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"ChemFUN" Android Application to Explore Students' Understanding of Chemical Representation on Matter Topic

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Abstract

This study aims to develop an android-based application to explore students understanding of chemical representation on matter topics. This study used a DDD-E development model as a research method, consisting of deciding stage, designing stage, developing stage, and evaluating stage. The deciding stage begins with analyzing the content and the software used to develop it. The designing stage consists of drawing a flowchart and the storyboard. Then, in the developing stage, the application was developed based on the flowchart and the storyboard. The last is evaluating stage, which involves five expert judges reviewing the application. The result shows that the "ChemFUN" Android application is compatible only with the Android operating system. However, there are many buttons the user can interact with. In guided inquiry, the materials show the chemical multiple representations view and the interconnections between macroscopic, microscopic, and symbolic views. The review result shows that the final average score on the content quality is 3.64, followed by the language category with an average score of 3.65 and the design category with an average score of 3.60. Although it still has a low audio, spelling, and grammar score, it has been revised. The average for all categories is 3.63, which is very good, indicating that the "ChemFUN" Android application is ready to be used in the learning activity to explore students understanding of chemical representation on matter topics. Also, this kind of research can be done with different chemistry topics, whether in National Curriculum or Cambridge Curriculum.

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Introduction

In the 21st century, technology development is rapidly increasing, becoming essential to all human beings (Nugraha et al., 2020), especially in education. Technology nowadays impacts the educational framework, the way of teaching, and also learning. Different types of media services, teaching and learning software, and new hardware solutions are becoming increasingly important in education and the workplace due to the enormous technological changes (Schuster et al., 2016). Several technologies in this era have a powerful side effect on education, such as computers, laptops, cell phones, games, interactive media, and the internet. One of the following technologies close to the current generation is smartphones. A smartphone is a mobile phone that, like a computer, can do various activities and calculations. It is gradually replacing older mobile phones. It has a sophisticated operating system, many helpful apps, and a high-speed data transmission capacity (Anshari et al., 2017). Virtually every student from Primary to Senior High School uses a smartphone for daily tasks (Widodo et al., 2020).

Smartphone users have rapidly increased in this era across all socioeconomic and age groups (Fook et al., 2021). Massive smartphone users can lead to its addiction. The addiction to smartphones, especially for teenagers, can bring a lousy impact on their education. They tend to play social media, watch random videos on youtube, and even play games all day instead of learning something useful for their education. Besides all the adverse effects, a smartphone can also assist students in learning. Students nowadays have easy access to information and knowledge via smartphones. They can engage in social media and receive rapid responses from classmates, teachers, and even experts (Anshari et al., 2017). Hence, using smartphones can support learning a particular subject, which is chemistry.

Chemistry is an applied science and a professional language used to explain complex natural processes via the interaction of representations, from chemical names, equations, formulae, and pictures (Markic & Childs, 2016). In addition, chemistry is a science-rich in notions and chemical phenomena, varying from the simple to the complex and concrete to the abstract (Eliyawati et al., 2020). Each chemical phenomenon has three levels of representation: macroscopic, microscopic, and symbolic (Gkitzia et al., 2011). The macroscopic representation is the observable chemical phenomenon, such as laboratory activities involving students' sense organs to recognize changes occurring during chemical reactions such as color change, odor release, and precipitation (Yusuf, 2020). The microscopic representation refers to the chemical phenomenon that naked eyes cannot see, such as atoms, ions, molecules, and compounds. Finally, symbolic representation refers to the chemical phenomenon represented by an image, video, animation, equations, and computational form.

Chemistry is considered a complex subject for junior high school students because it consists of many abstract concepts and objects that cannot be proven by their eyes (Tsaparlis et al., 2010). In addition, students tend to have a problem linking the macroscopic, microscopic, and symbolic (Tan et al., 2009). Especially for the microscopic level, while its concepts and components are regarded as true and real, they cannot be seen easily (Davidowitz & Chittleborough, 2009). Wright (2003) stated that many students lack mental models due to the microscopic level being disregarded compared to the macroscopic and symbolic levels of representation.

One effort to visualize abstract concepts and reactions at the microscopic level in chemistry is through a multimedia android application. Multimedia uses two or more integrated media types to input information into computer systems, such as texts, pictures, graphics, sounds, animations, and videos (Komalasari, 2019). It can display a wide range of information and features and construct a model that is not visible to the naked eye (Eliyawati et al., 2018). On the other hand, an Android smartphone is suitable for running and developing multimedia applications. It is supported by the fact that Android is a free open source platform, and all developers can freely create various Android applications (Ma et al., 2014).

The previous research is already developed an android application to help students learn chemistry. Astiningsih & Dwi (2020) develop and implement android media to construct students' motivation and metacognition ability on reaction rate topics. Saputra, Gürbüz, & Haryani (2021) also researched the development of Android-based animation for chemical elements and experiments. Another research was conducted by Eliyawati, Agustin, Sya'bandari, & Putri (2020). They develop “Smartchem” as an android application for learning multiple representations of the acid-base topic. Research from Putra, Asi, Anggraeni & Karelius (2020) showed the Android-based chemistry learning media for simulating electrolyte and non-electrolyte solutions. Moreover, the research about Augmented Reality (AR) in the Android operating system was conducted by Irwansyah, Yusuf, Farida & Ramdhani (2018) on the topic of molecular geometry. Another research has been conducted by Cahyana et al. (2017) that develops mobile game-based learning for high school students to learn chemistry. However, there is no research regarding developing an android application for junior high school students on matter topics to explore students’ understanding of macroscopic, microscopic, and symbolic representations. Therefore, an android application was needed to explore students’ understanding of chemical representations on matter topics. The lack of digital media to assist junior high students in learning chemistry need to be more developed. Therefore, this study aims to develop an Android application named “ChemFUN” to explore students' understanding of chemical representations on matter topics.

Method

The method that was used in this research is the developmental research method. Development research focuses on a given instructional product, program, process, or tool (Richey & Klein, 2014). The characteristics of development research are identifying general development principles or recommendations for specific situations. It is addressed in product design, development, and evaluation (Richey & Klein, 2014). This research method is suitable for the objectives of this research, which is to develop a “ChemFUN” android application.

This research used the DDD-E (decide, design, develop, and evaluate) development model adopted from (Ivers & Barron, 2002). There are four stages of development; (1) Deciding stage consists of determining the project goals and brainstorming the content of matter topics, especially the content related to multiple representations of matter topics. (2) Designing stage consists of drawing a flowchart, specifying the screen design, and creating a storyboard that covers macroscopic, microscopic, and symbolic representations. (3) Developing stage consists of the project's development, compiling any source of the image, video, graphics, and script to describe the multiple representations of the matter topic. (4) Evaluating stage consists of validating the project to gain a recommendation from experts.

The researcher created the “ChemFUN” Android application in an Android package or APK using Unity software and Android Studio on the computer. “ChemFUN” Android application can be accessed from any Android operating system device. Supervisors will supervise the final development of the “ChemFUN” Android application before the experts judge from chemistry content, language, and media. After “ChemFUN” goes through several revisions and suggestions, the application will be brought to the science teachers to get some recommendations and validation and review the students. In this study, five experts were chosen to assess and validate the game. The selection of experts is based on their proper educational backgrounds, as they are all chemistry graduates with expertise in the field of information and technology, as well as excellent English language abilities. All of the experts validated the application in chemistry content, language, and media.

The data was collected in the form of an experts' rubric. This rubric was adapted from Learning Object Review Instrument (LORI) (Leacock & Nesbit, 2007). It is often used to measure all kinds of media used in learning. This rubric consists of three indicators: chemistry content, language, and media. The scale is 1 to 4 to determine the quality of each aspect. The rubric also consists of blank spaces for feedback and suggestion. After the application was developed, the researcher distributed the rubric to the expert judgment via e-mail. The expert judgment then tests the application and fills the rubric. Finally, the researcher got the rubric results and started processing the data by counting the average of each aspect by the following formula:

$$\bar{X} = \frac{\Sigma x}{n}$$

(Wan et al., 2014)

The average got from the total score given by experts in each aspect and divided by five as the number of total experts. After the average of each aspect was counted, the deviation standard also can be counted by the following formula:

$$s = \frac{\sqrt{\Sigma (xi - \bar{x})^2}}{N - 1}$$

(Wan et al., 2014)

The data can also be classified whether it is good or not by looking at the Likert Scale criterion.

Results and Discussion

The development process is divided into four stages following DDD-E models:

1. Decide Stage

The first stage of development is deciding stage. In this stage, the researcher decided on the software used to develop the "ChemFUN" Android application and the chemistry topic raised in this study. This stage is described as follows:

a. Software to Develop The "ChemFUN" Android Application

Unity Software and Android Studio are used to develop the "ChemFUN" Android application. The minimum requirement to run Unity Software version 5.6 smoothly is Windows 7 or 10 with x64 architecture, DX10 – DX12 GPUs, 4 GB of RAM, and 3 GB of available storage. In other words, the Unity Software is still suitable for three-year-old laptops and PCs. The last software used to develop the "ChemFUN" Android application is Android Studio. The minimum requirement to run Android Studio is Windows 8 or 10 with x64 architecture, 8 GB of RAM, 8 GB of available storage, and 1280x800 minimum screen resolution. The leading software to develop the "ChemFUN" Android application is Unity Software, for Android

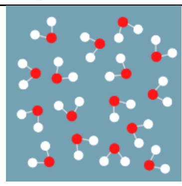
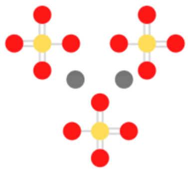
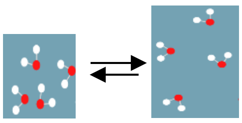
Studio to convert the project in Unity into Android Packaged (APK) file. Unity is not beginner-friendly because the users need to understand the basic programming in the C# language. The interface of Unity software is shown in Figure 1 below.

Figure 1. Unity Software Interface

b. Chemistry Topic of The "ChemFUN" Android Application

The Matter topic in Cambridge Curriculum was used in this research as the main idea of the "ChemFUN" Android application. The exact composition of the learning materials raised in the "ChemFUN" Android application consists of state of matter, pure substance, mixture, physical changes, chemical changes, separation method, and quiz. Here are some examples of content that is provided in the android application.

Table 1. Example of Chemical Multiple Representation on "ChemFUN" Android Application

No	Concept	Macroscopic Representation	Microscopic Representation	Symbolic Representation
1	Liquid			$H_2O(l)$
2	Compound			$Al_2(SO_4)_3(s)$
3	Physical Changes			$H_2O(l) \rightleftharpoons H_2O(g)$

2. Design Stage

The second stage of development is the designing stage. In this stage, the researcher designs the flowchart and the storyboard of the "ChemFUN" Android application. This stage is described as follows:

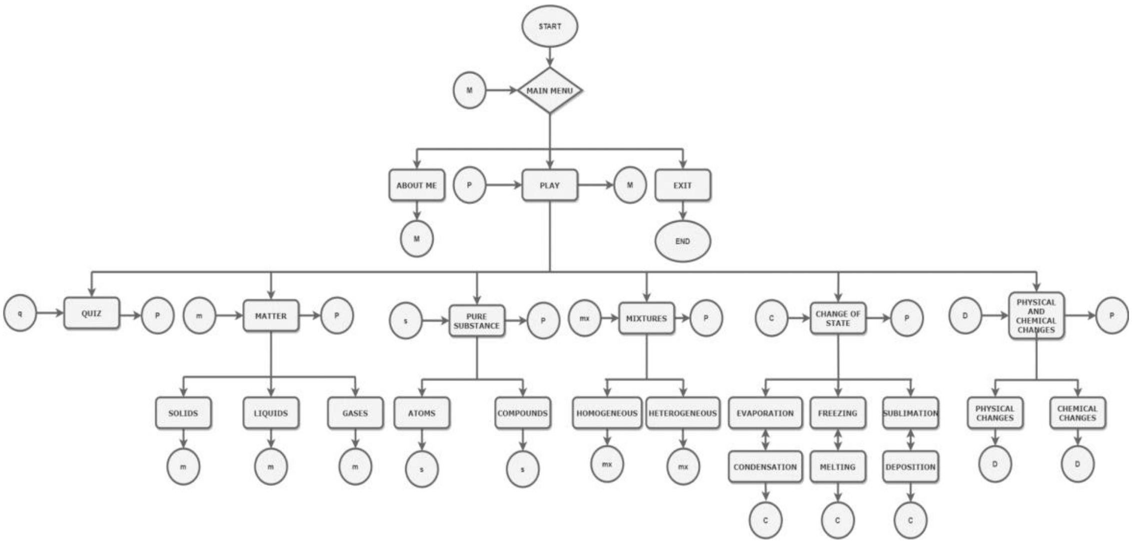
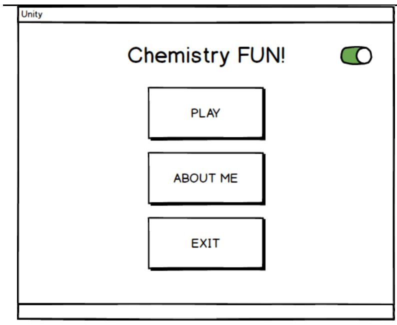
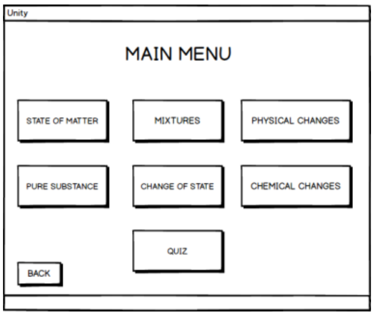
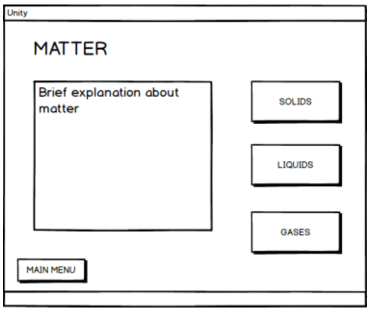


Figure 2. Flowchart

Here are some examples of the storyboard.

Table 2. Storyboard

Screen Design	Explanation
	1. This is the welcoming screen of the application. Four buttons can be clicked; the play button, about me button, exit button, and sound button in the top right corner. The title uses More Sugar Thin font, with a size of 108 in the Canva platform. The color of the title in the HEX code is #E17055 (red plume). The three-button below the title uses Bebas Neue font with a size of 70. For the buttons, the color in the HEX code is #2D3436 and #636E72 (black-grey). The sound button has a resolution of 110x110 with the color #7ED957 in the HEX code. The background uses white color, but there is a curvy line on the right, and left side, the color in the HEX code is #E17055, #FFFFFF, and #2D3436.

Screen Design	**Explanation**
	2. The main menu scene consists of many buttons to proceed into learning materials. The button's color is #2D3436 and #636E72 (black-grey), except for the quiz button, the color is #FF5757 (light red). The font used in this scene is More Thin Sugar for the title and Bebas Neue for the buttons, respectively, in 140 and 70 sizes.
	3. The matter scene consists of a brief explanation and three buttons that allow the users to proceed into the next scene. The font used for the title, buttons, and explanation is More Sugar Regular, Bebas Neue, and Glacial Indeference with 120, 70, and 50 sizes. The color of the text is all black, except white for the buttons.

3. Development Stage

The third stage of DDD-E is the development stage. In this stage, the researcher developed the Android application based on the deciding and designing stages. The results of the application are described as follows:

1) Welcoming Screen

At the beginning of the application, the welcoming screen will appear first, allowing users to choose whether they want to continue to the main menu, get to know the developer, or close the application. A toggle button is at the top of the screen for turning the music on or off.

2) About Me Screen

On this screen, there is some information regarding the developer. If the users want to get closer, they can go to this screen before going to the main menu.

3) Main Menu Screen

The main menu screen allows users to choose the topics by themselves. There are six topics; state of matter, change of state, pure substance, mixtures, and chemical and physical changes. In addition, there is a quiz if the users want to test their knowledge after learning all the topics. The button color of the topic and the quiz is different to make it easy to recognize. The main menu screen can be seen in Figure 3.

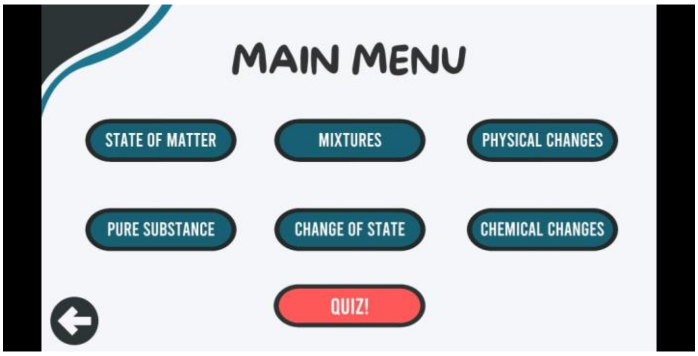


Figure 3. Main Menu Screen

4) Transition Screen

This screen will pop up before the users learn every topic. The main idea of the transition screen is to guide the user and give some apperception regarding the topic. Also, this screen comes with a conversation between two fictional characters. When the users finish reading the conversation, they can proceed into the topics by clicking the button.

5) State of Matter Screen

The state of matter screen consists of an explanation that matter is something that has mass and can occupy space. Three buttons can be clicked into a specific topic: solid, liquid, and gas. The state of matter screen can be seen in Figure 4 below.

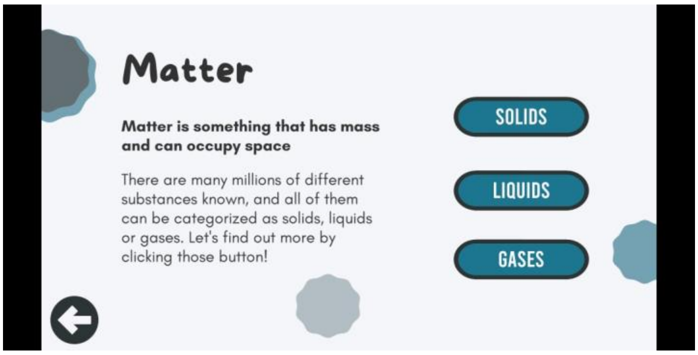


Figure 4. State of Matter Screen

6) Mixtures Screen

The mixtures screen explains that said mixtures are mixed physically, and the composition is not fixed. Two buttons represent the homogeneous mixtures and the heterogeneous mixtures that can be clicked. In addition, there is a separation method button in the top right corner, and it has an instruction that the button can be connected if the users do not know.

7) The Pre-Experiment Screen

The experiment for homogeneous mixture is making a sugar solution, and for heterogeneous mixture is making a sand mixture. Before the users go to the experiment screen, they need to know the molecular structure of each substance. The purpose of understanding the molecular structure is to prevent a misconception on the next screen because dots will represent the substance. The pre-experiment screen is shown in Figure 5.

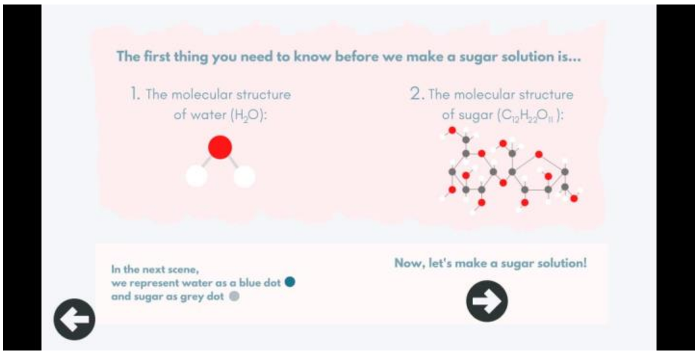


Figure 5. The Pre-Experiment Screen

8) The Experiment Screen

The experiment screen has two images with an explanation at the bottom. There is also an instruction "tap the picture for more." Because every image can be clicked, showing the microscopic view for each step of the experiment. A total of ten steps for each experiment were provided on this screen.

9) Separation Method Screen

The separation method screen consists of four buttons that can be clicked. Examples of separation methods are filtration, distillation, chromatography, and sublimation. A button will represent each example.

10) Pure Substance Screen

The pure substance screen consists of an explanation and two buttons; the elements and compounds button. There is an order to click the button in the explanation if the users do not know the button can be clicked.

11) Physical Changes Screen

There is an explanation, physical changes examples in the table, and a button that leads to the detailed description and video on this screen. Also, an instruction said, "tap me for detailed examples" and "tap to watch video" if the users do not know the button can be clicked. The topic includes evaporation, condensation, freezing, melting, sublimation, and deposition. For example, here is the evaporation screen.

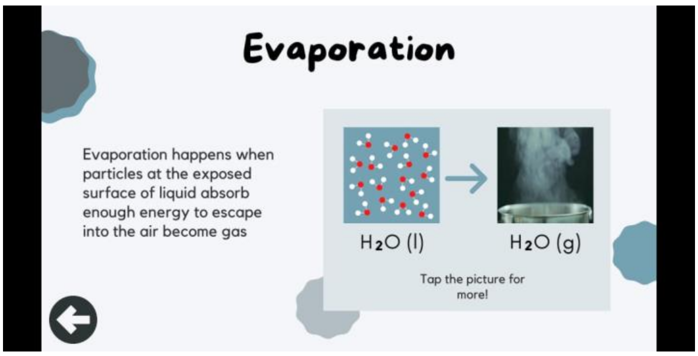


Figure 6. Evaporation Screen

12) Chemical Changes Screen

The same with the physical changes consist of an explanation and example in a table. In addition, a button leads to a detailed description of chemical changes or reactions and a video. Also, there is an instruction to guide the users.

13) The Quiz Screen

The quiz consists of ten questions, with four options in each number. There is a question number in the top left corner and a current score at the top right corner. The users must answer the questions accurately because they cannot return to the previous number.

4. Evaluation Stage

The evaluation is the last stage in the DDD-E model of development. The researcher needs to evaluate the Android application based on the expert judgment review. The "ChemFUN" Android application was reviewed by five experts' judgment in content, language, and design. The experts' judgment fills a rubric with a scale from 1-4, and it has a category and definition for each criterion. The results of the five experts' judgments are shown in Table 3.

Table 3. Expert Judgment Response

No.	Indicator	Aspects	Judge's Score					Average Aspect	Average Indicator	Deviation Standard
			A	B	C	D	E			
1	Content	Accuracy	**3**	**3**	**4**	**3**	**4**	**3.4**	**3.64**	0.55
2		Veracity	**3**	**4**	**4**	**4**	**4**	**3.8**		0.45
3		Chemical Multiple Representation (CMR)	**3**	**3**	**4**	**4**	**4**	**3.6**		0.55
4		Interconnection of CMR	**3**	**4**	**3**	**4**	**3**	**3.4**		0.55
5		Scientific Term	**4**	**4**	**4**	**4**	**4**	**4**		0.00
6	Language	Spelling Grammar	**2**	**4**	**4**	**3**	**4**	**3.4**	**3.65**	0.89
7		Text	**4**	**4**	**4**	**4**	**4**	**4**		0.00
8		Diction	**4**	**4**	**4**	**4**	**4**	**4**		0.00
9		Audio	**1**	**4**	**3**	**4**	**4**	**3.2**		1.30
10	Design	Presentation Design	**4**	**3**	**3**	**4**	**3**	**3.4**	**3.6**	0.55
11		Navigation	**4**	**4**	**3**	**4**	**4**	**3.8**		0.45
12		Information Structure	**2**	**4**	**4**	**4**	**4**	**3.6**		0.89
Average Score			**3.08**	**3.75**	**3.67**	**3.83**	**3.83**			
Average All Judge's Score			**3.63**							

The score was counted using an average for each aspect so that the deviation standard can be calculated. There is also an average for all judge's scores. The average and deviation standard for the content quality is shown in Figure 7.

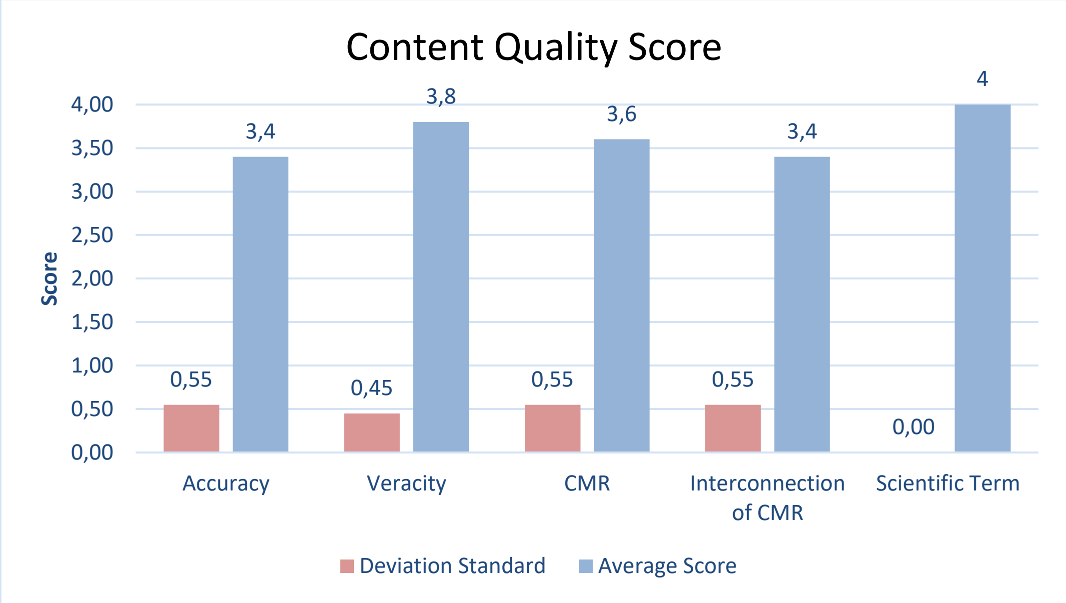


Figure 7. Content Quality Score

Based on Figure 7, the average score for the content quality varies from 3.4 to 4.0. The lowest score is the accuracy and the interconnection of the CMR aspect, with an average score of 3.4, and the highest score is the scientific term aspect, with a 4.0 score. The accuracy and interconnection of the CMR average score indicate still quite good, and the deviation standard is also at 0.55, meaning that those aspects did not require any revision. The average score is relatively high for veracity, CMR, and scientific terms, and the deviation standard is low, indicating that those aspects are already valid. In short, the content quality of the "ChemFUN" Android application is good enough, with a total average score of 3.64. This results in line with the research from Putra, Asi, Anggraeni & Karelius (2020) that the Android application got a good result on the content quality, which means the application is appropriate for learning.

According to Ozdamli & Cavus (2011), content is a fundamental component of mobile learning. According to Cairncross & Mannion (2001), the application's content should be integrated with the curriculum. Furthermore, they contend that the breadth of learning information influences student comprehension. According to Nordin et al., (2010), mobile learning material should fulfill the learning activities' aims and objectives. For the language indicator, the chart is shown in Figure 8 below.

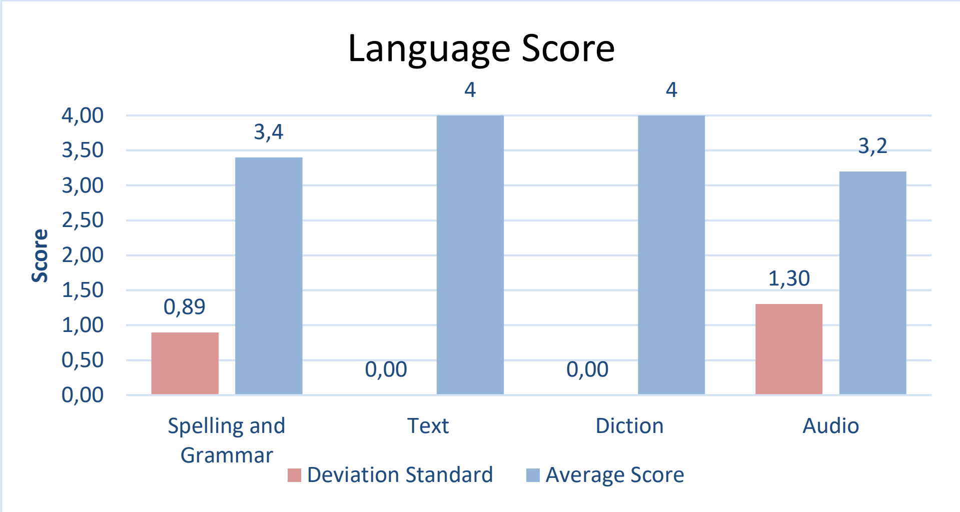


Figure 8. Language Score

The average language score varies from 3.2 to 4.0 based on Figure 8. The highest average score is the text aspect and the diction aspect with a 4.0 score and a deviation standard of 0, indicating the "ChemFUN" Android application has an easy-to-read and understandable text with a well-applied diction to support the comprehension of materials. Meanwhile, it has a relatively good average score for spelling and grammar, which is 3.4. However, it has a high deviation standard, 0.89, indicating that the application needs to revise its spelling and grammar. The last one is the audio aspect. It has a low average score of 3.2 and a high deviation standard score of 1.30. It shows that the application also needs a revision in the audio aspect. The spelling and grammar can get a low score because there is still some incomplete sentence and a typo in the application. The audio got a low score because one judge got a problem that the audio could not play, but it all got fixed. Overall, the language indicator has a total average score of 3.65, which is good, but it still needs to be revised in spelling, grammar, and audio. The last indicator is application design, and the chart is shown in Figure 9.

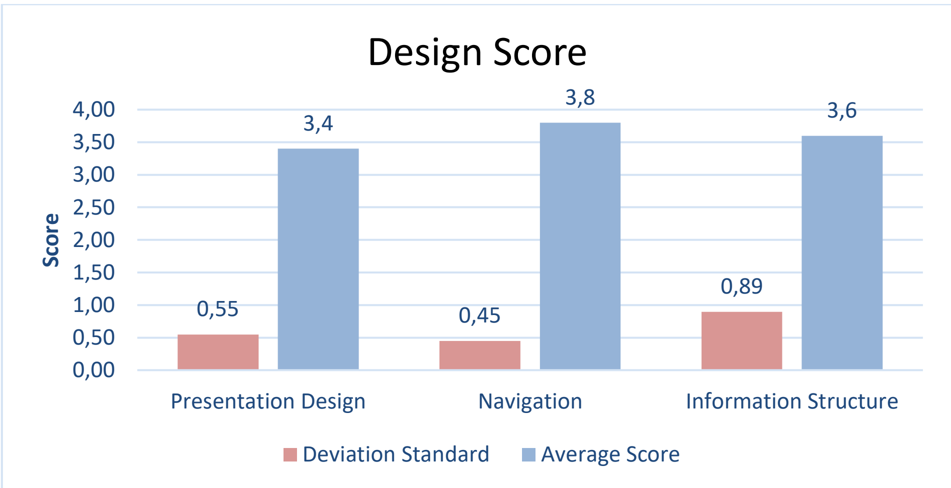


Figure 9. Design Score

Figure 9, the average design score varies from 3.4 to 3.8. The highest average score is the navigation aspect, with an average score of 3.8 and a low deviation standard of 0.45. Sure, it does not require any revision for the navigation aspect. The presentation design also has a relatively high average score of 3.4, and because it has a low deviation standard of 0.55, it does not require any revision. The last aspect is the information structure with a high average score which is 3.6. However, it also has a high deviation standard of 0.89, indicating that the information structure aspect can still be revised. The design indicator shows good results with a total average score of 3.6, which is good enough. The design results are in line with Saputra (2021), which got a good score on the application's appearance, which means the application satisfied the users and is ready to be used.

Besides the results based on the rubric, the expert judgment gives recommendations to improve the “ChemFUN” Android application quality. For example, one of the judges said:

“*It would be better to put some instruction so the user knows where to begin.”*

Even when there is a guide in the application, the judge’s still got a little confused, indicating the application needs user guidance to make the users fully understand the application. So another recommendation from other judges is:

“for the questions on the quiz are still classified as middle-order thinking, maybe it can still be developed into high-order thinking.”

It means some quiz questions can still be revised because the question is too easy for students. The last suggestion is stated below:

“*To me, the navigation button is less attractive. You can make each button lighter when mouse over it to improve their attractivity.”*

The navigation button tends to be static because of the limitation of the Unity software. However, the developer can learn in the future how to make the application more interactive. Based on the expert judgment score and feedback, the application needs to improve audio, spelling, and grammar. Furthermore, the application has been revised and fully developed in terms of audio, spelling, and grammar before it comes to the science teachers and the students.

Conclusion

Based on the research questions and the finding of the development of the “ChemFUN” android-based application to explore students' understanding of chemical representation on matter topic, it can be concluded that the “ChemFUN” Android application comes with compatibility only for the Android operating system. There are many buttons the user can interact with. In guided inquiry, the materials show the chemical multiple representations view and the interconnections between macroscopic, microscopic, and symbolic views. Currently, the application just got one English version, following the matter topic in the Cambridge curriculum.

The “ChemFUN” Android application can be developed through four stages. The first stage is deciding stage. In this stage, the researcher tries to analyze the content and also the application used for development. The second stage is the designing stage. In this stage, the researcher starts making a flowchart of the application and a storyboard. The third stage is the development stage. In this stage, the researcher started to develop the application based on the deciding and designing stages, and all need to be precise. Finally, the fourth stage is the evaluation stage. In this stage, the application was brought to the expert judgment to be reviewed. After that, the application was revised based on the expert.

The review result shows that the final average score on the content quality is 3.64, followed by the language category with an average score of 3.65 and the design category with an average score of 3.60. Although it still has a low audio, spelling, and grammar score, it has been revised. The average for all categories is 3.63, which is very good, indicating that the "ChemFUN" Android application is ready to be used in the learning activity to explore students understanding of chemical representation on matter topics. Also, this kind of research can be done with different chemistry topics, whether in National Curriculum or Cambridge Curriculum.

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References

Anshari, M., Almunawar, M. N., Shahrill, M., Wicaksono, D. K., & Huda, M. (2017). Smartphones usage in the classrooms: Learning aid or interference? *Education and Information Technologies*, *22*(6), 3063–3079. https://doi.org/10.1007/s10639-017-9572-7

Astiningsih, A. D., & Partana, C. F. (2020). *Using Android Media for Chemistry Learning Construction of Motivation and Metacognition Ability*. *13*(1), 279–294.

Cahyana, U., Paristiowati, M., Savitri, D. A., & Hasyrin, S. N. (2017). Developing and application of mobile game based learning (M-GBL) for high school students performance in chemistry. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(10), 7037–7047. https://doi.org/10.12973/ejmste/78728

Cairncross, S., & Mannion, M. (2001). Interactive multimedia and learning: Realizing the benefits. *Innovations in Education and Teaching International*, *38*(2), 156–164. https://doi.org/10.1080/14703290110035428

Davidowitz, B., & Chittleborough, G. (2009). *Linking the Macroscopic and Sub-microscopic Levels: Diagrams*. 169–191. https://doi.org/10.1007/978-1-4020-8872-8_9

Eliyawati, E., Agustin, R. R., Sya'bandari, Y., & Putri, R. A. H. (2020). Smartchem: An Android Application for Learning Multiple Representations of Acid-Base Chemistry. *Journal of Science Learning*, *3*(3), 196–204. https://doi.org/10.17509/jsl.v3i3.23280

Eliyawati, Rohman, I., & Kadarohman, A. (2018). The effect of learning multimedia on students' understanding of macroscopic, sub-microscopic, and symbolic levels in electrolyte and nonelectrolyte. *Journal of Physics: Conference Series*, *1013*(1). https://doi.org/10.1088/1742-6596/1013/1/012002

Fook, C. Y., Narasuman, S., Aziz, N. A., Mustafa, S. M. S., & Han, C. T. (2021). Smartphone Usage among University Students. *Asian Journal of University Education*, *17*(1), 283–291. https://doi.org/10.24191/ajue.v17i1.12622

Gkitzia, V., Salta, K., & Tzougraki, C. (2011). Development and application of suitable criteria for the evaluation of chemical representations in school textbooks. *Chemistry Education Research and Practice*, *12*(1), 5–14. https://doi.org/10.1039/c1rp90003j

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

Ivers, K. S., & Barron, A. E. (2002). *Multimedia Projects in Education: Designing, Producing, and Assessing LIBRARIES UNLIMITED TEACHER IDEAS PRESS*.

Komalasari, K. (2019). *International Journal of Instruction*. *12*(1), 113–126.

Leacock, T. L., & Nesbit, J. C. (2007). A Framework for Evaluating the Quality of Multimedia Learning Resources- Special Issue on "Quality Research for Learning, Education, and Training." *Journal of Educational Technology & Society-*, *10*(2), 15.

Ma, L., Gu, L., & Wang, J. (2014). *Research and Development of Mobile Application for Android Platform*. *9*(4), 187–198. https://doi.org/http://dx.doi.org/10.14257/ijmue.2014.9.4.20

Markic, S., & Childs, P. E. (2016). Research and Practice Language and the teaching and learning. *Chemistry Education Research and Practice*. https://doi.org/10.1039/C6RP90006B

Nordin, N., Embi, M. A., & Yunus, M. M. (2010). Mobile learning framework for lifelong learning. *Procedia - Social and Behavioral Sciences*, *7*(C), 130–138. https://doi.org/10.1016/j.sbspro.2010.10.019

Nugraha, I., Athfyanti, N. N., & Prabawa, H. W. (2020). The development of computer-assisted instruction game on mirror reflection concepts for junior high school students. *Jurnal Inovasi Pendidikan IPA*, *6*(1), 1–10. https://doi.org/10.21831/jipi.v6i1.28927

Ozdamli, F., & Cavus, N. (2011). Basic elements and characteristics of mobile learning. *Procedia - Social and Behavioral Sciences*, *28*, 937–942. https://doi.org/10.1016/j.sbspro.2011.11.173

Putra, P. S., Asi, N. B., Anggraeni, M. E., & Karelius. (2020). Development of android-based chemistry learning media for experimenting. *Journal of Physics: Conference Series*, *1422*(1). https://doi.org/10.1088/1742-6596/1422/1/012037

Richey, R.C., Klein, J. D. (2014). Design and Development Research. *Handbook of Research on Educational Communications and Technology: Fourth Edition*, 1–1005. https://doi.org/10.1007/978-1-4614-3185-5

Saputra, D., Gürbüz, B., & Haryani, H. (2021). Android-based Animation for Chemical Elements and Experiments as an Interactive Learning Media. *Journal of Science Learning*, *4*(October 2020), 185–191. https://doi.org/10.17509/jsl.v4i2.28787

Schuster, K., Groß, K., Vossen, R., Richert, A., & Jeschke, S. (2016). Engineering Education 4.0. *Engineering Education 4.0*, *Icelw 2015*. https://doi.org/10.1007/978-3-319-46916-4

Tan, K. C. D., Goh, N. K., Chia, L. S., & Treagust, D. F. (2009). *Linking the Macroscopic, Sub-microscopic and Symbolic Levels: The Case of Inorganic Qualitative Analysis*. 137–150. https://doi.org/10.1007/978-1-4020-8872-8_7

Tsaparlis, G., Kolioulis, D., & Pappa, E. (2010). Lower-secondary introductory chemistry course: A novel approach based on science-education theories, with emphasis on the macroscopic approach, and the delayed meaningful teaching of the concepts of molecule and atom. *Chemistry Education Research and Practice*, *11*(2), 107–117. https://doi.org/10.1039/c005354f

Wan, X., Wang, W., Liu, J., & Tong, T. (2014). Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. *BMC Medical Research Methodology*, *14*(1), 1–13. https://doi.org/10.1186/1471-2288-14-135

Widodo, W., Sudibyo, E., Suryanti, Sari, D. A. P., Inzanah, & Setiawan, B. (2020). The effectiveness of gadget-based interactive multimedia in improving generation z's scientific literacy. *Jurnal Pendidikan IPA Indonesia*, *9*(2), 248–256. https://doi.org/10.15294/jpii.v9i2.23208

Wright, T. (2003). Images of atoms. *Australian Science Teachers Journal*, *49*, 18–24.

Yusuf, N. B. (2020). Colleges of Education Students' Awareness of Use of Multiple Representations in Explaining Chemistry Concepts in Kwara State, Nigeria. *Acta Didactica Napocensia*, *13*(1), 13–18. https://doi.org/10.24193/adn.13.1.2