutiérrez et al. (2015a) in their study which concludes that students improved their spatial skills after using an AR application that has been created to improve spatial skills using didactic content of graphics. Likewise, the results of this study further prove the conclusion of Hornbuckle et al. (2014) that spatial skills improvement does not occur by chance alone, but by instructional interventions like the ones utilized in this study. The instructional interventions helped the students develop domain-specific spatial skills which are important in chemistry because they are critical in connecting particulate representations of molecules to conceptual and symbolic knowledge.

The recorded normalized high gains for spatial skills in the content specific test items further corroborates the research findings of Terlecki et al.

(2008) that spatial skills can be enhanced by continuous usage of models regardless of students' initial spatial experience and appeared to be long lasting. In the present study, the molecular models that were used were AR virtual objects that can be manipulated by tactile controls, instead of the regular handheld models. As conveyed by a student participant, the AR component helped them visualize clearly the molecular structure and gave them a better learning experience. Furthermore, this is also similar to the findings of Kurniawan et al. (2018) which articulates that human anatomy learning system with interactive AR helped students visualize and learn human anatomy more easily. As such, it can be said that this technology is proving to be a game changer on how lessons that require 3D modelling can be presented innovatively to the class in order to enhance specific student attributes like spatial skills.

Using interactive AR images as a tool in presenting abstract concepts in chemistry provided experiential learning which enhanced the spatial skill of students. Spatial skills are learned and developed through life experiences (Harle and Towns 2011). Student manipulation of intuitive AR virtual images in the developed instructional material in this study resulted to deeper and broader understanding of concepts by concretizing their experience through conclusions and applications.

Likewise, because the instructional material used an innovative approach of presenting images other than 2D pictures, the multimedia learning theory gives potential explanation on how the AR component resulted to improved spatial skills, especially on items that required all skill areas. The interactive 3D virtual images gave the students an opportunity to construct pictorial mental models and to build connections between them.

Students' learning experience on the use of eS²MART Teaching and Learning Material

With regard to the use of e²SMART TLM, the students have a very positive learning experience of using augmented reality-enabled teaching and learning material. The students conveyed that the experience they got cannot be obtained in traditional books alone, that the AR component helped them understand the lesson better. This result agrees with the findings of Akçayir and Akçayir (2017) which reveals that AR technology in education leads to adoption of positive attitude toward AR enhanced learning activities. The novelty of the technology makes learning chemistry more interesting and fun. The ability of AR to rescale virtual objects and enable the manipulation of the properties and relationships of objects that would either be too small or too large to examine in real life (Johnson et al. 2010) has been capitalized in this study to develop a new hybrid of teaching and learning material with AR.

The findings of this study prove that the developed augmented reality-enabled teaching and learning material is a useful and effective tool resulting to enhanced spatial skills and positive learning experience in chemistry among the student participants. Moreover, the combination of printed text and augmented reality with the use of mobile software application ushers a new type of teaching and learning material that is adaptive to the learning styles of 21st century learners and is a well-needed educational resource that will enhance spatial skills, an important attribute for students to become successful in the disciplines of science, technology, engineering and mathematics. Finally, because of the students' positive learning experience on the use of augmented reality, curriculum experts in the country should consider updating our regular textbooks and incorporate this innovative technology to enhance student engagement.

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