A Case Study on Augmented Reality Applications for Chemistry Subject using Heuristic Evaluation

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Abstract— Augmented Reality (AR) has been acknowledged as a method that is effective in learning and becomes complementary to conventional learning, especially for Chemistry subjects. However, chemistry textbooks only consist of images and formulas; thus, students have difficulties understanding the concept, which may lead to misconceptions in understanding the topic. Therefore, this research focuses on developing and designing an Augmented Reality application for Chemistry subjects since no specific guidelines in developing an AR for education, especially for Chemistry. This paper aims to study the current heuristic guidelines and evaluating the existing Augmented Reality application for Chemistry subjects in order to determine the problem using Heuristic Evaluation. Kubu AR Kimia T5 was chosen as the existing application to be used in the Heuristic Evaluation process because Heuristic Rules are used by multiple researchers. The improvement of AR application developed based on the evaluation received. A custom set of the improvements heuristic principles was developed in this study and as a new guideline in designing other AR applications for Chemistry subjects in the future. In a conclusion, user acceptance tests take place to measure the effectiveness of AR using Heuristic Evaluation. The AR application that was developed is part of the educational tool in learning Chemistry subjects in high school and assist in learning and teaching methods to provide a better understanding of learning chemistry.

Index Terms—Augmented Reality (AR), Chemistry, Heuristic Evaluation.

I. INTRODUCTION

Augmented Reality (AR) technology with additional multimedia elements has been proposed to enhance interest in learning science. The potential of AR in the educational area has been proven in previous studies to implement this technology in an environment of education or real classroom environment. The AR is a computer-generated system that allows the user to see the digital objects in the real-world environment. In fact, AR has been acknowledged as one of the effective learning methods indirectly becoming a complementary to the traditional learning particularly in Chemistry subject [2]. Moreover, AR is an advanced technology that enables users to interact with virtual and real world in real time applications that bring more natural experience, raises attention and motivation of students with a high potential to enhance the learning experience [1].

The AR has been known as a method that is effective in learning and becomes a complementary to conventional learning especially for Chemistry subject [3]. This study focuses on the Chemistry subject, based on the Chemistry Textbook Form 5. A case study has been conducted on existing AR application used for Chemistry textbook for Form 5 and is evaluated through Heuristic Evaluation to identify problem and develop a new high-fidelity prototype.

II. RELATED WORK

The previous study has discussed how heuristic evaluation techniques are implemented in designing the Augmented Reality application.

A. Adapting Usability Heuristics to the Context of Mobile Augmented Reality

Selection of the application through Apple App Store with search string "augmented reality home design" and narrowing the numbers from 14 to 7 applications which are excluding the applications that did not update within a month in order to focus on the active projects. The apps selected this way were: IKEA Place, Houzz Home Design Renovation, Interior Define AR, Stresslesshome, Graham Brown Design Renovation, and Sayduck. The common goal of the AR home design apps is to enable the user to view virtual objects (e.g. furniture, wallpapers, and tiles) in a physical environment to get a sense of how it would look in real life.

All the applications selected were analyzed thoroughly using the following questions:

Q1: How users interact with the AR objects?
Q2: What kind of information is presented on the mobile screen and how?
Q3: What aspects of the app are well designed?
Q4: What are the prominent usability issues?

Then, mapped each feature and issue identified in those questions to the Nielsen's 10 Usability Heuristics. This served as groundwork to the first draft of interpretation of Nielsen's heuristics in AR home design apps.

1: Visibility of system status
2: Match between system and the real world
3: User control and freedom

4: Consistency and standard
5: Error prevention
6: Recognition rather than recall
7: Flexibility and efficiency of use
8: Aesthetic and minimalist design
9: Help users recognize, diagnose, and recover from errors
10: Help and documentation

The prominent findings are that many usability issues in AR home design apps are associated with the current limitations of AR technology. These technological limitations can affect usability. When developing an AR mobile app, identifying technological limitations and taking them into consideration during the design process is critical. Further, because mobile AR is still an emerging technology, most AR app users should be considered as novices. several actions such as surface detection or object manipulation (i.e. interactions with virtual 3D objects on a 2D space) can be confusing [4].

Therefore, when developing an AR mobile app, identifying technological limitations and taking them into consideration during the design process is critical. It is important to show the users how to use the technology and how to interact with the objects with gestures. The mapping to Nielsen's heuristics is specific to AR mobile home design apps and they could be used to establish more general heuristics and guidelines about mobile AR design. To evaluate their validity, more analysis on other applications is needed and a user study where UX designers use the heuristics to design or evaluate AR home design interfaces could be done in future work.

The goal of this research was to interpret Nielsen's 10 Usability Heuristics in the context of AR home design mobile apps. Six AR home design apps from the Apple App Store were analyzed to determine their well-designed features and usability difficulties, which were then mapped to Nielsen's criteria. This project is a first step toward developing more comprehensive heuristics and recommendations for the creation of mobile AR apps.

B. Heuristic Evaluation for Games: Usability Principles for Video Game Design

The paper introduces a new set of heuristic for evaluating the usability of video games, the first design principles that focus on the game usability, which is based on structured analysis of usability problems in various of games covering several major genres. The researcher believes that a custom set of design principles are needed in order for heuristic evaluation to performed in determining the usability problems in video games. The approaches used in this paper more closely aligned with Dykstra, who suggests that heuristic can be developed for specific software categories by evaluating existing product and developing principles that describe the usability problems found. The steps used in the evaluation process as follows:

Step 1: Identify Problems in Games Reviews
Step 2: Develop Categories that Group Problems
Step 3: Develop Game Heuristics

Five evaluators that had significant experience in playing video games and also had formal training in carrying out usability evaluations recruited. The evaluators were given a time to spend to play the game, then inspection process take place to identify instances, which is did not adhere to the principles outlined in the heuristic. They need to write the problem on the form, give severity rating to each problem and completed an open-ended questionnaire at the end of the study.

The evaluation provides initial insights into how successful the heuristics were at meeting these objectives. People were able to find a wide range of problems, and they found multiple problems with the heuristics developed. Researcher believes the results provide enough evidence to conclude that the heuristics are well suited to uncovering important usability problems in the game context [5].

The primary purpose of this research was to create heuristics that may be utilized to specialize the video game usability inspection process. There are three goals that are intertwined. First, to give comprehensive coverage of usability issues that arise in a wide range of games. Second, the heuristics must be simple to implement for those who are familiar with usability concepts and have some prior experience working with games. Third, the researchers hoped that people would be able to utilize the heuristics to spot real issues that could influence game usability.

C. Heuristic Evaluation for Gameful Design

Despite the recent emergence of various gameful design methodologies, designers still lack conventional evaluation tools. There are no recommendations for evaluating the introduction of gameful design components into a system, despite the fact that various studies have explored the success of gameful applications by researching their users. For other established areas of UX, heuristic evaluation methods are commonly used.

The heuristic evaluation methods are quick and low-cost tools for identifying and addressing design issues early in a project. Heuristic evaluation methods are not intended to replace user tests, but rather to complement them: while heuristic evaluation can be used early in a project, user tests are used later to uncover issues that were missed previously.

By proposing a new set of rules for heuristic evaluation of gameful design in interactive systems, this study aimed to contribute to the HCI community. The first step would be to examine a variety of gameful design frameworks and methods in order to determine which dimensions of motivational affordances were most prevalent. Then, create a set of heuristics for each of the dimensions that have been discovered. The heuristics provide a new approach of assessing gameful user experiences such as "it's the first tool of its sort", which focusing on analyzing gameful design using intrinsic and extrinsic motivational affordances.

There are a number of heuristic assessment models for game design. So far, no heuristics set for gameful design is available. Some criteria for judging games or playability could be applied to gameful apps, but not cover the entire variety of motivational affordances.

Some of the existing gameful design methods, namely Octalysis, HEXAD, and Lens of Intrinsic Skill Atoms, suggest procedures to evaluate an existing system. Because they lack a coherent set of design heuristics with concise descriptions that might be swiftly evaluated by an outside expert, they are less appropriate for use as a separate evaluation tool by an independent quality control team. Methods used in this study as follow:

Method 1: Review of Gameful Design Methods
Method 2: Gamification Heuristic

A set of 28 gameful design heuristics aimed at enabling experts to evaluate a gameful system created to identify design gaps. By categorizing the heuristics according to motivational type (intrinsic, extrinsic, and context dependent motivation), this model contributes to raising designers' awareness of the different motivational types. Furthermore, the heuristics are written in a concise form to enable expert evaluation.

This study has proposed a fresh and comprehensive methodology that spans a broad range of motivational affordances by deriving a set of heuristics from the common characteristics of motivational affordances used by different gameful design techniques. Furthermore, by categorizing heuristics by motivational type (intrinsic, extrinsic, and context dependent motivation), this approach helps designers become more aware of the many motivation kinds. The heuristics are provided in a concise manner to allow expert judgement [9].

III. METHOD

In order to satisfy the objective of this study, a qualitative and quantitative research were conducted. Qualitative research is the most appropriate to apply for small samples because it gives in detailed and complete description and analysis of the project presented [6]. Qualitative research method is implemented since the focus group have been used at the beginning of the project. In the testing phase, quantitative data is collected using the Likert Scale questionnaire, each item is given a numerical score (1 to 5) so that the data can be analyzed quantitatively.

Kubu AR Kimia T5 uses Heuristic Evaluation and is applied to identify issues when using the application. Subject matter expert (SME) and students were involved in the evaluation process. The heuristic rules adopted in this study is from Kumar and Goundar [7], Machado Neto and Pimentel [8] and David [5]. There are several rules described regarding on developing AR for education and the following are the adopted rules:

Rules 1: Match Between System and Real World
Rules 2: Consistency and Standards
Rules 3: User Control and Freedom
Rules 4: 3-Dimensional Model
Rules 5: Multimedia Elements
Rules 6: Visual Representation
Rules 7: Provide Instruction, Guide and Help
Rules 8: Content

The existing application chosen was Kubu AR Kimia T5 because it was developed based on the Chemistry's Textbook form 5. This application developed using Unity Engine and available on the PlayStore only. There is no access for Android user.

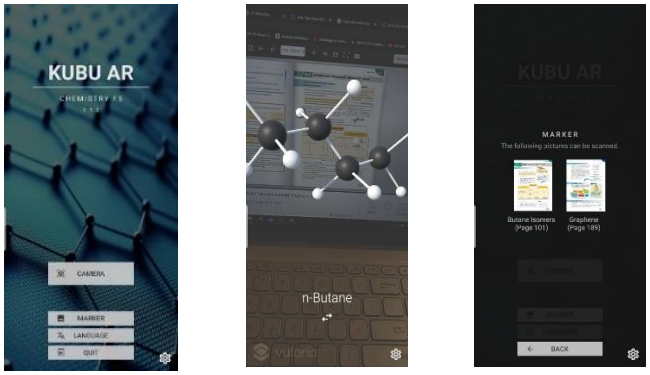

Fig. 1. Kubu AR Kimia T5 Interface.

TABLE I
PARTICIPANT'S PROFILE

	SME	Students
Participants	6	10
Gender	Female: 5 Male: 1	Female: 6 Male: 4
Occupation	Teacher: 4 Substitute Teacher:1 Pharmacist Assistant: 1	Students
Education	Bachelor's Degree in Chemical	
Chemistry Students		Yes

As shown in Table 1, there are two focus group conducted in this study which are with Subject Matter Expert and high school students. The evaluation process conducted through direct Phone call, WhatsApp application and Google Meet platform due to the current pandemic situation that limits for face-to-face meeting. A semi-structured of "one-on-one" interview is conducted with a subject matter expert and a group discussion for students.

Open-ended question is conducted based on the specific topic discussed. Interviewer modifies questions to match with the participant's specific experiences. All the questions involved in the interview developed based on heuristic principles adopted. For one-to-one session, each interview conducted with the teacher took 30 to 60 minutes for each participant. As for the students, it took about one hour to finish the session. A briefing given to all the participants before focus group evaluation conducted. During the briefing process, the participants allowed to ask any questions related to the discussion topic.

A. *Focus Group – Interview*

Data from the Heuristic Evaluation process conducted for both groups is summarized in Table 2.

TABLE II
PROBLEM ENCOUNTERED

Heuristic		**Problem Encountered**	
Rules 1: Match Between System and Real World		Menu button confusing	
Rules 2: Consistency and Standard		Icon led to wrong page	
Rules 3: User Control and Freedom		No home and back button	
Rules 5: Multimedia Element		No video and audio included	
Rules 7: Provide Instruction and guide		Confusing, No explanation about the model used.	
Rules 8: Content		The content is not sufficient.	
Features	**Problem**	**Problem Rating**	**Design Change**
3D Model	Without description	Not Sufficient	Give the explanation in text
Audio	Not included		Provide the explanation in the form of audio recorded
Icon	Confusing the users	Annoying	Using icon that are represent the function
Variables	**Problem**	**Problem Rating**	**Design Change**
Visual representation	No explanation	Confusing	Provide explanation in details
Content	Not sufficient	Unsatisfied	Provide more related explanation to give better understanding about the topic

TABLE III
CONCLUSION FROM EVALUATION

Heuristic	**Apply**
Rules 1: Match Between System and Real World	No
Rules 2: Consistency and Standard	No
Rules 3: User Control and Freedom	No
Rules 4: 3-Dimensional Model	Yes
Rules 5: Multimedia Elements	No
Rules 6: Visual Representation	Yes
Rules 7: Provide Instruction and Guide	No
Rules 8: Content	No

Table 3 indicate the conclusion has been made from the evaluation conducted through focus group. From all the eight rules, there are only two rules applied for the current application which are rule number 3 which is 3D Model and rules number 6, Visual Representation. The others 6 rules are not applied in this application.

B. Design Improvement

Based on the data received from the Heuristic Evaluation conducted, the improvements to the current application have been developed. The new prototype of Augmented Reality application would cover more related content and provide more 3D models. The 3D model appears with the indicator as explanation on the model displayed to avoid any confusing for the user.

On every page in this application, there is a back and home button to make it easy for user to navigate the system freely while exploring the application.

More multimedia elements are included in this application such as video and audio. Home and Back button is added to the application so that user will find it more convenience to use. Designing the menu button is considering the color used and suitable for students. This application was separated into two parts with two different markers which are Chemistry textbook page 73 and 74.

The selection of this Alkane and Alkene topic was based on suggestions from the teachers during the interviews. These two topics contained sub elements of the chemical compound. There will be various of 3D models needs to be presented in each compound. They recommended that this topic be used as content in this AR application since it appears to be well-suited to visualization in the form 3D representation that can help students to get more detailed on how the model looks like.

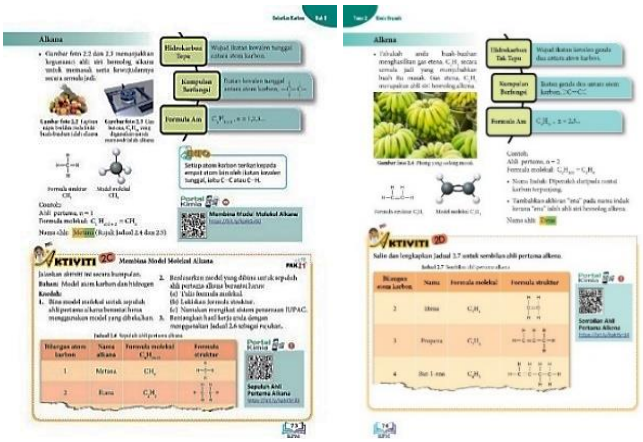

Fig. 2. AR! CarCom – Marker

Fig. 2 show two images that have been set as marker for users to scan through a Blippar AR application in the smartphone. Blippar is available on Google Play Store and Apple AppStore.

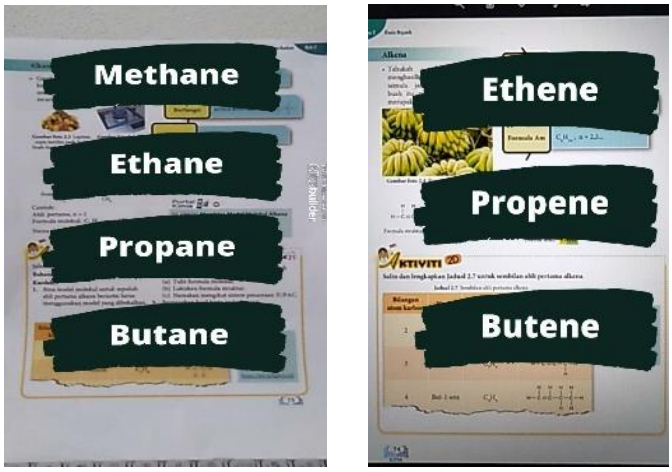

Fig. 3. AR! CarCom – Alkane and Alkene Home Interface

In Fig. 3, in each interface there is a chemical compound listed for each Alkane and Alkene family.

Fig. 4. AR! CarCom – Information Interface Pages

As shown in Fig. 4, in term of content, the improvements on the explanation displayed in the AR application, detailed information for each chemical compound available in the new application developed. The explanation also comes with the audio acts as a narration to give more options to the user while using the application.

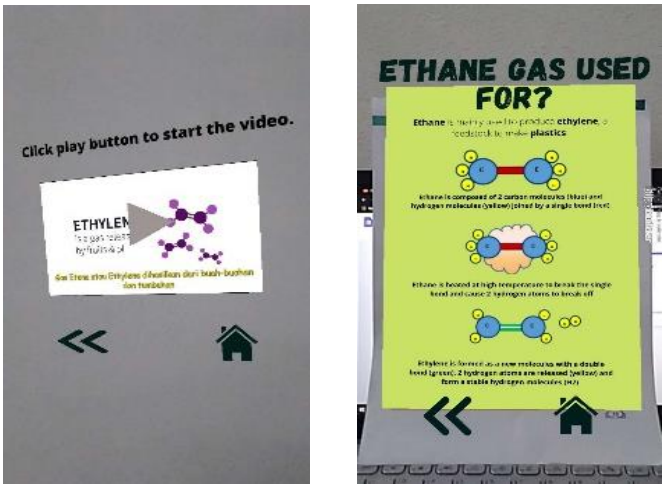

Fig. 5. AR! CarCom – Extra Info Interface

As shown in Fig. 5, extra information also part of the new features in the application. In this part, there are related information or extra knowledge provided that are not available in the textbook. This information gives a bigger a picture to the students on how the chemical compound used in the industry.

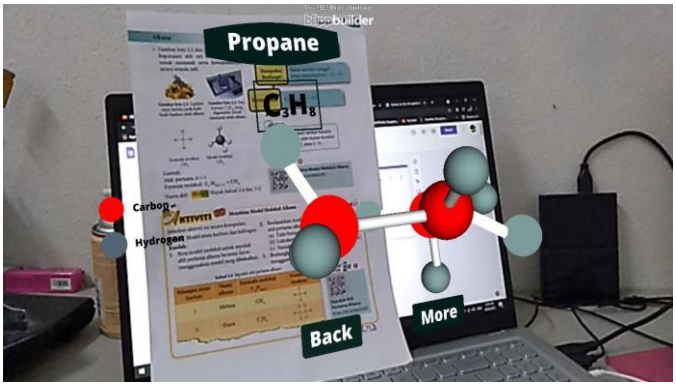

Fig. 6. AR! CarCom – Propane 3D Interface

As can be seen in Fig. 6, this page displayed the 3D model of the Propane compound, users can move forward the camera to the object so that the model appears bigger and more detailed and students also can get to visualize the object in deeper.

IV. RESULT

As a result of the findings from the interviews, a proposed set of questions was developed. This set of questions developed is based on the appropriate heuristic rules adopted to be used to evaluate the heuristics for AR! CarCom application. This set of questions is based on a pre-evaluation analysis conducted prior to the development of system improvements.

In designing and developing any education AR application in the future, developer is recommended to consider this set of questions to use in evaluation process.

TABLE IV
RESULT FROM EVALUATION

Suggested a set of Applicable Questions	
Rules 1: Match Between System and Real World	Q1: Is the icon/button meaningful, identifiable, and sufficiently visible? Q2: Are icons clear and familiar? Q3: Are the menu buttons ordered in the most logical way? Q4: Is there something that user don't understand?
Rules 2: Consistency and Standards	Q1: Users still can control the model if the marker was removed? Q2: All the icon buttons lead to the correct function of the page? Q3: Each interfaces have consistent icon design? Q4: Uses of color displayed on screen was consistent?
Rules 3: User Control and Freedom	Q1: Is there any way to inform user about where they are and how to undo their navigation? Q2: Users can move backward and forward among all the pages in the application? Q3: Users still can control the model if the marker was removed?
Rules 4: 3-Dimensional Model	Q1: 3D model used appropriate to the topic? Q2: Does indicator given on the 3D model helps to distinguish the elements contained in the chemical compound? Q3: Are the 3D models used presented in the right way. Q4: Did the 3D models help in understanding chemistry better?
Rules 5: Multimedia Elements	Q1: Appropriate multimedia elements such as image, video and audio help in terms of delivery a topic. Q2: Explanation in the form of audio will help students to understand better? Q3: Does the use of images and multimedia content add value? Q4: Are images well sized? Are they understandable? Is the resolution appropriate?
Rules 6: Visual Representation	Q1: What is your opinion about the menu on the screen? Q2: How difficult is reading character on the screen? Q3: Menu button used fit logically into categories that have readily understood meanings? Q4: The application was well designed visually.
Rules 7: Provide Instruction, Guide and Help	Q1: Any instruction or guide included in the application? Q2: Are instruction or guide helps while using the application? Q3: Are the instructions given easy to understand? Q4: The instructions make the application easy to used?
Rules 8: Content	Q1: Does the content in the application related to the topic in textbook? Q2: Content provided can increase students' knowledge in studying chemistry subjects. Q3: Do you think this AR application is helpful in the Chemistry learning process? Q4: Is the content enough for students to use as a tool in learning Chemistry?

Set of questions based on the heuristic as shown in Table 4 is a set of questionnaires that can be used for any AR application developments for educational purposes in the future.

In the user testing phase, quantitative data collected through a set of heuristic-based questionnaires. Likert Scale questionnaire used scale from 1 to 5 where each question has a different indicator. New AR applications developed have been recorded in the form of video and uploaded on YouTube. The link to the video has been attached in the Google Form where the Likert Scale questionnaire will be distributed.

TABLE V
RESULT FROM EVALUATION

Rules 1	**Q1**	**Q2**	**Q3**	**Q4**
SME (Mean)	4.33	4.5	4.5	4.5
Students (Mean)	4.7	4.7	4.66	4.33
Rules 2	**Q1**	**Q2**	**Q3**	**Q4**
SME (%)	Yes (100)	Yes (100)	Yes (100)	Yes (100)
Students (%)	Yes (100)	Yes (100)	Yes (100)	Yes (100)
Rules 3	**Q1**	**Q2**	**Q3**	
SME (Mean)	4.33	4.33	4.33	
Students (Mean)	4.7	4.5	4.7	
Rules 4	**Q1**	**Q2**	**Q3**	
SME (Mean)	4.83	4.6	4.5	
Students (Mean)	4.7	4.7	4.7	
Rules 5	**Q1**	**Q2**	**Q3**	**Q4**
SME (Mean)	5	4.83	4.83	4.66
Students (Mean)	4.8	4.7	4.5	4.7
Rules 6	**Q1**	**Q2**	**Q3**	**Q4**

SME (Mean)	4.5	4.5	4.66	4.5
Students (Mean)	4.5	4.6	4.4	4.6
Rules 7	**Q1**	**Q2**	**Q3**	**Q4**
SME (%)	Yes (83.3) No (16.7)	Yes (100)	Yes (100)	Yes (100)
Students (%)	Yes (100)	Yes (100)	Yes (100)	Yes (100)
Rules 8	**Q1**	**Q2**	**Q3**	
SME (Mean)	4.33	4.66	4	
Students (Mean)	4.7	4.6	4.5	

The evaluation process for the testing part was conducting through the Google Form. The link was shared through a WhatsApp group platform where students that participate in this study were gathered. Anything that are not clear or confusing, they can directly voice out in the group chat.

The data gathered is analyzed based on the value of mean for each question. As can be observed in Table 4, all the questions given get the mean value bigger than 4, indicating that the participants were satisfied with the new improvements of the AR application developed.

The prominent findings from heuristic evaluation conducted would be the positive feedback from the participants on the new high fidelity prototype AR developed compared to the existing application in the textbook as can observed in Table 5. It is proven that by considering set principles in developing an Augmented Reality application especially for Chemistry, a better quality of application is produced.

TABLE VI
CONCLUSION FROM EVALUATION

Heuristic	**Apply**
Rules 1: Match Between System and Real World	Yes
Rules 2: Consistency and Standard	Yes
Rules 3: User Control and Freedom	Yes
Rules 4: 3-Dimensional Model	Yes
Rules 5: Multimedia Elements	Yes
Rules 6: Visual Representation	Yes
Rules 7: Provide Instruction and Guide	Yes
Rules 8: Content	Yes

As can observed in Table 6, there are no rules that have been violated while developing and designing this AR!CarCom application resulting a satisfaction to consumers when using the application. The set of questions that have been built in each rule also can be considered as an appropriate set of question to use for future guidelines. The results also show that this application is suitable to be used as a learning material in studying chemistry subjects especially in the topic of carbon compounds.

V. CONCLUSION

This research aimed to determine the guidelines/rules that should be considered in developing an Augmented Reality application for Chemistry subject, as well as to know how Heuristic Rules can help improve the AR application during the development phase.

Based on the qualitative and quantitative analysis obtained from the Heuristic Evaluation through two focus groups, it can be concluded that the rules/guidelines adopted can be new improved guidelines that can be used to develop other Augmented Reality (AR) applications in education especially for Chemistry subjects. This is because based on the analysis made on the new prototype developed, the result indicates that they are satisfied with the product and there are no rules that have been violated in designing this application. The application developed does not violate any of the rules, as shown in the analysis phase, and the majority of the participants were satisfied with the product.

Without using any guidelines in designing and developing an AR application for educational purposes, problems will arise when the users use the product. Practitioners should consider following rules/guidelines in designing an AR application to ensure a high quality of product will be developed. The findings from the study show that a better application AR can be developed from practicing the guidelines when designing the application.

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