InCell VR: A Virtual Reality-based Application on Human Cell Division for Mobile Learning

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Abstract—Numerous teaching and learning tools incorporate current technologies to enhance the interactivity of the learning experience, ensuring that the learners are fully engaged in the learning process. Some of the technologies adopted in the mobile-based education systems are virtual reality, augmented reality, and mixed reality. In Biology, one of the problems faced by the learners is the difficulty to visualize complex cellular processes such as cell division in the form of mitosis and meiosis. In this work, an interactive mobile learning application with virtual reality technology has been designed and developed to help learners visualize the human cell division process thus improving the understanding and interest of the learners. The mobile application which is known as *InCell VR* also includes mini games which can help to test the learners' knowledge retention. The development process was done using the Agile framework based on the requirement analysis among experts and learners. The *InCell VR* was developed using Unity, a game engine platform for developing high performance commercial games. The final evaluation conducted among 25 learners assessed two parts: (1) the learners' knowledge gain after using the application and; (2) the application's usability. Overall results indicated that the proposed application had a significant positive impact on the development of learners' knowledge. The usability study also showed that the *InCell VR* application is useful, easy to use, and gives satisfaction to the users.

Keywords—Biology, e-learning, mobile application, usability study, virtual reality

1 Introduction

e-learning elevates education beyond the boundaries of traditional classroom. One of the subcategories of e-learning is mobile learning which can provide a macro perception of learning. Mobile learning permits students to retrieve education resources and references at anyplace and anytime, by using the Internet and mobile devices such as smartphones, wireless laptops, tablets, and personal computers (PC) [1].

Other current learning technologies are augmented reality, holograms, mixed reality, and virtual reality. Virtual reality (VR) is an immersive digital environment that generates a three-dimensional, virtual imaginary and interactive media environment that the user sees like in the real world. Users can also manipulate the objects and

navigate through the environment by using VR. Conventional teaching can be improved by using VR since it is not only an interactive multimedia technology but also an educational environment that is tremendously near to reality [2].

Teaching and learning using mobile devices such as smartphones and tablets are now becoming a trend [3 – 5]. Instead of using slideshow or textbooks to understand the concept of certain subjects, learners can use VR technology for better understanding and gain interest in their studies. By implementing VR technology, the learners can learn more effectively and easily visualise the concept of certain topics or subjects in their studies. This technology has been adopted by many levels of education and across many fields [6 – 8].

Biology is a natural science's topic that contains many sub-disciplines which one of them is the cell division. In cell division, the parent cell divides into two or more cells called daughter cell. The topic which talks about cell division types which are mitosis and meiosis, has been reported as one of the hardest topics for 11th grade students in Turkey [9]. Learning about cell divisions require the learners to think and imagine how the cells look like and visualize the biological process. The application of animation by instructors could significantly help enhance the learning experience.

Therefore, this present work aims to propose a design and development the InCell VR, an Android mobile learning application combined with VR technology to help the users learn and visualise the human cell division processes. Realistic three-dimensional models of the human cells will be created before being animated and placed into the virtual environment for a more engaging learning session. Next, a VR-based mobile application for the cell division topic that allows interaction between users and human cells three-dimensional models will be designed and developed. An assessment in the form of mini games (quiz and jigsaw puzzle) will be added to test the learners' knowledge retention and further ensure they have a better understanding of the topic. Hence, this study is focused on the research questions below:

1. What are the processes involved in developing Android mobile application with VR technology for teaching and learning of the human cell division?
2. What is the level of effectiveness of the mobile application?

The rest of this paper is organized as follows. Section 2 discusses some recent related work on VR-based mobile applications for learning the human cell division topic. Section 3 introduces the methodology performed in the development process which is the Agile method. Results of the evaluations are discussed and analysed in Section 4. Here, the statistical analysis will be conducted and based on the results, the second research question will be answered. Section 5 concludes this paper. The scope for future work will also be explained in this section.

2 Literature Review

Evolution of VR technologies that learners can use easily, allowing them to effectively engage and participate in the teaching and learning process. Therefore, learners can understand the information easily and obtain the full value of it. This section pre-

sents some background on the theoretical framework that introduces and describes the theories behind this study. Some introduction about VR technologies and their importance in assisting the teaching and learning will also be presented. Lastly, reviews of some related mobile applications which focus on the human cell division and related Biology topics will also be summarised.

2.1 Theoretical framework

This study is based on the mobile learning theory and model within the context of theories of connectivism, communities of practice and activity theory [10]. According to [11], five basic elements of mobile learning model are learners, teacher, content, assessment, and environment. Researcher in [10] noted that the pedagogical approach puts the learner at the heart of the learning process where the concept of interactive learning is involved. An active function can be played by the learners from the determination of the goals until the evaluation stage. Teachers convey books and other media elements which contain information to students usually in traditional learning environments.

Content which the expected matters that will be studied by learners plays an important role in mobile learning. It can be in the form of texts, graphics, images, animations, and videos. According to [12], learners could differ depending upon the learners' educational desires in which the detail and extent of the contents will be provided. Additionally, interactive games or quizzes can be offered with the content and graphics video and other multimedia elements need to be supported by content. Another important element in mobile learning is the assessment.

Researchers in [13] claimed that the ability of the students, proposing diagnosis and formative guidance based on achievement have been matched by assessment. A decent design course which offers exhaustive content and instant feedback can assist the learners to evaluate their understanding of the topic.

The final element which is the environment must be properly designed to gain positive learning involvements. For online learning, learners should be able to access to the content, learning outcomes, assignments, and all related resources, anytime and anywhere. For blended mode (face to face plus online learning), learners can receive part of the content in class and additional contents online through the mobile technologies [12]. This study will try to implement all the elements of the mobile learning in developing the application that gives impact to the teaching and learning process.

2.2 Virtual reality in education

VR is one of the technologies that can be used as the environment to share learning contents. Most of the VR applications allow the user to look or navigate through the virtual environment. By using VR environments, users can experience as another person and take different roles from another individual. VR glasses are worn to allow users to view and immerse in the virtual environments from a first-person perspective. Several examples of VR glasses are virtual-reality goggles, virtual reality headsets and head-mounted virtual reality displays.

Other researchers have focused on the results and benefits of VR in the fields of education [14 – 16]. VR learning contents make learners learn in an immersive and engaging way. However, as side effects, VR cause the user to get eye strain, fatigue, dizziness, and motion sickness but these can be reduced by using hand controllers and gaze interaction [17]. According to [18], eye controller is convenient to be operated and it would be better to use eye controller with other interactive control modes such as the handle mode. Therefore, this work will utilize a VR environment and a Bluetooth controller to help the learners to visualise and navigate within a virtual world. In the virtual world, the learners can gain knowledge and experience while interacting with the immersive environments.

2.3 Related works

There are few existing non-VR mobile applications on the market for mobile learning related to the human cell division such as FCS Mitosis & Meiosis, Split-A-Cell and Mitosis and Meiosis. In our knowledge, not much of the VR application available specifically for human cell division, as most of them focus on the human anatomy topic in general such as the AnatomyouVR and INVIVO Bloodstream Explorer VR. One interesting VR application that worth to be mentioned is the Eukaryo which is a multi-reality (both AR and VR) application that allows learners to explore the complex environment within a biological cell [19].

Throughout the application, the three-dimensional models display main functional elements of a typical eukaryotic cell. Learners can explore the cell, its structural components, its organelles, and some primary metabolic processes using multiple modes. Unlike textbook diagrams and videos, Eukaryo immerses viewers directly in the biological world, offering a more comprehensive explanation of how cellular processes work, how cellular functions are influenced by compartmentalization, and how life machinery works. This is also the aims for the development of this work. See Figure 1.

Some of the mobile applications provide assessments in the form of quizzes and games to test on the knowledge retention of the learners. FCS Mitosis & Meiosis and Split-A-Cell applications provide assessment and a mini-game related to the content of the application which is the cell division. Assessment is very important in order for the learners to test their understanding. Split-A-Cell is a very simple application and easy to be used although no instructions on how to use the app or how to play the game were included.

Fig. 1. A view of the Eukaryo cell model and the functions available (adopted from [16]).

Some of the VR applications provide choices for the users to either view the content as an animation on their mobile screen or they can discover the virtual environment using the VR glasses, such as the INVIVO Bloodstream Explorer VR as in Figure 2. AnatomyouVR application uses user's gaze to perform some of the tasks such as to read information about the body system. However, some of the three-dimensional models of the body need to be purchased separately. AnatomyouVR also does not provide a quiz or assessment for testing learners understanding after exploring the content.

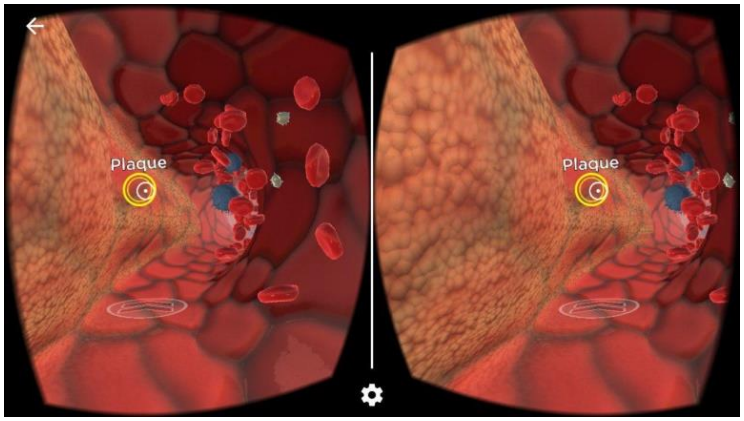

Fig. 2. Interface for INVIVO Bloodstream Explorer.

In recent years, VR technologies play an important role in assisting the teaching and learning activities especially on complex topics such as the human cell division. Hence, VR-based technologies can help in the learning of the cell division topic focusing on human cells. VR can help learners to learn more efficiently, visualise intangible cells and most importantly, it can help to improve the learners' interest in learning the topics.

3 Methodology

This study employed the Agile Model Development methodology which is one of the important models in software development process. This answers the first research question of this study. The development process involves constant design improvements and testing based on rapid feedback and changes among the developers and the stakeholders (in this case, the educators and learners). Each of the phases will be discussed in detail in the next subsections.

3.1 Requirement analysis

The requirement analysis is crucial to the success of a mobile application development. The data are collected through the interview session with the target users of the mobile application which are the teachers (as the content experts) and students between 16 – 17 years old that undertake the subject of Biology in secondary schools in Malaysia. The data were also being compared with the subject's textbooks and workbooks in order to filter which topics are important and related to the topics chosen for this work. Table 1 shows the details of data collection process. Some of the users' needs captured by the interview are realistic visualization of the cell division process, notes taking function, assessments in the form of mini games, and users' personal account to store self-notes and current marks of the assessments.

Table 1. Content verification

Expert	Secondary school teachers
Content	Human cell division process

3.2 Mobile application design

The mobile application was designed in this phase to satisfy the requirements identified in the analysis phase. In this phase all the functions for the user interfaces, the design flow of the application and the design of the virtual environment will be outlined and presented to the stakeholders. Figure 3 shows the wireframe for this proposed application.

3.3 Mobile application development

The development of this proposed application was conducted on a laptop running on the Microsoft Windows 8 Professional operating system, with Intel ® Core ™ i5 CPU. A VR headset and a Bluetooth controller were also being used in the testing phase. The three-dimensional models of the human cells were created using the Blender software and animated using the Unity software. Unity was also being used to create the environment of a virtual cell and to develop the Android mobile. All the graphics or images used in this project are royalty-free images in Portable Network Graphic (PNG) and JPEG formats and edited by using Adobe Photoshop.

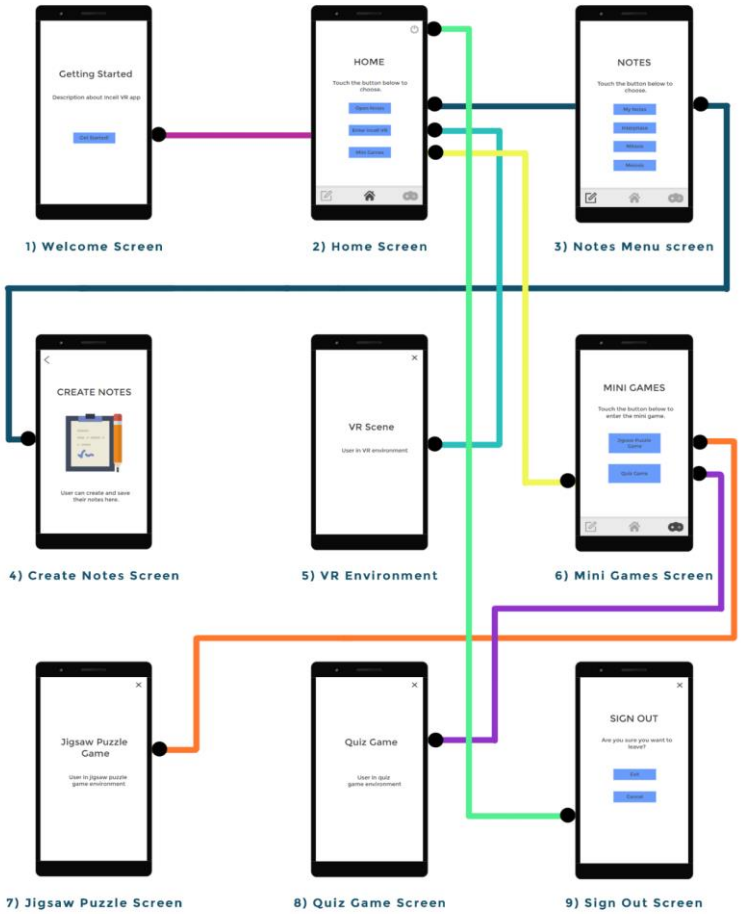

Fig. 3. Wireframe for the InCell VR application.

There are several functions provided on the Home page which are the "Open Notes", "Enter *InCell VR*" and "Play Mini Games", as shown in Figure 4. In Open Notes page, several buttons have been listed which are "My Notes", "Interphase", "Mitosis" and "Meiosis" buttons. Each button represents text notes which helps the learner to add or edit the notes on their own.

When the user clicks the "Enter *InCell VR* Environment" button, the *InCell VR* Environment scene will be shown, and this is when the user needs to insert the mobile device into a VR glass and can starts using the controller. When the user gazes and clicks the "Meiosis I" button on the controller in the *InCell VR* environment, several options of the subphases of "Meiosis I" will be displayed. See Figure 5.

In the Mini Games page, a user can choose to play either the Jigsaw Puzzle or Quiz. As shown in Figure 6, when the user clicks the Jigsaw Puzzle, he will enter the

game page and some of the descriptions related to the Jigsaw Puzzle will be shown. Figure 7 shows the Quiz Game pages.

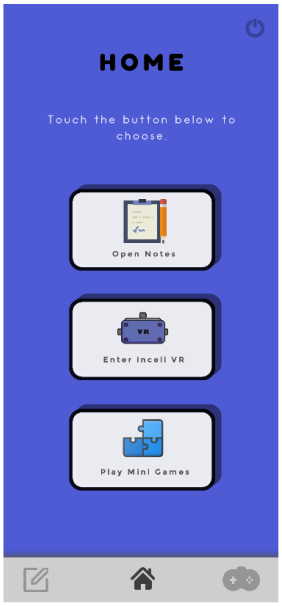

Fig. 4. Home screen of InCell VR.

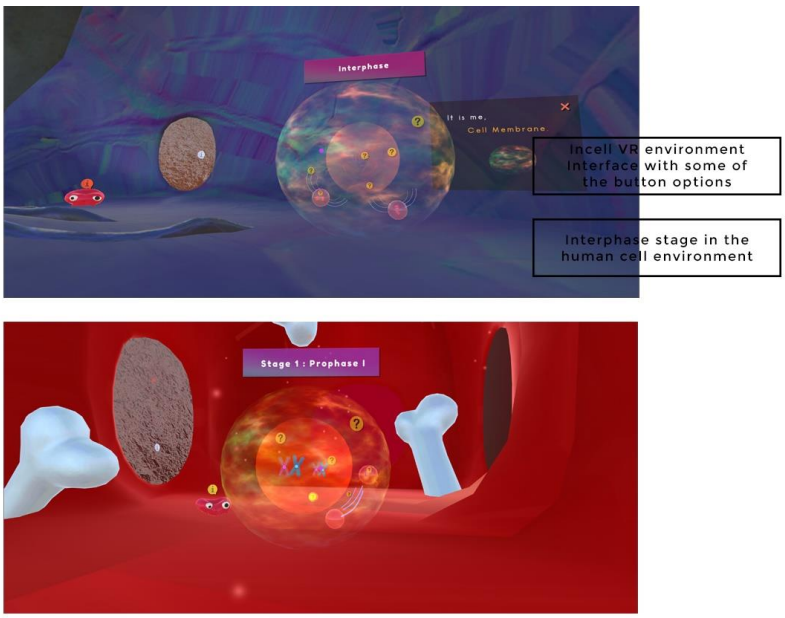

Fig. 5. Selected scenes in the *InCell VR* environment.

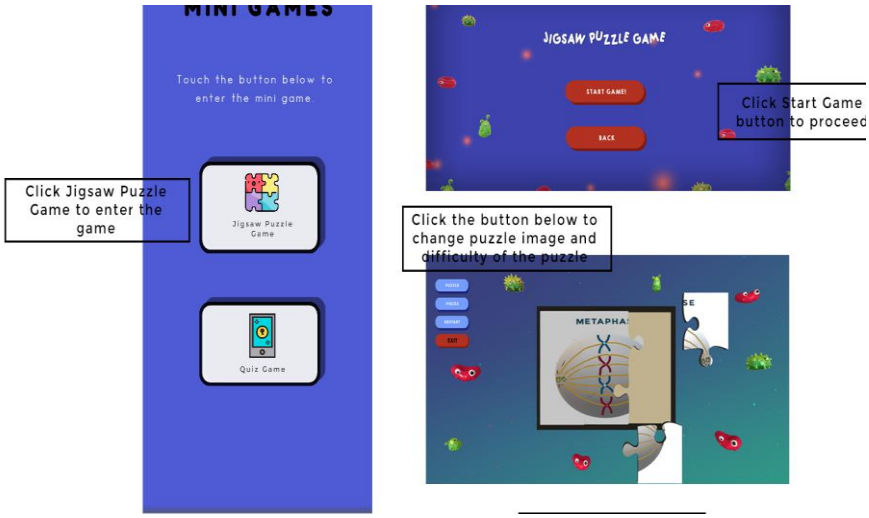

Fig. 6. Jigsaw puzzle pages.

3.4 Validation of application contents and design

Before the actual implementation, the content validity and the interface usability of the InCell VR were evaluated. These were to ensure that the application addresses all substantial aspects of the subject's content, so that the findings of this study can be accepted academically. Content validity is also an important factor in ensuring the correctness and completeness of the content to match the questions in the quiz.

Fig. 7. Quiz game pages.

The two components being focused in the validity test are the application design (5 indicators) and instructional design (5 indicators). This evaluation is conducted in order to determine whether the application is intuitive and correctly constructed. The findings indicated that the design of the application was outstanding, with a score of 90 out of 100 for this analysis. The questionnaire is also appropriate and suitable for this study. Overall, the validity scores showed that the InCell VR was ready to be implemented.

3.5 Instruments

The evaluation data in this study were collected using test and survey. The two outcome measures collected were:

1) Improvement in student's knowledge, as derived from pre- and post-test questions, which consisted of five questions and the same set of questions were given for both pre- and post-usage (the order of the questions might be different)
2) A usability questionnaire consisting of 10 items as an indicator of the users' acceptance and experience after using the InCell VR application.

The pre- and post-test questions were derived from the Biology textbook used by the Form 4 students from the government secondary schools in Malaysia which also included as the contents of the application itself. See Table 2. The usability questionnaire was adopted based on the validated USE Questionnaire developed by researcher in [20]. In this questionnaire, the users evaluated the application based on four dimensions namely; usefulness, ease of use, ease of learning and satisfaction. The questionnaires were constructed using the five-point Likert scale measuring from 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree) to 5 (strongly agree).

Table 2. Pre- and post-test for assessing knowledge gain

	Questions
1	What happened during the process? (with picture)
2	Meiosis distributes duplicated chromosomes into two identical daughter nuclei. True or false?
3	What phase is this? (with picture)
4	What is the name of the cell in the round circle? (with picture)
5	During the Meiosis I, the homologous chromosomes undergo synapsis (resulting in a bivalent). True or false?

3.6 Data collection and analysis techniques

A total of 25 respondents participated in both pre- and post-tests. Five questions covering the basic knowledge of the cell division process have been selected for the pre-test and the same five questions were given immediately after learners completed the application usage. The pre-test was given to students in order to know their initial ability on the human cell division knowledge before they were using the InCell VR application while the post-test was carried out to investigate the student's learning outcomes immediately after they used the application.

For the first outcome, the descriptive statistical and inferential statistics were used as the analysis techniques. Descriptive analysis was carried out by looking into the tendency of the increment or decrement for each question. Inferential statistical analysis which is the paired t-test technique was conducted to find out whether there are differences between the pre-test results with the post-test results. The testing of inferential statistics was carried out with the assistance of SPSS version 22.

All the 25 respondents also answered the second part of the evaluation which is the usability questionnaire. The students answered using an online survey form which contained some aspects such as the application's usefulness, ease of use, ease of learning and satisfaction. The results were analysed using the descriptive analysis.

4 Results Evaluation and Analysis

Mobile applications that have been developed need to be tested to check for any unspecified failures or system bugs. Two testing sessions have been conducted for this work. The first testing which is the preliminary testing was conducted during the development phase to guarantee that the application is free from bugs. The second round of the testing is the survey which evaluates two parts: the learners' knowledge gain after using the application and usability evaluation of the application.

4.1 Demographics

From the total of 25 respondents, 21 respondents were from the age group of 16 to 20. Three respondents were between 21 and 25 years old and only one respondent from the age group of 26 to 30. 15 respondents were female, and the rest were male. Almost 64% of them have heard about VR technologies and another 9 respondents (36%) have not. For the question of mobile phone ownership, 22 respondents own a mobile phone and the rest do not have a mobile phone.

There was also one question on the preferences of studying whether the respondents prefer to read physical books or notes, reading notes through mobile phones or reading notes through tablets. 44% of the respondents preferred to read the hardcopy of the books or notes. Eight respondents like to read notes through mobile phones followed by 6 respondents preferred the tablets. As for the existing knowledge about cell division, most of the respondents (19 out of 25 respondents) do have knowledge about cell division and the others do not know or might have forgotten about the cell division process as some of them left the school for quite some time. Almost all the respondents were interested to learn the cell division process by using the VR application.

4.2 Pre- and post-test questionnaires

To explore the impact of the InCell VR application usage on the development of learners' knowledge, a paired student t-test was conducted. The pre- and post-test scores were compared using the paired samples' t-test and the p values were being

calculated. $p < 0.05$ was considered as significant. Table 3 and 4 show the statistics of the pre- and post-test questionnaires results. The results show that the post-test results (M=4.40, SD=.577) were highly significant than pre-test results (M=2.00, SD=.707); t(24)=14.697, p=0.000. Therefore, it can be concluded that the InCell VR is effective in teaching and learning the human cell division topic.

Table 3. Paired samples statistics

	N	Mean	St Dev	SE Mean
Post-test	25	4.40	.577	.115
Pre-test	25	2.00	.707	.141

Table 4. Paired samples test

	Paired Differences					t	df	Sig. (2 tailed)
	Mean	*Std. Deviation*	*Std. Error Mean*	*95% Confidence Interval of the Difference*				
				Lower	*Upper*			
Post-test – pre-test	2.400	.816	.163	2.063	2.737	14.697	24	.000

Table 5. Pre- and post-test responses

Questions	Correct responses (*n = 25*)		*p* value
	Pre-test	*Post-test*	
Q1.	8	24	.000*
Q2.	16	23	
Q3.	4	20	
Q4.	7	20	
Q5.	15	23	

* This difference is considered to be statistically significant.

Table 5 shows the comparison of the correct and incorrect answers between the pre- and post-test for each question and the p value. As seen in Table 5, the total correct responses for all questions were increased after using the InCell VR application. This confirm the t-test results where it shows that the application indeed helps to improve the learners' knowledge and they were able to understand the key objective of the application.

4.3 Usability evaluation

The second part of the final testing is evaluating the users' acceptance and experience after using the InCell VR application. Most of the respondents strongly agreed that the proposed application is useful for their studies and helped them to be more effective. See Fig. 8. All respondents agreed that the application can help them to be more productive in learning. In terms of the application's ease of use, surprisingly only 44% of the respondents strongly agreed that the application is easy to use. It might be because of the VR technology which is quite new to most of the respondents

and they were not quite familiar in handling the headset. Nevertheless, all the respondents agreed that InCell VR is a user-friendly application (21 respondents strongly agreed, and 4 respondents agreed). See Fig. 9.

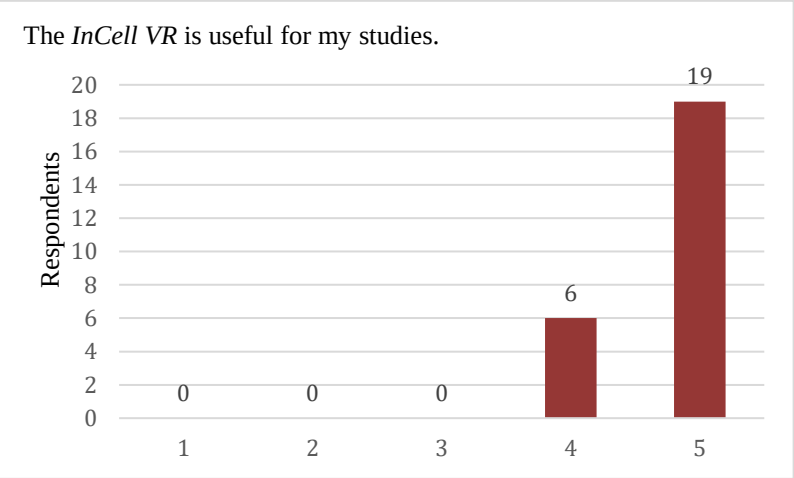

Fig. 8. The results that show the *InCell VR*'s usefulness.

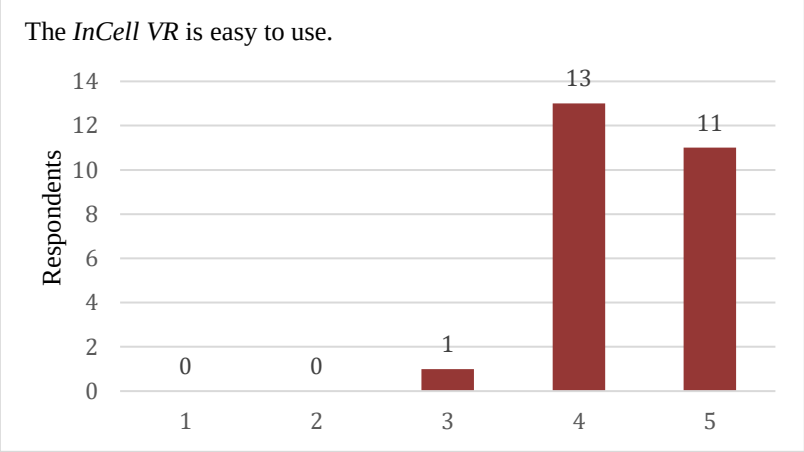

Fig. 9. The results of ease of use of the *InCell VR*.

As for the ease of learning dimension, almost 20 respondents strongly agree that they remembered on how to use the application easily and they managed to learn using the InCell VR application in a shorter time. More than 80% of the respondents satisfied with the application. 22 respondents strongly agreed that the application is pleasant and fun to be used. Almost all respondents agreed to recommend the proposed InCell VR application to their friends. See Fig. 10 and 11.

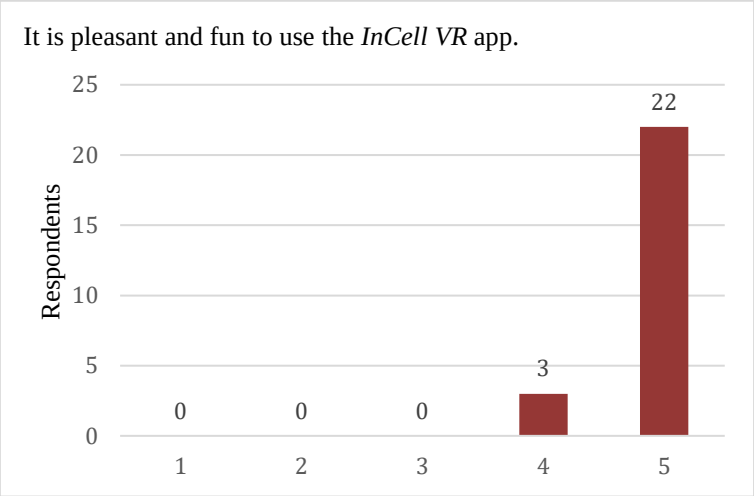

Fig. 10. The results that show the *InCell VR* is fun to be used.

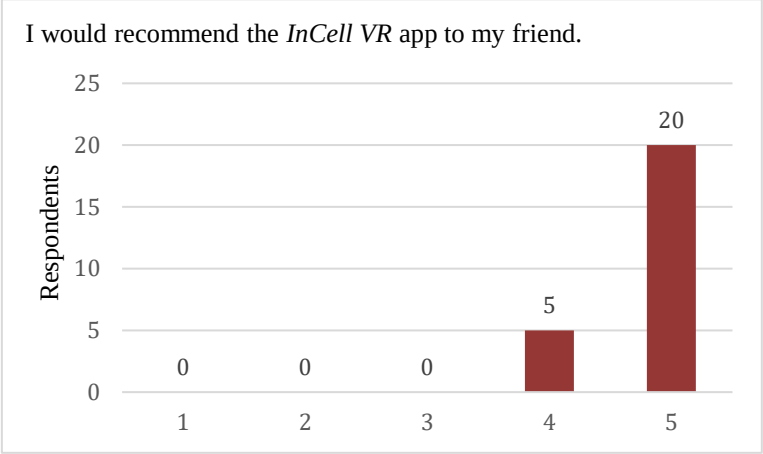

Fig. 11. The number of respondents that would recommend the *InCell VR* to their friend.

4.4 Discussion

Agile method is proven to be a good alternative to ADDIE development framework which is usually being used in most of the e-learning materials development. The learners and developers were on regular discussions throughout the development. Rapid testing sessions were being done along the way before the final evaluations were conducted at the final stage. This finding aligns with the first research question of this study.

All students showed positive acceptance towards using InCell VR application. The most crucial factor which contributes to the results lies in the usefulness of the mobile learning [3]. Majority of the students perceived InCell VR to be useful in assisting them in learning the processes of human cell division. This is deemed important because a tool which is perceived to be not useful will not be used by learners. Besides, VR technology is indisputably useful, as mentioned in many previous studies as it allows learners to visualise complex and abstract concepts. This finding aligns with the second research question of this study thus showing the practical use and effectiveness of the InCell VR application for the teaching and learning of the human cell division.

Along with the potential of this application to support the learning, it comes with two important challenges that must be addressed. Learners without a VR headset or Bluetooth controller could not get the total access of the application thus imposed the technical challenge in using the application. Therefore, the requirements for these learners need to be addressed during the designing of any application. Cultural differences in relation to perceptions and attitudes toward technology also posed a challenge in mobile learning. Parents and some educators need to be convinced in the significant potential of using mobile devices in transforming the children's learning.

There are some suggestions for the improvement of the application. The proposed application should cover more contents and information regarding the human cell. More animation should be added into the application to attract learners in reading more about the topic. Finally, additional type of assessments should be included to produce a more fun and interesting application that can help improve the learners' knowledge on the topic. It is concluded that this application could be one of the learning tools that will help learners to get richer information on human cell division processes and brings benefits in terms of innovations in teaching and learning to the public.

5 Conclusion

The main focus of this work was to design and develop an Android-based interactive mobile learning application with virtual reality technology which help learners visualise the human cell division process. The development was using the Agile method which shown to be suitable in developing e-learning materials based on the learners and educators needs. The evaluations have shown that the InCell VR application received positive feedback from the users. The usage of the proposed application was seen to give positive impact on the development of learners' knowledge from the pre- and post-test sessions. The usability study showed that InCell VR application is useful, easy to use and gives satisfactions to the users.

This study does not aim to develop a complete VR-based mobile application for all the topics related to the human cell division. Consequently, the focus is more specific to the initial application of VR in the teaching and learning of the cell division which is quite scarce in the educational field. It is hoped that this study will kick-start a more comprehensive development of mobile learning application of human cell division

and other complex technical subjects which could benefit from the application of VR and animation.

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