Interactive Augmented Reality with Natural Action for Chemistry Experiment Learning

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***Abstract* - Conventionally, the interaction between a user and augmented reality (AR) application is limited. Mostly, it allows virtual information browsing on the AR marker or basic manipulation such as moving and resizing of the 3D model. This study presents a rich interaction that allows users to mimic physical action such as shaking and pouring in chemistry experiment using card-based or box-based marker design. The user is required to follow the instruction to select the correct AR marker that represents apparatus or solutions and performs the physical action to conduct an experiment. Usability's result showed the respondents were satisfied with the application.**

***Keywords* - Educational Augmented Reality, Human-Computer Interaction, Interactive Augmented Reality, Tangible Augmented Reality.**

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1. Introduction

Researchers have studied the Augmented Reality (AR) for the education in chemistry. Visualize the abstract concept using AR technology for atoms, molecule and crystalline lattices were among the popular research topic; Yet, only few were researches working on the lab or the chemistry experiment topic using AR technology. Hence, this paper focuses on the utilizing AR technology in a chemistry experiment setup. In convention, to conduct a chemistry experiment, it always requires sufficient cost and time which not all the schools are able to cover with the budget for all the experiment topics. Student might also need to team up in big group to perform the experiment. The biggest concern was the hazardous chemical; accidents during conducting chemistry experiments can happen, for instance explosion, chemical burn, gas and etc. [1], [2], [3]. The old lab facilities, small space and inadequate safety lab equipment always threaten the safety of students and teachers. With the help of AR technology, these safety problems can be eliminated by visualizes the apparatus, chemical substance and chemical reaction in virtual form such as the corrosive, explosion, flaming and others. Besides, AR can also virtually speed up the chemical reaction so that the students do not have to spend their time waiting for the chemical reaction to complete. Furthermore, the repeatable ability in virtual environment allows student to keep repeating experiment to help them to understand the concept of the experiment and reduces the cost.

The AR is a technology that combines both of the real world and the computer-generated virtual information [1]. Users can interact with the virtual object that overlay the real environment to have a more blended and natural experience. Most of the conventional AR applications only allow users to browse the AR content or minimal interaction such as moving and rotating the virtual object [2]. For example such as to visualize the molecule structure on the AR marker [3], visualize corresponding 3D model on the alphabet AR marker and touch the smartphone screen to move it [4]. Previous researchers have shown different types of interaction could be possibly applied in the AR such as tangible interaction [5], multimodal interaction [6], natural user interface [7], [8], [9], virtual menu [10], etc., in different contexts. In this study, researchers explore a rich and active interaction between the user and the AR environment that mimic actions required to perform a chemistry experiment. The developed AR application can be an alternative or complement tool for the constructivist approach learning [11]. Students can use their smartphone to run the AR application to perform the chemical experiment virtually by themselves at any time and in any place. It is able to encourage the student to actively discover the knowledge via the application and learn by themselves. This study was an initial step to discover the possibility of the interactive AR in chemistry experiment topic.

The rest of the paper was structured as follows. In the next section, a related research on the augmented reality in the education field was described. Section 3 presented the storyboard and architecture of the developed mobile AR application, namely the ARChemEx. Section 4 discussed the user evaluation study along with the questionnaire result and findings. Finally, the conclusion was drawn in the final part of the paper.

2. Background Study

The computers and communication technologies are rapidly growing, and they can be used for various purposes. They had been used widely in education to make the learning process easier. For example, Bloody Buddy was a game-based application for Biology subject to encourage students in learning and was able to help student in understanding biology content through animated games [12]. This game-based learning application was developed with two modes; story mode and quiz mode, to help students to understand the structure, functions and principles of the important cells in the circulatory system and the immune system in human body. To evaluate this application, pre-test and post-test had been carried out by eleven respondents from twelve grade students. Results proved the game-based learning was better than traditional learning in terms of the knowledge gain. A study on the process of developing an educational application for children aged three to 5 for improving their skills and abilities in Arabic education had been carried out [13]. This application required children to pronounce Arabic letters properly within the formats. Arabic language includes three primary formats which are fatha, dama and kasra and the application pronounced the correct formats to the children properly. The application consists of three primary sections which involve alphabet letter section, alphabet letter with formation section and training section. The first section displayed the letter with a sound, the second section displayed a sign, letters and simple words. The last section displayed a simple quiz to test the students' understanding. The pre-test and post-test had been done to measure the usability of this application. There were total of twenty-eight respondents including teachers and students that took part in the testing process. Based on the usability questionnaire result, it showed a positive feedback from the respondents and had proved that the application had potential as a tool to help students in learning Arabic language. An android based application had been introduced to help students in learning and memorizing Kanji language in a more comprehensive way [14]. The application consists of two features which include Kanji section and quiz section that allowed students to learn Kanji and to complete a quiz to test their understanding about Japanese Kanji. The result of the study showed that the application was easy to use and can be easily understood by the students. The previous studies had showed that the students and teachers agreed that the use of smartphone in learning enabled them to benefit.

2.1. Augmented Reality Application in Education

The AR in education is a good innovation and with the capability to attract student attention into interesting and fun learning environment by implementing the AR technology [15]. There were a lot of studies that had been done and a lot of ongoing researches which related to the AR in education. The traditional learning environment can be replaced to a more edutainment environment by using AR technology [16]. An AR application had been developed in order to help children to improve their pronunciation by integrating orthography (visual script) and phonology (audio) as a teaching method [17]. This AR application used speech recognition to enhance the productive in vocabulary learning. 3D model with animation and AR marker had been used to attract the attention of the students. User satisfaction, usability and learnability of this application were determined through interviewing, observation and questionnaire. Based on the results, researcher had concluded that this application was useful and easy to learn. This application allowed students to improve their vocabulary and pronunciation by providing interesting content. By integrating the two approaches; orthography and phonology, the vocabulary learning process becomes more effective and efficient. Besides, this application had been equipped with speech recognition to allow the application to recognize pronunciation mistakes made by students. An electronic book in physics using the AR technology had been developed [18]. In this study, the AR technology utilized the animation, sound, and video technology. This book used the AR technology to improve learning through observation, experimentation, and stimulation activities. The developed electronic AR book had the same outlook as the regular textbook, except for some of the contents such as images were equipped with the AR concept. Based on the evaluation, the developed electronic AR book had fulfilled the physics teaching materials requirement. There were three evaluations conducted to test the electronic AR book which were material and media expert's validation tests, field tests of teachers and student legibility and limited tests. Material and media expert's validation test was conducted to validate the suitability of the electronic AR book as a teaching material. Field test with teachers and students legibility were done in order to receive important feedback from teachers and students to further improve the AR book. Limited test involved pre-test and post-test to measure the difference of student's knowledge before and after using the electronic AR book. The results concluded that there was an improvement in average from 28 to 77 when student used the AR book in learning the subject. However, the AR research mentioned above had very limited interaction between the user and the application, while our study was more interested on utilizing the rich interaction in the AR application.

2.2. Interactive Augmented Reality Application in Chemistry Education

The menu type interaction is a common interaction that can be found in a lot of researches such as [3], [19], [20]. ARKimia Kit was developed to overcome the student's problem in visualizing an atom and their reactivity reaction [3]. This application included learning phase about 3D model of atoms and video of real experiments related to the reaction of the elements. In this application, the researchers used touch screen, simple menu and button as an interaction approach for users to interact with the application. This application consisted of introduction, core and exercise part. Pre-test and post-test were done to compare the students result before and after using the application. The results showed that the application of the effectiveness of the ARKimia Kit and satisfaction level of the students in this experiment were positive. Virtual Laboratory had explored the learning of experiment manipulation and scientific concepts for students before they enter the real chemistry laboratory [19]. An educational mobile AR game was developed by combining with virtual environment and AR technology for the exploration of the virtual experiments. The students can drag items and chemistry materials for experiment operation at the Virtual Lab stage. Besides, users are able to interact with the AR applications through scanning the cards. They used mobile devices to find correct experiments items at the AR stage by scanning the cards. The evaluation included fifty-two senior high school students and the result showed that the students improved their learning significantly after they played the game. Other than that, the high scores in each dimension of flow and acceptance were achieved. The AR technology in Visualization Mindtools enables students to obtain experience in commonly invisible phenomena while exploring chemical tools [21]. In this mobile AR application, students used Visualization Mindstools learning model to adjust the parameters of pressure and temperature via the slider menu. Then users can observe the diversification inside the gases accordingly to improve their learning performance. Students used tablets equipped with digital camera and scanned the AR cards which represent chemical learning materials. After the AR cards are recognized, the AR learning system will provide relevant digital learning materials and virtual objects on the tablet. The evaluation involves seventy 11th-grade students and the hypothesis is that using the inquiry-based learning strategies combined with visualization tools to guide and assist students can help them learn effectively and reflect on their learning.

Research from [22], [23] showed the possibility of the tangible interaction in the chemistry subject. Study in [22] was performed to provide a better understanding of the properties of chemical elements. In this application, researchers implement touch screen and simple menu button for users to interact with the application. Other than that, tangible interaction concept was utilized. Tangible interaction allows user to interact with a system through physical medium or object. In their case, the element's AR marker attached on a cube as a physical medium. The cube type physical medium consisted of six AR marker, one for each face, and able to visualize six elements. When users place the physical mediums together, it will illustrate the chemical interaction between the elements in their AR application. This application focused on the perception and experience of a mobile AR application designed for chemistry teachers in teaching chemistry. A total of 15 teachers took place in the testing process. The result of semi structured interview showed positive feedback from

Figure 1. ARChemEx storyboard

the teachers and they claimed that this application allows a better understanding of the properties of the chemical elements and experiment.

Furthermore, the study also exposed some limitations of this application; the application was not professional enough for chemistry teaching in senior level while more visual effects were needed for depicting a real chemical reaction process and the content was not comprehensive because it only covered 36 elements. Researches showed tangible interaction can bring huge advantages to chemistry education [23]. Researcher in [23] had also explored the tangible interaction in an interactive educational workbench, namely Augmented Chemistry (AC). The AR application enabled users to choose chemistry element from booklet menu and composed into 3D molecular models. Users were allowed to interact with models in this AR environment using the physical interaction such as medium booklet, a cube, a platform which the user can select, position, rotate, compose, and deselect 3D models, thereby affecting the virtual environment. The AR tracking available in the application enabled identification of new composite molecular models and offered appropriate system feedback to its users.

The visualization of the virtual animation on the physical chemistry apparatus has been applied in [20], [24] which is an attractive visualization; users can see the chemical reaction animation rendered on the apparatus. The students can experience the AR games in electrochemistry experiment activities. This study investigated the effects of types of AR and guiding strategy in the student learning performance and motivation on electrochemistry concepts. Static-AR was developed to present the virtual assisted information as static figures, using the arrow to demonstrate the migration of ions and electrons. In comparison, Dynamic-AR was developed to present the virtual assisted information with animation on top of the physical chemistry apparatus to demonstrate the migration of ions and electron. 152 participants had been involved in the testing process. Comparison between learning environment of static AR and learning environment of dynamic AR had been made through the testing. As a result, they had concluded that the learning environment of static AR was more helpful for the learners especially about conceptual understanding and provided a higher motivation compared to learning environment of dynamic AR. Biochemical education using AR tool to improve the learning curve had also been studied [24]. The AR tool was used to depict the redox reaction between hydrogen peroxide and sodium hypochlorite solutions, two ubiquitous oxidizing agents, to create oxygen, a combustible gas. The users interact with the AR applications through menu. They will ration the volume of hydrogen peroxide solution delivered into seven portions. After the delivery of each volume portion, they were expected to wait and then measure the volume of generated oxygen gas. Visualization of oxygen gas was rendered on the physical chemistry apparatus. The evaluation included ten high school students and results showed that the confidence in handling chemicals had increased. At the same time, it lessened the used of materials and reduced the laboratory set up time. The implementation on the actual tools had become easier as the students were getting used with the AR tools.

3. ARChemEX

Figure 1. showed the storyboard of ARChemEx application. ARChemEx prototype is equipped with a main page which has two options as shown in Figure 1. Option one was a demonstration video about the chemistry experiment. Users were advised to go through the demonstration video to understand the steps and the content of the experiment before they start the experiment. This option was included based on the interview feedback from secondary school teachers. It was an important function to let the students to expose the steps and concept of the experiment before the lab began. Whenever users were ready, they can choose the experiment option to start the AR based chemistry experiment. The camera function on the mobile device will open automatically.

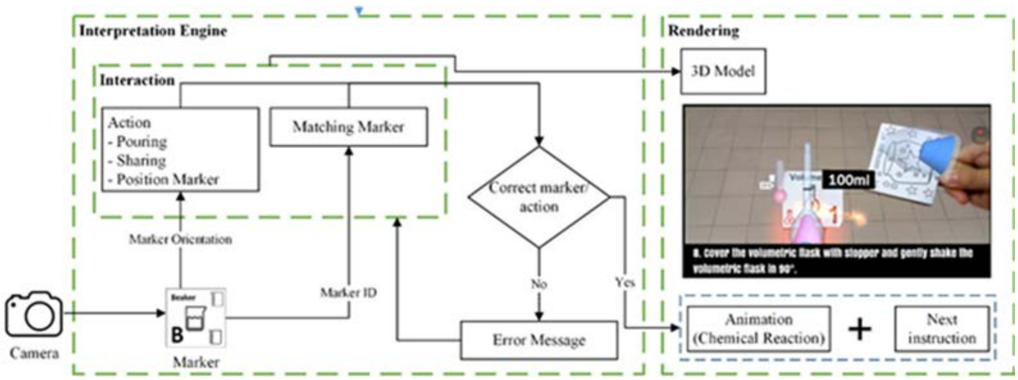


Figure 2. ARChemEx framework

When the marker was detected by the camera, the virtual object will superimposition on the marker. Users can move or rotate markers like manipulating apparatus tools to obey instructions, + either pouring, shaking or position apparatus to an appropriate location. All chemical reactions were observed from the mobile device. It consists of ten steps in total. The experiment involved dilution of concentrated acid solution. Briefly, the filter funnel was first put on top of the volumetric flask and the volumetric flask was filled with certain amount of distilled water. Then, some concentration acid solution from the reagent bottle was poured into the beaker to be used later on. Certain measured amount of concentrated acid was then taken using pipette and filled into the volumetric flask. After that, distilled water was added into the volumetric flask with filter funnel on top of it until the solution reached the graduation mark. The volumetric flask was covered with stopper and shook gently in 90 degrees for few times. Finally, certain amount of diluted acid was prepared. A scene will be displayed to the user once they have successfully completed the experiment.

3.1. Framework of ARChemEx

The framework of ARChemEx application consisted of two main components which were interpretation engine and rendering part (Figure 2.). The frameworks start with getting a stream of images from the smartphone camera, the images will then be analysed by recognition and tracking algorithm to detect marker and then render the 3D model on it. The marker represented the chemistry laboratory apparatus or the chemical solution. Each marker consisted of a unique ID. The camera will detect the marker held by the user and the marker's ID will send to the interpretation engine. The interpretation will analysis the combination of the correct markers; Different steps requires different combination of markers (apparatus and chemical solution) to trigger the chemical reaction. Meanwhile, the marker orientation data was sent for the purpose of detecting the correct action. For example, the orientation of the marker was analysed to detect the rotation, it is for the action of pouring the chemical compound into the apparatus and shaking the apparatus as shown in Figure 3.

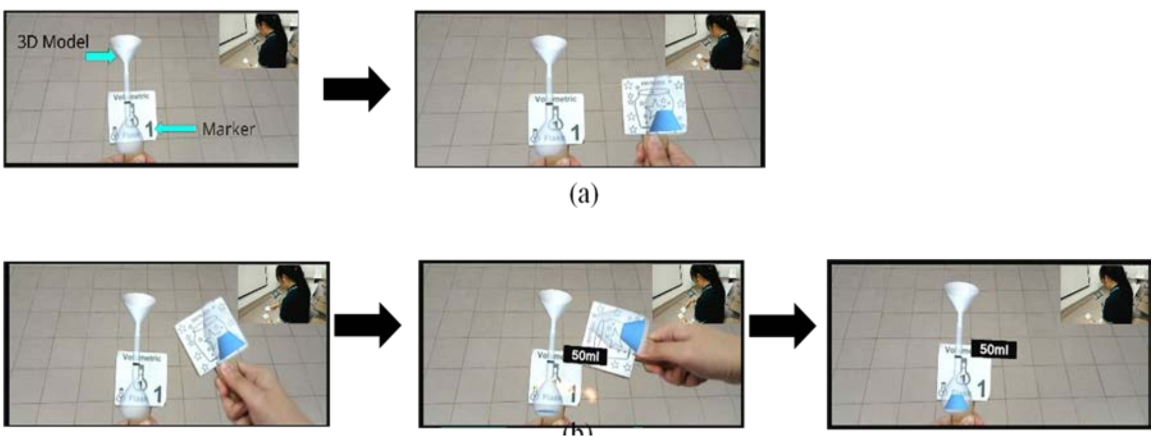


Figure 3. Interpretation engine: (a) To detect the right combination of the marker based on maker's ID, (b) To detect the pouring action with the orientation data of the maker

(a) (b)

Figure 3. Design of the marker: (a) card-based with slim handler and, (b) box-based which has volume feeling

The position data was for detecting the position of markers such as the pipette's marker should at above of beaker's marker to animate the action of drawing up the chemical solution from beaker. After the interpretation confirms the correct action and marker, the animation of the chemical reaction will be rendered. It included filling animation of chemicals into the apparatus, warm heating reaction with a red colour around the apparatus, the current millimetre unit for the chemical solutions etc.

3.2. Design of the Marker

The marker's design of current experiments involved six different markers. Figure 4. showed that the beaker, pipette, filter funnel, hydrochloric acid, volumetric flask and distilled water were part of the experiment's apparatus. Each marker represented the exact chemical or apparatus used in the real experiment to increase the understanding of the user. The apparatus will be manipulating accordingly to the steps' requirements either move or rotate. Two types of markers were designed to be compared in the evaluation later. The box-based marker had the volume feeling like holding an apparatus. Meanwhile, the card-based marker had a smaller handler. Even though the box-based marker might give the user feeling like they are holding an apparatus, which contributes in better psychomotor learning; The box-based marker might hinder the interaction between the user and the AR environment due to the size of it. Hence, the card-based was designed to reduce the difficulty to handle the marker to perform interaction with the AR environment.

4. Experiment Setup

Sample of the study involved thirty participants (N =30) which included eighteen males and twelve females. All the respondents were students age between seventeen to thirty. Most of the respondents were degree students. Twenty-eight of them were from information technology faculty, one of them is from chemistry and another is from law background. All the respondents stated that they had been performed chemistry experiments physically. Evaluation of the ARChemEx was conducted to ensure all the application components were well connected and functioned. Usability testing ran to determine the user satisfaction towards this application and to get the feedback from the user. Respondents were given a set of markers which were physical object markers to perform the experiment. After the respondents used the ARChemEx application, they had to answer a questionnaire. The students will learn about the dilution equation and how to perform the dilution through this experiment. Table 1. showed the tasks that needed to be performed by the respondents.

5. Results and Discussion

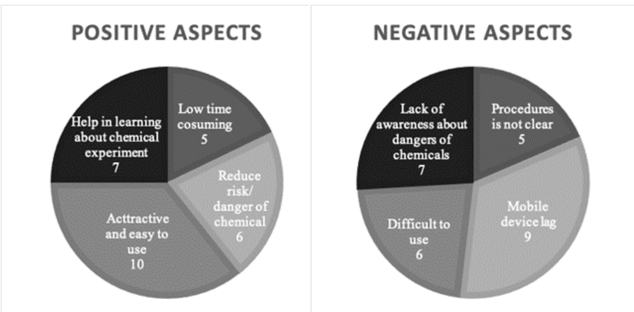
The evaluation of the application had been conducted based on 5 factors which are usefulness, ease of use, learnability, satisfaction and aesthetic. Table 2. showed the outcome of the evaluation conducted. Cronbach's alpha was used to measure the internal consistency which was item consistency in a factor. The closer Cronbach's alpha coefficient is to 1.0, the greater the internal consistency of the items in the scale [25]. The outcome from the questionnaire was reliable because the Cronbach's alpha shown was greater than 0.7. The average min value of all factors was greater than 4 which means all the respondents agreed with this ARChemEx application. Aesthetic factor got the most positive feedback (mean value = 4.48) which means the respondents were satisfied with the application design.

Positive and negative aspect of this ARChemEx application were collected from thirty respondents. Figure 5. (a) showed the value of positive aspects for this application. While, Figure 5. (b) showed the value of negative aspect for this application. From the positive side, users agreed the ARChemEx can perform chemistry experiment at any time without worrying about safety. This application also helps

Table 1. Test case specification of experimental procedures

No.	Task	Response of ARChemEX
1	Pick up the filter funnel marker and put on the top of the volumetric flask.	The animation of putting the filter funnel on the volumetric flask will be displayed.
2	Select the distilled water and volumetric flask markers. After that perform the pouring action.	The animation of the distilled water filling up into the volumetric flask will be displayed.
3	Select the beaker and hydrochloric acid markers. After that pour the hydrochloric acid into the beaker.	The animation of the hydrochloric acid filling up into the beaker will be displayed.
4	Hold the beaker marker. Select the pipette marker and put the pipette marker on top of the beaker marker.	The animation of drawing the hydrochloric acid from the beaker using pipette will be displayed.
5	Hold the pipette marker. Select the volumetric flask marker and put the pipette marker on top of the volumetric flask marker.	The animation of dropping the hydrochloric acid from the pipette into the volumetric flask will be displayed.
6	Hold the volumetric flask marker. Select the filter funnel marker and put the filter funnel marker on top of the volumetric flask marker.	The animation of putting the filter funnel on the volumetric flask will be displayed.
7	Hold the volumetric flask marker. Select the filter distilled water marker, perform the pouring action to the volumetric flask marker.	The animation of adding the distilled water into the volumetric flask until specific volume will be showed. The temperature indicator will be displayed follow by the animation of covering the volumetric flask using stopper.
8	Perform the shaking action on the volumetric flask (two times).	A light transparent red colour will be rendered on the volumetric flask.

users to reduce time consumption by expediting the process of chemical reaction without long waiting for the chemical to react. Users also feel the application is attractive and easy to use for them. However, this application had a few limitations such as the progress of the chemistry experiment is not clear, they do not know which step they are in. A progress indicator should provide to inform users the status of the chemistry experiment. Other than that, the app is lagging during experiments and users suggest the application should provide the part of awareness to students about the dangers of the chemicals.



(a) (b)

Figure 4.(a) Feedback of positive aspect;s (b) Feedback of negative aspects

Other than that, there are some insights we gained based on the observation and the feedback from the unformal interview with the participants. The animation of the experiment, the chemical reaction and the animation of moving certain apparatus different position, should be presented in certain duration. Initially, the animation was too fast for participant to notice the changes of the apparatus position and the chemical reaction. Therefore, the animation duration was adjusted before the evaluation so that the participants have time to digest the information of the animation. Secondly, participants prefer to have known the progress of the chemical experiment. Other than the current step being informed and performed by participants, they also wanted to know how many steps remained to the final step. Thirdly, because the interaction was new, it is not a conventional way and considered as a hidden type of interaction, participants require some guideline from the instructor to give them instruction to use the app for the first time. An instruction or hints to select which marker and the correct action was given in each step of the chemical experiment. Users can access that information via a simple tutorial icon at the top right of the user interface. The above finding is important to improve the usability of an AR application especially the instruction or tutorial of hidden interaction should be given to the users. Finally, the size of the marker should be considered carefully. If the marker size was big, users have to extend their arm to make sure the marker is in the camera view and at the same time to make sure they can see all the 3D models and animations inside the camera view.

Table 2. Usability evaluation outcomes

	Mean ± SD	**Cronbach's alpha**
Usefulness	**4.30 ± 0.65**	**0.88**
This application is useful in process of learning chemistry subject.	4.47 ± 0.51	
This application helps in learning chemistry experiment effectively.	4.37 ± 0.56	
This application saves my time in running chemical experiments compared to running a chemical experiment in a traditional way.	4.37 ± 0.62	
Instructions on each step is helpful for me to do the experiment.	4.27 ± 0.58	
I was able to learn chemical experiments via video in this application.	4.33 ± 0.55	
This application will show the following step after completing the current step.	4.30 ± 0.70	
3D objects on the screen are reallocated as I did.	4.33 ± 0.71	
I can know the step is complete based on the animation included in this application.	4.13 ± 0.73	
I can know I use wrong tool during performing the experiments.	4.20 ± 0.85	
This application is easy for me to remember how to perform chemical experiments using this application.	4.23 ± 0.68	
Ease of Use	**4.27 ± 0.63**	**0.72**
I can easily use this application without a written guide.	4.30 ± 0.54	
I can restore from errors quickly and easily	4.33 ± 0.61	
This application is user-friendly.	4.30 ± 0.65	
I did not notice inconsistencies while using this application.	4.03 ± 0.72	
The use of this application for performing chemical experiments is simple.	4.37 ± 0.62	
Learnability	**4.41 ± 0.65**	**0.86**
I can quickly dominate the application.	4.40 ± 0.56	
I feel the application is easy to learn.	4.47 ± 0.63	
I can understand the function of the application quickly.	4.57 ± 0.50	
I can understand and follow the step experimental display on the screen.	4.43 ± 0.57	
I can understand the 3D apparatus that match with the marker.	4.50 ± 0.68	
I can observe chemical reactions on the screen when performing the experiments.	4.07 ± 0.83	
Satisfaction	**4.36 ± 0.75**	**0.78**
I am satisfied with the application.	4.40 ± 0.50	
This application works as I expect.	4.23 ± 0.63	
This application is not lag.	4.00 ± 1.17	
I feel the application is fun.	4.63 ± 0.56	
I am satisfied with the application user interface.	4.47 ± 0.63	
I am satisfied with the 3D object shown in this application.	4.43 ± 0.73	
Aesthetic	**4.48 ± 0.57**	**0.83**
Application user interface design looks attractive.	4.43 ± 0.57	
Colors in the application are suitable.	4.43 ± 0.57	
I am satisfied with the icons and images used in the application.	4.53 ± 0.57	
I can read the text content of the applications clearly and easily.	4.60 ± 0.50	
I like the animation shown in the application.	4.50 ± 0.57	
I can get to know when the experimental step is done.	4.40 ± 0.68	

The 3D model is partially available on the screen if the marker is too close the camera view. Different participants have different length arm, it is difficult for the participant to extend their arm to perform the action while they want to maintain the 3D model in the view to see the experiment. Other than that, based on the observation, participants also found out it is not easy to put the marker on top of the marker with the box-type marker.

6. Conclusion

In general, the study has shown the potential of the interactive AR in the chemical experiment case. Respondents supported ARChemEx application able to help them in learning especially in the chemistry experiment. Using ARChemEx is not time consuming and is safe. The marker tracking is stable and only simple algorithm is needed to detect the rotation and position to infer the action of the user. The interaction that mimic the action in the real life providing a familiar and fun way to learn the chemical experiment. The longer exposure of students to the app, the more knowledge they could retain. This fact will be confirmed by having another empirical study in the future after the usability of the app is improved. Other than that, the study also suggests the elements needed to be consider for developing an interactive AR application including the duration of the animation, instruction should provide for the hidden interaction, and showing the progress of a long series of work. The design of the AR marker size and volume is important, the AR marker design should not hinder user to perform the action. Lager marker size will make the user have to extend their arm to perform the action which is uncomfortable.

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