An Augmented Reality-Based Solution for Visualization of Crystal Model and Composition to Improve Students' Learning

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Abstract—Conventional platforms for learning crystals are websites, books and mobile applications. The learning materials in these learning platforms may work but lack interaction and are attractive. Crystals can be classified into several categories and the related knowledge is quite complicated and confusing. Students may face difficulty during learning the specified crystal knowledge. Besides, Augmented Reality (AR) technology as an effective supporting tool is popular in the education and learning field recently. Hence, this project aims to improve students' learning in the crystal field by visualizing the crystal model and crystal composition through AR technology. Qualitative and quantitative methods were used for gathering the requirements of the project. This project is developed by using Jmol, Blender, Adobe Photoshop and also Unity. This paper specifically proves AR learning is effective than conventional learning. The AR technology is suitable to merge with crystal learning to help students learn crystal knowledge in an effective and interesting way. The completion of the application enhances the user understanding of the crystals.

Index Terms—Augmented Reality (AR), Crystal Visualization, Improve Students' Learning

I. Introduction

Augmented Reality (AR) technology is widely used in learning and education now. According to [1], 41% of the respondents said the technology is the most applicable for education. AR technology is help to enhance the real environment with interactive computer generated input such as visual elements and sound. AR learning is much more interesting than traditional learning methods because the users can interact with the 3D model directly. Through the integration of AR technology with learning tools, users can learn in interactive way rather than self-learning with a dull book. From the results of the survey of use mobile augmented reality for teaching materials by [2], the response received from respondents are positive such as AR is fun, interesting and can produce a new learning experience.

A crystal is a solid that has long-range positional order and come in many different colors. Crystals can be classified based on the crystal structure, crystal system, lattices and properties. Moreover, crystals can be identified by color, chemical structure and crystal system. The crystal learners may confuse of the type of crystals because some of the crystals are similar in color but with different chemical structure and vice versa.

This project is aim to integrate the AR technology with crystals learning. The crystal model and crystal composition is visualized to help the learners to learn the crystals easily.

II. Related Work

A. Augmented Reality in Learning

Augmented reality creates new teaching and learning methods that fulfill the requirement of 21st century learner. AR considers as effective learning tool among the works done onto how advance technology can enhance the teaching. AR technology makes learning process become more effective and interesting because learner is possible to interact with the virtual objects, exploring the complicated concept and phenomena through the visualization and realization [3]. AR creates complex mechanism and theories and apply in subjects like astronomy, chemistry, biology, physics mathematics and geometry education [4].

B. Augmented Reality in Learning Chemistry

Augmented Reality has become supporting of traditional learning and defined as an effective learning way especially in chemistry [5]. AR provides innovative learning process by integrating multiple media element and theoretical instruction to strengthen the learners' science motivation [6]. AR technology solves the teaching obstacle related to 2-dimensions and 3-dimensions that help students to learn about crystallography concepts [7]. According to the evaluation of [8] from five chemistry education application, 67% of the users felt these applications were more useful than traditional exercises.

C. ARChemistry Learning Application

The ARChemistry Learning application consists of four modules which are "learn with the manual", "learn with the cards", "test your knowledge" and "add a substance". In the module "learn with manual", learners can scan certain unfamiliar chemistry words by phone's camera and the related information shows on the screen. The "learn with cards" module is help learners to form chemical compound by focusing the camera on the card according to the indication. "Test your knowledge" module is aim to test the learners can add any compound that created by themselves through "add a substance" function.

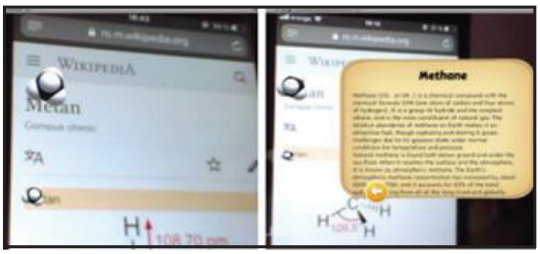

Fig. 1. Example of screen in ARChemistry Learning.

III. PROJECT REQUIREMENT

Qualitative assessment and quantitative assessment were used for gathering the requirements of the project. For qualitative assessment, interviews were conducted with the gemology field expert and crystal's seller. On the other hand, questionnaire was distributed to target users to collect the requirement data.

A. Interview

An interview was carried out with the gemologist and he had provided some crucial point of view and suggestions in the interview. He agreed with the point of current crystals learning way is too boring and lack of interaction. From his point of view, AR learning is a great idea and makes the dull learning process more attractive and interesting. He suggested the system to visualize the crystals according to the crystal system and helps the beginner learners to distinguish the crystals.

In addition, another interview was conducted with the crystal's seller. From her experience, customers are concerned and curious about the crystals' functions the most. Customers usually ask about the crystals for health, study, love, wealth and protection. She believes the AR learning mobile application is useful for the beginner crystals lover to learn the function of crystals and gain some related extra knowledge.

B. Questionnaire

The questionnaire contains 10 questions and it was distributed to 25 target users via Google form. The aim of the questionnaire was to collect their opinion and requirements. Fig.2 to Fig.11 show the results of questionnaire obtained from the responds of 25 respondents.

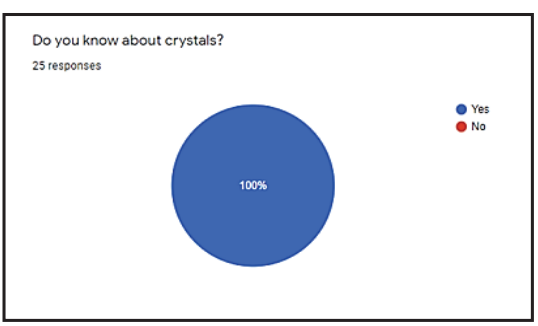

Fig. 2. Do you know about crystals?

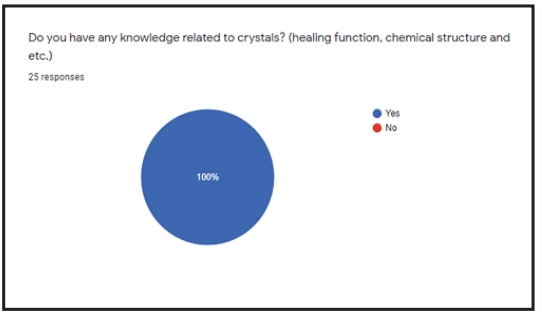

Fig. 3. Do you have any knowledge related to crystals?

The first question is asked about the respondents whether they know about crystals and the second question is asked about whether the respondents have any related knowledge about crystals. These two questions are to ensure all of the respondents are heard about crystals before and all of them are the project's target users. From the results shown on Fig.2 and Fig.3, 100% of the 25 respondents are knowing about crystals and having the crystals related knowledge.

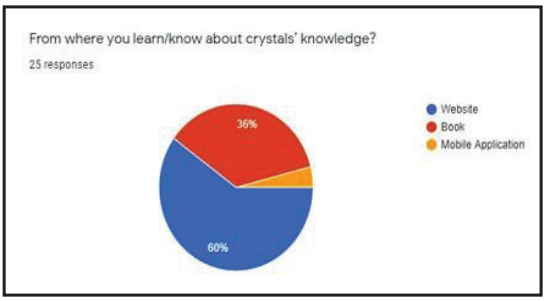

Fig. 4. Where you learn/know about crystals' knowledge?

Question 3 is to identify the methods used by the respondents in learning crystals. Based on Fig.3, 60% of the respondents learn the crystals knowledge through website, 36% of them know the crystals' knowledge from book and only 1 respondent (4%) knows the crystals' knowledge through mobile application. The results have shown that all of the respondents are using conventional methods to learn the crystals.

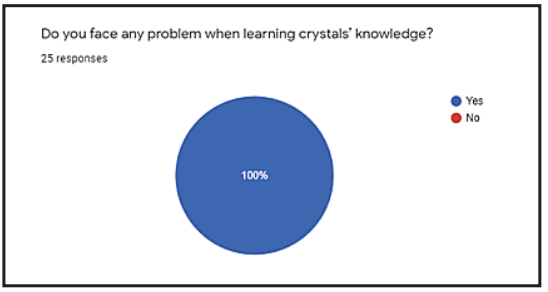

Fig. 5. Do you face any problem when learning crystals' knowledge?

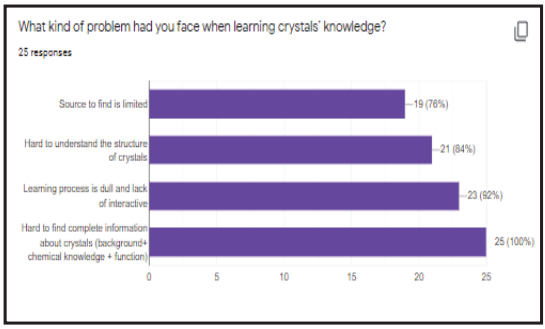

Fig. 6. Do you face any problem when learning crystals' knowledge?

Question 4 and question 5 are to determine the condition of respondents during the process of learning crystals. From the results, all of the 25 respondents (100%) did face some problems when learning the crystals' knowledge. 19 respondents (76%) faced the problem that the source of the crystals knowledge is limited. 81% of the respondents feel hard to understand the structure of crystals and 92% of them feel the learning process is dull and lack of interactive. Next, 100% of the respondents are hard to find the complete information about the crystals.

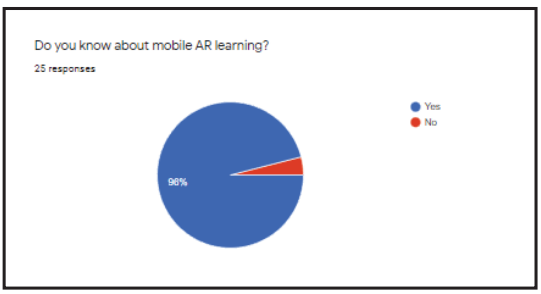

Fig. 7. Do you know about mobile AR learning?

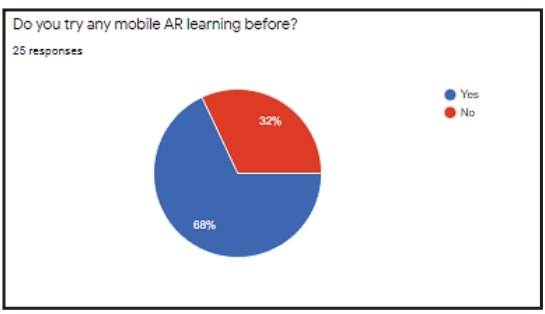

Fig. 8. Are you interested in learning crystals through AR mobile application?

Question 6 and question 7 are mainly to know the experiences of respondents toward mobile AR learning. There are 96% of the respondents know about the mobile AR learning and only 1 respondent (4%) never know about mobile AR learning. Furthermore, 68% of the respondents have tried the AR mobile learning in the past and 32% of the respondents do not have related experience.

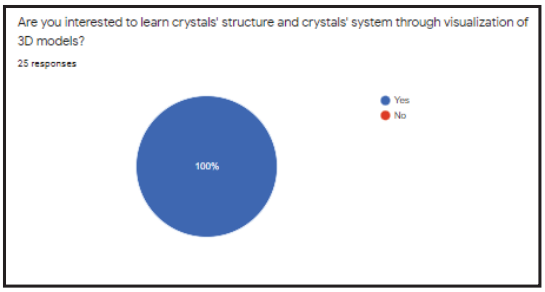

Fig. 9. Are you interested in learning crystals through AR mobile application?

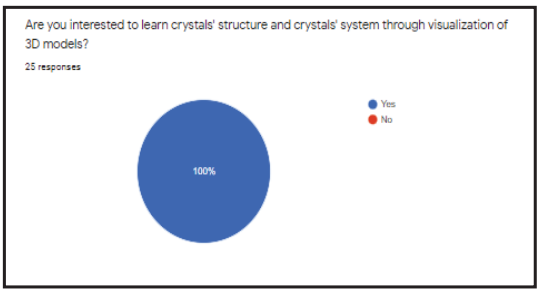

Fig. 10. Are you interested to learn crystals' structure and crystals' system through visualization of 3D models?

Question 8 and question 9 are focus on collecting the interests of target users. Fig. 8 shows 100% of the 25 respondents are interested in learning crystals' knowledge through the AR mobile application. Fig. 9 shows all of the 25 respondents are interested to learn the crystals' structure and crystals' system through visualization of 3D models.

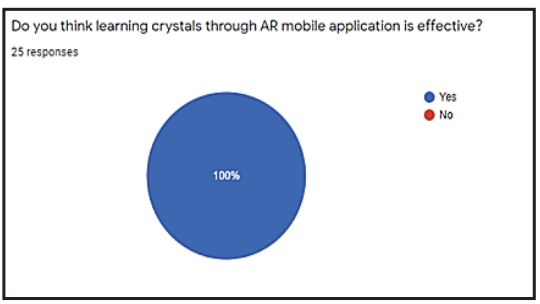

Fig. 11. Do you think learning crystals through AR mobile application is effective?

The last question is asked about the opinion of respondents whether they think learning crystals through AR mobile application is effective. Based on Fig. 11, 100% of the respondents think that this way of learning crystals is effective.

IV. Development and System Design

The development of the project is involved several software such as Jmol, Blender, Adobe Photoshop and Unity. Jmol is computer software that is used to create the crystal composition. Blender is a free and open source 3D computer graphic software tools that is used in the project to create the 3D models of crystals and coloring the atoms. Other than that, Adobe

Photoshop is used for logo and interface design in the project. All of the media creation is combined with the augmented reality technology by using Unity and develop into mobile application. Fig. 12 shows the process of the media integration.

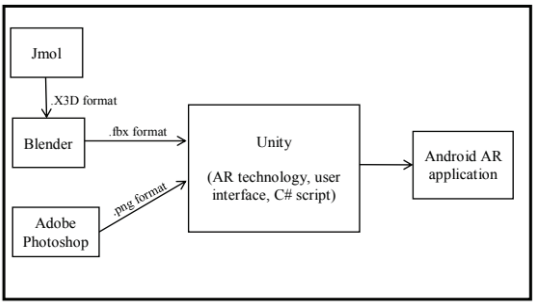

Fig. 12. Process of the Media Integration

Fig. 13 shows the system architecture of AR application. The system architecture briefly explains the overview of the application. As the project is an AR mobile application, so users need to give permission to access the mobile camera before using AR function. After that, the application processes the visual rendering and load the 3D models.

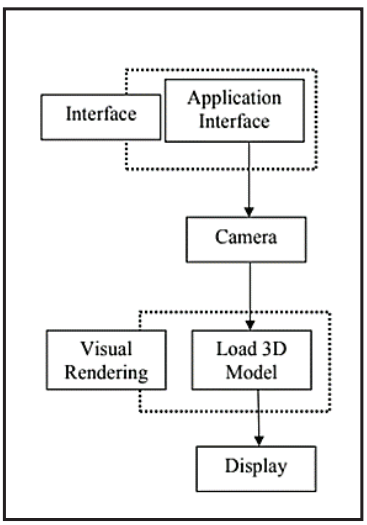

Fig. 13. System Architecture

Fig. 14 shows the GUI navigation flow diagram of the application. The navigation diagram is used to model the interactions that users have with the mobile application as defined in a single use case.

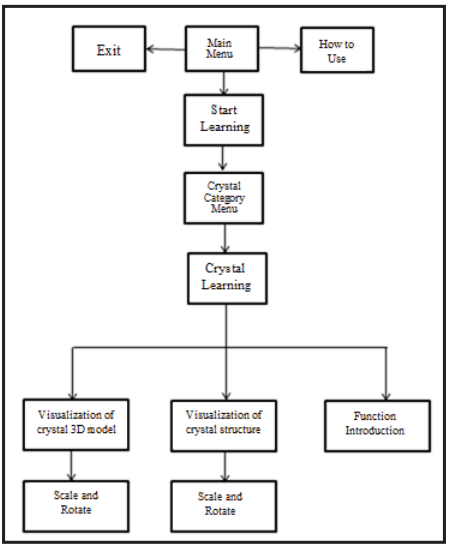

Fig. 14. GUI Navigation Flow Diagram

Fig. 15 shows the examples interface design of the menu page. There are total of six categories of crystals includes in the AR page according to suggestion of expert on popularity among public. After user selects one of the categories from crystal menu, the scene as shown in Fig. 16. In this page, user can select on the crystal that interested to learn more about the information. Then, the user needs to give the permission of using phone camera before entering the AR pages.

Fig. 17 and Fig. 18 show the examples interface design of the AR pages. The scene shows in Fig.5 enable the user to view and interact with the crystal 3D model in augmented reality. Furthermore, the user can view and interact with the crystal 3D crystal structure model to learn the crystal composition. The visualization of the 3D models can help user to learn and understand the crystal knowledge in interactive and interesting way. The slide bars are used to scale and rotate the 3D model and user can click on the rotate button to let the model self-rotate.

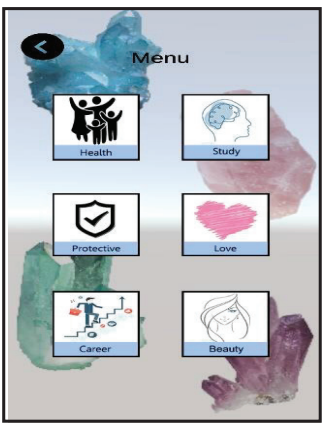

Fig. 15. Interface Design of Menu Page

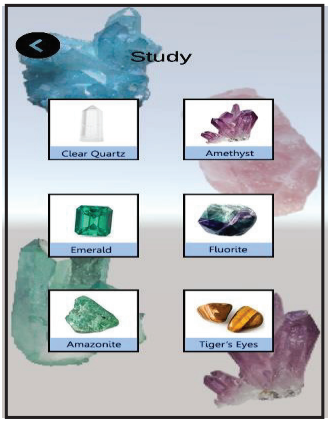

Fig. 16. Interface Design of Crystals Group Page

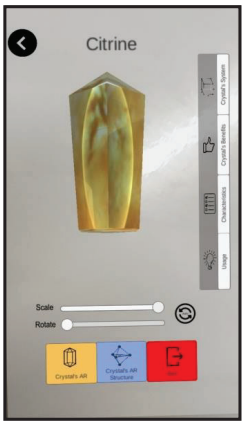

Fig. 17. Interface Design of 3D Crystal Model Page

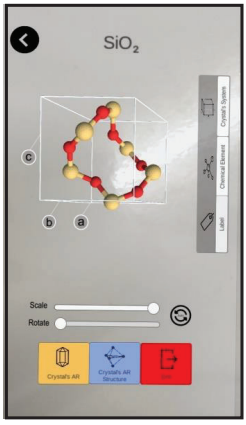

Fig. 18. Interface Design of 3D Crystal Structure Page

V. METHOD

User acceptance test and pre-post-test were carried out to evaluate the AR application and verify the effectiveness of augmented reality in learning crystals. There are two categories of respondents involved in the testing phase which are 5 experts from the gem and crystal field and 30 end users. The user acceptance test for expert help to evaluate the functionality, content, learnability, interface design of AR application and collect their valuable feedback. Besides, the user acceptance test for end user used to evaluate and compare the functionality, content, learnability, interface design of conventional learning material and the AR application. The user acceptance test given scale was from 1 to 5 which were strongly disagree, disagree, neutral, agree and strongly agree. Before user acceptance test for end user conducted, the pre-test and post-test were carried out among them to test the effectiveness of conventional learning and AR learning.

Fig. 19 shows the test design for the expert test while Fig. 20 shows the test design for the end user test. For the expert test, the apk file and user acceptance test form of the Crystal AR application was delivered to the expert via Google Drive link. A short briefing about the Crystal AR project was given to the experts before testing the application. Then, each of the experts was given some time to explore and test the AR application. The user acceptance form was distributed to experts for evaluation purpose after finished the application testing.

Besides, the end user test included pre-test, post-test and user acceptance test. Firstly, Google Drive link was given to the 30 respondents to download the learning material and *.apk file*. They were given 15 minutes to read through the learning material before answer the pre-test. After the pre-test, the respondents were given 5 minutes to download and install the AR application. Then, 15 minutes was given to the respondents to learn the crystal knowledge through the application and another 10 minutes for them to answer the post-test. Lastly, the end user acceptance test form was provided for them to response.

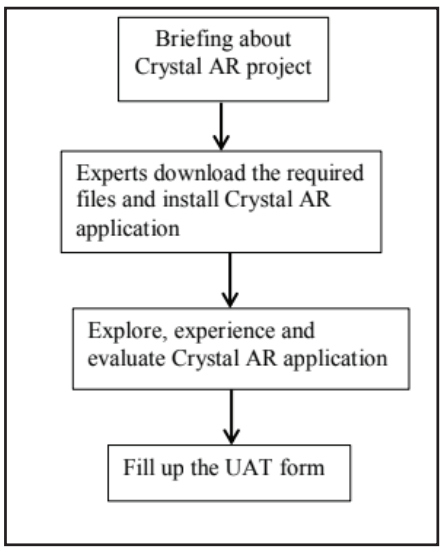

Fig. 19. Test Design for Expert Test

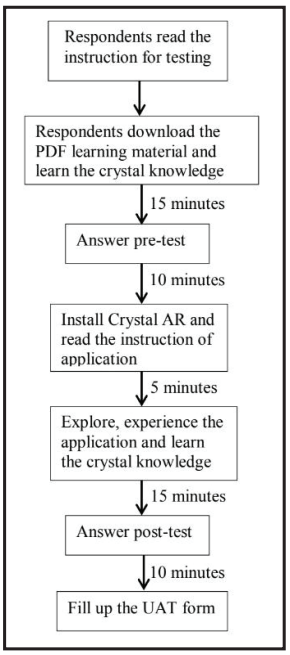

Fig. 20. Test Design for End Usert Test

VI. Result and Discussion

A. Expert Test Result

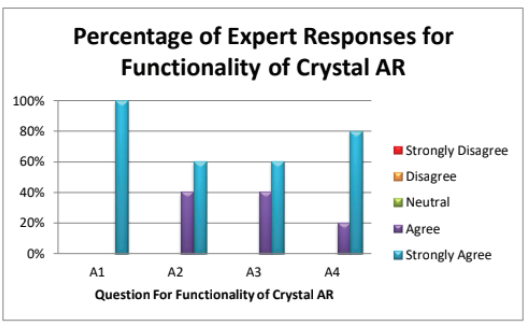

Fig. 21. Percentage of Expert Responses for Functionality of Crystal AR

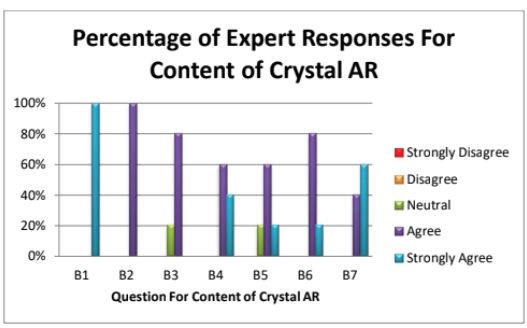

Fig. 22. Percentage of Expert Responses for Content of Crystal AR

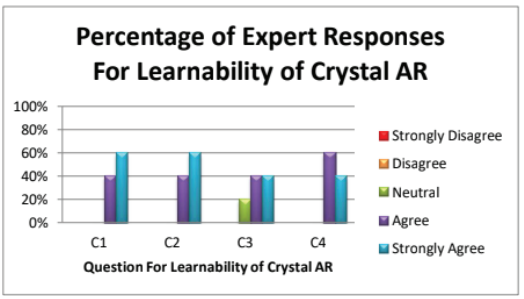

Fig. 23. Percentage of Expert Responses for Learnability of Crystal AR

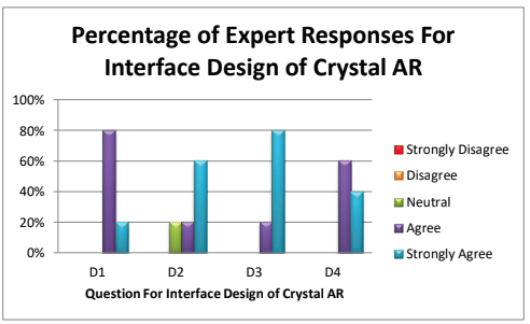

Fig. 24. Percentage of Experts Response for Interface Design of Crystal AR

Fig. 21 to Fig. 24 illustrates the result of user acceptance test for expert. The graphs shown clearly states that most of the experts give a positive response with strongly agreed and agreed to the functionality, content, learnability and interface design part questions of user acceptance test. One of the experts (20%) responds neutral for the crystal chemical knowledge related questions in content part because she is crystal shop owner and does not have related experiences. Based on the graph result analyzed, AR application is suitable for user to learn the crystal's knowledge effectively.

B. End User Test Result

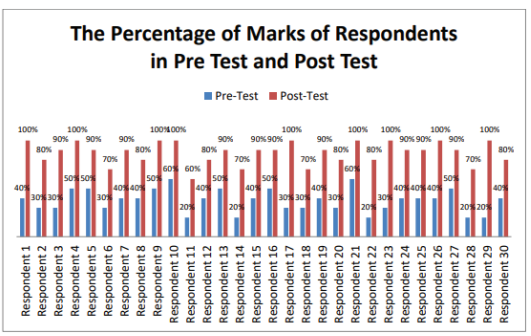

Fig. 25. The Percentage of Marks of Respondents in Pre-test and Post-Test

Fig. 25 illustrates the results of 30 respondents in pre-test and post-test. In overall, the post-test (AR application) marks of respondents are higher than pre-test (conventional learning) marks. The pre-test and post-test results have proved that the Crystal AR application is more effective than conventional learning material in learning crystals.

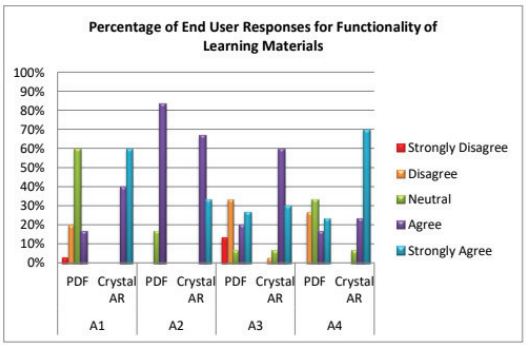

Fig. 26. Percentage of End User Responses for Functionality of Learning Materials

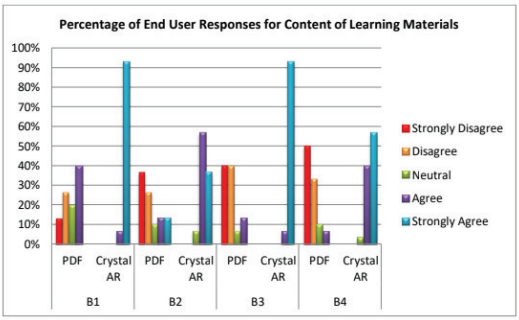

Fig. 27. Percentage of End User Responses for Content of Learning Materials

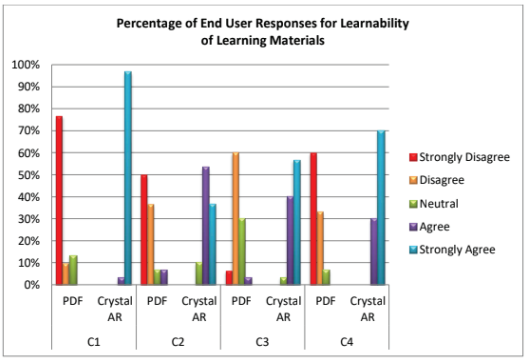

Fig. 28. Percentage of End User Responses for Learnability of Learning Materials

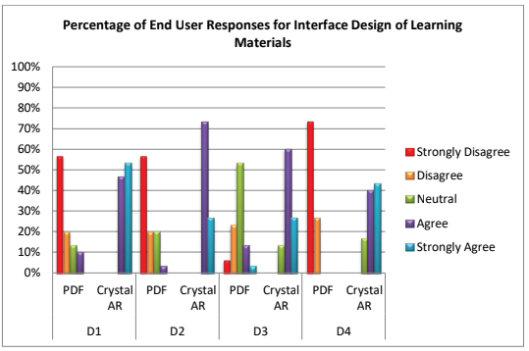

Fig. 29. Percentage of End User Responses for Interface Design of Learning Materials

Fig. 26 to Fig. 29 illustrates the result of user acceptance test for end user. The aim of the user acceptance test was to compare the functionality, content, learnability and interface design between the conventional learning (PDF) and AR application. Overall, the functionality of AR application is better than the conventional learning material based on the graph and result analyzed. In addition, the content of AR application is more understandable, clear, attractive and complete. The learnability of Crystal AR application is better and the interface design of Crystal AR application is more attractive and comfortable to use if compared to conventional learning material. In short, the functionality, content, learnability and interface design of AR application is better than conventional learning material (PDF).

In a nutshell, the purpose of the testing phase is to evaluate the user acceptance and effectiveness of augmented reality in learning the crystals compared to conventional learning methods. Besides, the testing also aims to evaluate the functionality, content, learnability and interface design of the Crystal AR application. The expert test result has proved that the content of Crystal AR application is suitable for the user to learn crystal's knowledge. The pre-test and post-test results have proved that learning crystals by using augmented reality is effective than conventional learning methods. From the result of end user acceptance test, the functionality, content, learnability and interface design of Crystal AR application is better than conventional learning material. The result showed that the user acceptance of augmented reality in learning the crystals is high.

VII. Conclusion

In conclusion, AR learning is effective than conventional learning method. The visualization of crystal model and crystal composition enable the students to learn crystal in interesting and effective way. Thus, it is suitable for students as learning tool to improve crystal knowledge.

Acknowledgment

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