Mobile augmented reality in learning chemistry subject: an evaluation of science exploration

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Article Info

ABSTRACT

Various technologies have been used in making teaching and learning sessions more effective, fun, and enjoyable. One of the ways to make teaching and learning interactive is by emphasizing the use of mobile augmented reality (MAR). Thus, this study has proposed using MAR for a chemistry subject, namely science exploration (SCIENEX). This study adopted design and development research (DDR) by employing the analysis, design, development, implementation, and evaluation (ADDIE) model. The phases involved in DDR are ADDIE. SCIENEX was evaluated based on its validity, usability, and effectiveness. Five experts validated SCIENEX after it had been completely developed. The samples for usability testing and effectiveness of SCIENEX were 30 secondary school students who were studying chemistry. The results of the evaluation of the experts' validation revealed that SCIENEX is a valid and appropriate MAR application for the learning of topics in chemistry. The result also revealed that the majority of students strongly agreed that SCIENEX is appropriate for the usage of MAR in learning chemistry, as it is fun, easy to use, and helps students to understand their learning. Interestingly, SCIENEX could increase students' performance in their learning (t=21.754; p=0.000). Thus, it can be concluded that SCIENEX is valid, can be used for learning chemistry, and can help students in their learning. The limitations of this study and future suggestions for research are also discussed.
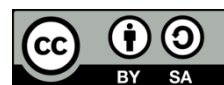
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1. INTRODUCTION

Teaching and learning during the 21st century require secondary school students to acquire many skills, such as critical thinking skills and problem-solving abilities. These skills are needed in learning chemistry, as this subject is one of the most difficult subjects for secondary school students. It requires students to think critically and to imagine the content to achieve in-depth understanding. Meanwhile, teachers

in the 21st century must be creative and should emphasize innovation in their teaching style to boost students' critical thinking skills. Thus, there is a need to have innovation in pedagogy and learning for chemistry to help both teachers and students. One way to emphasize innovation is by using technology for teaching and learning. Various technologies have been used in the classroom, such as game-based learning [1], [2], learning via courseware [3], task-based learning [4], modular learning [5], [6] mobile technology [7], and augmented reality (AR) [8]–[11]. These technologies have a positive impact on students' achievement, engagement, motivation, and curiosity in their learning.

Singhal *et al*. [12] revealed that AR could support the seamless interaction between real and virtual environments. In addition, their study also found that AR technology allows the use of a tangible interface metaphor for object manipulation. Hanid *et al*. [13] conducted a review of 26 studies and found various learning strategies can be applied using AR, such as interactive learning, mobile learning, experiential learning, creative design learning motivation, problem-based learning, collaborative learning, game-based learning, argumentation-based science learning, blended learning, and ubiquitous-learning (u-learning). This finding proved that AR is a powerful tool that can be used in both teaching and learning. In addition, other studies found that AR can motivate students in learning [14], [15] emphasize the excitement and enjoyment in learning [16], [17] promote interactive learning [18], increase students' interest in learning [19], increase students' achievement in learning [20], [21] and improve the quality of teaching and learning [22].

Due its effectiveness, AR technology has a high potential for improving learning among secondary school students in Malaysia. However, to date, there is a lack of technology in the teaching and learning of chemistry for secondary school students in the country [23], [24]. In addition, certain topics in chemistry need to be visualized to facilitate understanding, as some are difficult to comprehend. Therefore, there is a need to propose the use of AR in teaching and learning chemistry, in this instance, science exploration (SCIENEX), as one of the pedagogical tools for use with secondary school students in Malaysia.

AR is an enhanced version of the real physical world; it is achieved using digital visual elements, sound, or other sensory stimuli delivered via technology. Thus, AR is one of the technological tools that can be used for teaching and learning in education. Research by Tobar-Muñoz *et al*. [25] used AR in teaching and learning to promote reading comprehension among primary school students and found that AR could increase motivation and interest in problem-solving, exploration, and socialization behaviors. Another study conducted by Hung *et al*. [26] found that an AR educational book could improve primary school students' learning when using picture books. Moreover, AR had also been implemented through mobile augmented reality (MAR) for learning in studies such as MAR learning media with metaverse to improve student learning outcomes in science class [27], a virtual reality-based application on human cell division for mobile learning [28], entrepreneurship education through MAR for introducing universities and small and medium-sized enterprises (SMEs) in higher education [29] and MAR for campus visualization using marker less tracking in an Indonesian private university [30].

In Malaysia, it was found that using AR among school students has a positive impact on learning. Bistaman *et al*. [31] revealed that AR improved the whole class collaboration through communication with each other to learn and obtain mutual benefits. Research also found that AR could trigger students' motivation, enjoyment, and curiosity in learning. Furthermore, Tan and Lim [32] revealed that AR could support the interaction between students and cultivate more interest in learning. The following are the AR applications used for creative learning among secondary school students in Malaysia: an AR system for biology science education in Malaysia [33], a science textbook enhanced using AR [34]–[37]. AR in teaching and learning English reading [35], developing vocabulary knowledge among low achievers using MAR [36], and designing a game-based learning kit with the integration of AR for learning geography [37]. AR is one of the creative pedagogical approaches used in Malaysian secondary schools.

However, previous studies have focused only on subjects such as Biology, History, Science, English, and Geography, and there is a lack of studies on the use of AR applications for studying chemistry in secondary schools. Saidin *et al*. [38] proposed using MAR for learning chemical bonds; Lam *et al*. [24] developed interactive AR with natural action for learning chemistry experiments; Jamil and Yasak [39] developed the AR application for the study of chemical bonds. However, no studies have proposed the application of AR in chemistry focused on the reaction of potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) with water. Thus, this study proposes an AR tool, namely SCIENEX, for studying this aspect of chemistry for secondary school students. Therefore, the following research objectives are posed to guide the implementation of this study: i) to develop a visual 3D animated model of the reaction for potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) with water; ii) to develop an interactive MAR known as SCIENEX for the chemistry topic "Reactivity of Metals"; iii) to validate SCIENEX for use in teaching and learning chemistry from the experts' perspective; iv) to evaluate the usability of SCIENEX for use in teaching and learning chemistry from the users' perspective; v) to examine the effect of SCIENEX on

students' performance in learning chemistry. The hypothesis in study as: there is no significant difference in students' performance before and after using SCIENEX (H^0).

2.   RESEARCH METHOD
2.1. Research procedure
Firstly, the 3D animated models of the reaction for potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) with water were developed. After that, SCIENEX was developed using augmented reality. Next, five experts validated SCIENEX as appropriate for use in learning chemistry. Then, the usability of SCIENEX was evaluated based on the users' perspective. Finally, the effect of SCIENEX on students' performance was examined.

2.2. Respondents
This study involved two groups of respondents, namely experts and users. The purposive sampling technique were employed in this study. Several criteria were used to select the experts: i) had more than 10 years in AR; ii) was expert in teaching chemistry subject for more than 10 years; and iii) had experience in the design of mobile applications. Next, the other sample of this study was the users of SCIENEX. The sample comprised 30 students studying at one of the secondary schools in Malaysia. There were several criteria, such as: i) students were enrolled in learning chemistry; ii) students are in form 4; and iii) students had problems in learning the reactions for potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) with water. The samples evaluated the usability of SCIENEX in terms of screen, navigation, content, and ease of use through a survey. Besides that, these samples were also involved in investigating the effect of students' performance in learning chemistry before and after using SCIENEX.

2.3. Research design
This study employed the design and development research (DDR) approach, which has several strengths. First, the DDR can establish new procedures, techniques, and tools based on a specific needs analysis [40]. Second, this methodology is also formerly known as an established method for developmental research [41]–[43]. In addition, several applied studies have employed DDR to develop AR for pedagogical tools as their established research design [44], [45]. This finding proved that DDR is an appropriate research design for the development of SCIENEX in this study.

2.4. Analysis, design, development, implementation, and evaluation (ADDIE) model
This study adopted the ADDIE model to design and develop SCIENEX. This involved five phases as shown in Figure 1 which are analysis of the software and Topic in SCIENEX, design of the 3D model and interface for SCIENEX, development of the 3D model and SCIENEX, implementation of SCIENEX via mobile applications and evaluation of SCIENEX.
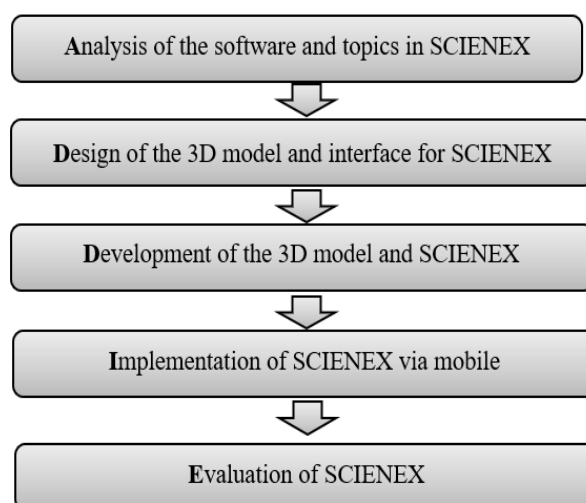

Figure 1. Analysis, design, development, implementation, and evaluation (ADDIE) model

2.4.1. Analysis of the software and topic in SCIENEX

In the analysis section, the software and topics in SCIENEX were analyzed. SCIENEX was successfully developed using Unity Hub, Vuforia, and Blender as the supporting software. Unity Hub is the main software to develop SCIENEX. Next, Vuforia has its own database, which can be used by users as detection and to create a database button for SCIENEX. Vuforia allows developers to create limitless databases; it also supports 3D model detection and single image detection in SCIENEX.

The quick response (QR) code image was produced using a QR code maker, which is free and has a function of multiple QR code determinations. The QR code is decided based on the selection used to determine the shape of the QR code. To make the QR code image easily recognizable by users, a logo was uploaded to the website. The logo was the name of the markers consisting of potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) and water. The logo was placed in the middle of the QR code image. The topic for SCIENEX is "Reactivity of Metals".

2.4.2. Design of the 3D model and interface for SCIENEX

The 3D model and interface of SCIENEX were designed in the following phase. Unity Hub can create 2D and 3D high-definition RP using Universal Render Pipeline. This study used Unity Hub to design the atom structure and visualize the 3D animated reaction for potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) with water for SCIENEX. The interface for SCIENEX was also designed in this phase.

2.4.3. Development of the 3D model and SCIENEX

As stated previously, SCIENEX has four QR code images, which are potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) and water. Figure 2 shows the result of the development of QR codes for SCIENEX created by QR Code Maker. SCIENEX also has several animations in the interface, such as the interface for the main page and start menu as shown in Figures 3 and 4. In Figure 5, the green 3D text shows the 3D atom structure of potassium. The red 3D text shows the number of protons, blue for the number of neutrons, and yellow for the number of electrons for kalium. Figure 6 shows the reaction of potassium with water. Next, Figure 7 shows the 3D atom structures of sodium (*natrium*), and Figure 8 shows its reaction with water. Lastly, Figure 9 shows the 3D atom structures of lithium (*litium*) and Figure 10 shows its reaction with water. After SCIENEX was fully developed, it was validated by five experts, who agreed that SCIENEX is appropriate for learning chemistry.

Figure 2. Result of QR code images created by QR code maker
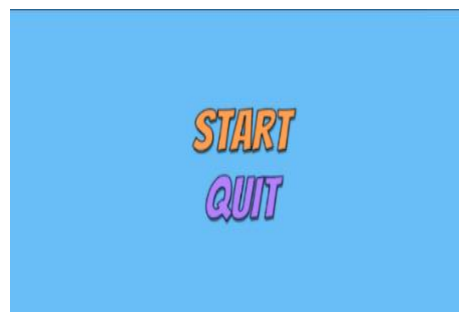

Figure 3. SCIENEX interface in mobile

Figure 4. The main menu of SCIENEX in mobile

Figure 5. 3D atom structures of potassium (*kalium*)

Figure 6. Potassium (*kalium*) reaction when reacted with water

Figure 7. 3D atom structures of sodium (*natrium*)

Figure 8. Sodium (*natrium*) reaction when reacted with water

Figure 9. 3D atom structures of lithium (*litium*)

Figure 10. Lithium (*litium*) reaction when reacted with water

2.4.4. Implementation of SCIENEX via mobile applications

After the development of SCIENEX was completed, it was implemented via a mobile app. The duration of the implementation of the SCIENEX is 3 weeks. Next, usability testing was conducted on SCIENEX.

2.4.5. Evaluation of the SCIENEX

The evaluation in this study consists of two parts, which are the usability of SCIENEX and the effect of SCIENEX on students' performance. Previous studies have employed multiple analyses, such as the Rasch model analysis [46]–[48], confirmatory factor analysis, t-test, and others to conduct an evaluation analysis. Usability testing analysis is one of the approaches for evaluating the design and development of products. The evaluation of SCIENEX was carried out in this study using usability testing of the screen, navigation, content, and ease of use. A survey was conducted to test the usability of SCIENEX on 30 secondary school students. After using SCIENEX, they answered the questionnaire that was adapted from previous study [49]. The questionnaire has five parts: demographics (4 items), screen (6 items), navigation screen (7 items), content screen (4 items), and ease of use screen (4 items). Before proceeding with the data collection, two experts who were senior lecturers from one Malaysian university validated the questionnaire. A pilot study was conducted on 15 secondary school students, and the result revealed that the value of Cronbach's alpha was 0.91; the score is almost perfect [50]. Thus, the questionnaire used was valid and reliable for this study.

After that, the effect of SCIENEX was evaluated based on students' performance using pre-test, post-test, and t-test. The pre-test consists of ten subjective questions regarding the reactivity of metals, whereas the post-test includes the same questions as the pre-test. However, the numbering for the questions was rearranged to avoid students from remembering that they are the same questions. The pre-test and post-test were validated by three experts who are teachers who taught chemistry in school. To establish the reliability of the pre-test and post-test, this study conducted a test-retest on 15 students for the pilot study. The reliability of the pre-test and post-test was obtained via the test-retest for the correlation coefficient. The result reveals that the correlation coefficient was 0.93, which is categorized under the higher and good category. Thus, it is proven that all items in the pre-test and post-test were consistent and could be used for this study.

3.   RESULTS AND DISCUSSION
3.1. Result of validity of SCIENEX

The results of the validity test for SCIENEX from the experts' perspective are shown in Table 1. Several criteria were evaluated by the five experts. Four experts evaluated the design of SCIENEX as excellent, and one expert assessed it as good. All the experts evaluated that all elements in SCIENEX as excellent. In addition, all the experts evaluated the ease of understanding of SCIENEX as excellent. Then, four experts evaluated the usability of SCIENEX as excellent and one of the experts evaluated it as good. All the experts also stated that SCIENEX is fun and enjoyable for learning chemistry. Next, the content of SCIENEX was evaluated as excellent by all experts. Thus, it was proved that SCIENEX is a valid and appropriate MAR tool for learning chemistry. The experts' validation in the development of an AR application is very important to establish its validity in terms of media, content, and design [51], [52]. The experts' judgement was also important to improve SCIENEX, if any improvement were needed. Thus, it is established that SCIENEX can be used for learning chemistry.

Table 1. The validity of SCIENEX

Criteria	Experts	1-2 Need improvement	3-4 Average	5-6 Fairly good	7-8 Good	9-10 Excellent
Design of SCIENEX	1					/
	2					/
	3					/
	4					/
	5				/	
Elements in SCIENEX	1					/
	2					/
	3					/
	4					/
	5					/
Ease of understanding SCIENEX	1					/
	2					/
	3					/
	4					/
	5					/
Usability of SCIENEX	1					/
	2				/	
	3					/
	4					/
	5					/
Fun and enjoyment of SCIENEX	1					/
	2					/
	3					/
	4					/
	5					/
Content of SCIENEX	1					/
	2					/
	3					/
	4					/
	5					/

3.2. Result of usability of SCIENEX
3.2.1. Demographic of respondents

The result from the demographic section of the survey revealed that 67% (n=20) of the students were male, while 33% (n=10) were female. Most of them (100%) agreed that metal reactiveness was a difficult topic, and they also agreed that SCIENEX helped them to learn metal reactiveness better. Table 2 shows the result of the demographics in this study. Midak *et al.* [53] revealed that using AR could help students to visualize some images for learning chemistry, while Schez-Sobrino *et al.* [54] stressed that AR is one of the modern approaches that supports visualization from 2D notation to 3D. Thus, it is proven that AR is a powerful tool to visualize images in helping students understand complex topics or subjects.

Table 2. Demographic of respondents

Items		Frequency (n)	Percentages (%)
Gender	Male	20	67
	Female	10	33
Metal reactiveness is a difficult topic	Yes	30	100
	No	0	0
SCIENEX helps students to learn metal reactiveness better	Yes	30	100
	No	0	0

3.2.2. Screen of SCIENEX

Usability testing was used to evaluate SCIENEX based on the screen of SCIENEX as in Figure 11. A total 100% of the students strongly agreed that SCIENEX is fun and that the use of sound made learning easy, that its menu was easy to use, and it had a simple design. In addition, 99% of the students strongly agreed and 1% agreed that SCIENEX has a selectable button. Meanwhile, 92% of the students strongly agreed and 8% agreed that SCIENEX has a simple menu design. This finding proved that AR can make learning more fun [55]. Similarly, Yavuz *et al.* [56] also found that an AR application could make students enjoy and have fun in their learning. A good screen can affect students' learning satisfaction, as they are comfortable with their learning tools. Similar findings were revealed Chou *et al.* [57] in which AR is related to students' learning satisfaction.
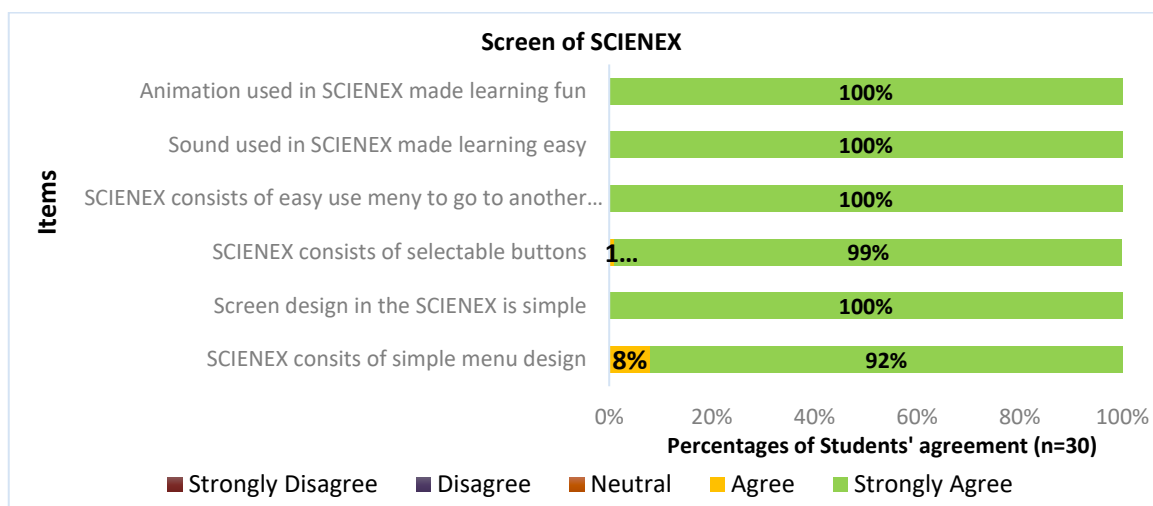

Figure 11. Result of usability testing for the screen of SCIENEX

3.2.3. Navigation of SCIENEX

Next, another usability test was conducted on SCIENEX to assess its navigation. Figure 12 shows the result of this test. 100% of the students strongly agreed that SCIENEX has a detectable quick response (QR), short loading time, and straightforward application. They also agreed that it is simple to go to another menu, and the button works well when it is touched. In addition, 5% of the students agreed that when using SCIENEX they know where they are in the application and 2% of the students agreed that SCIENEX is a responsive application. AR has been used by other studies for the development of a mobile application because it can provide excellent navigation [58]–[60].
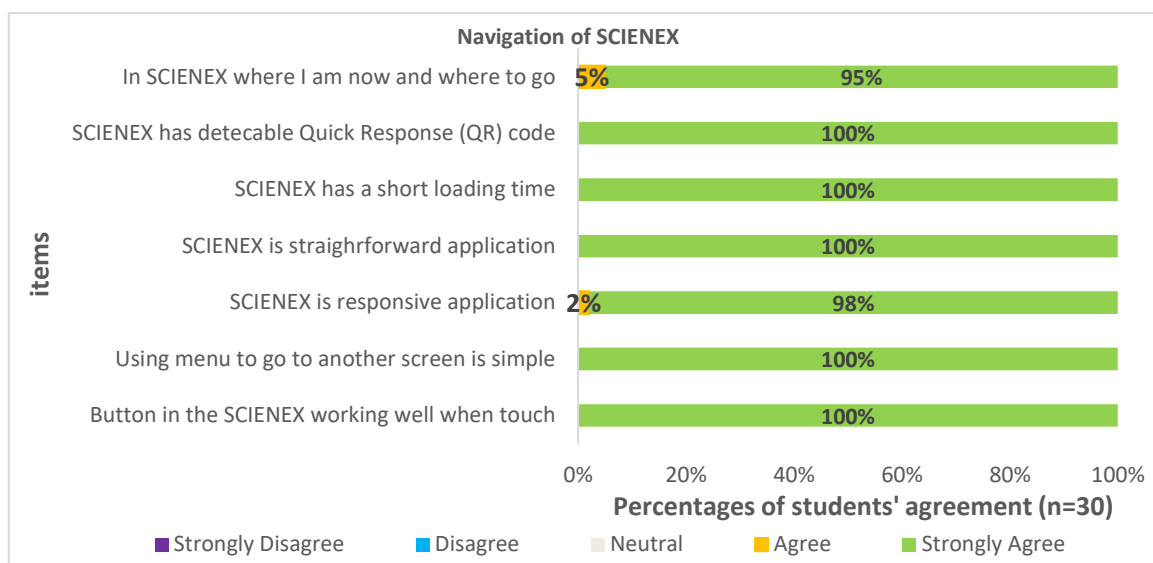
Figure 12. Result of usability testing for the navigation of SCIENEX

3.2.4. Content of SCIENEX

The usability testing of the content of SCIENEX was also evaluated; 100% of the students agreed that SCIENEX has helped them to differentiate the type of reaction process clearly (i.e., potassium, sodium, and lithium), while 98% of the students strongly agreed and 2% of the students agreed that SCIENEX helped them in distinguishing metal reactiveness (i.e., potassium, sodium, and lithium). This finding is supported by previous researchers [54], [61] who found that AR can help students to visualize content that is difficult to differentiate via teaching and learning in the classroom. Next, 94% of the students strongly agreed and 6% agreed that SCIENEX provides fun learning experiences. Abdinejad *et al.* [62] proved that using an AR application can boost students' enjoyment of learning. In addition, Kao and Ruan [63] found that AR can make students' learning fun. In total, 97% of the students strongly agreed and 3% agreed that SCIENEX contained useful information. This finding is strongly supported by several studies [64], [65] which stated that AR can help students learn better and have a better understanding of the reaction for potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) with water when using SCIENEX through visualization in AR. Figure 13 shows the result of usability testing for the content of SCIENEX.
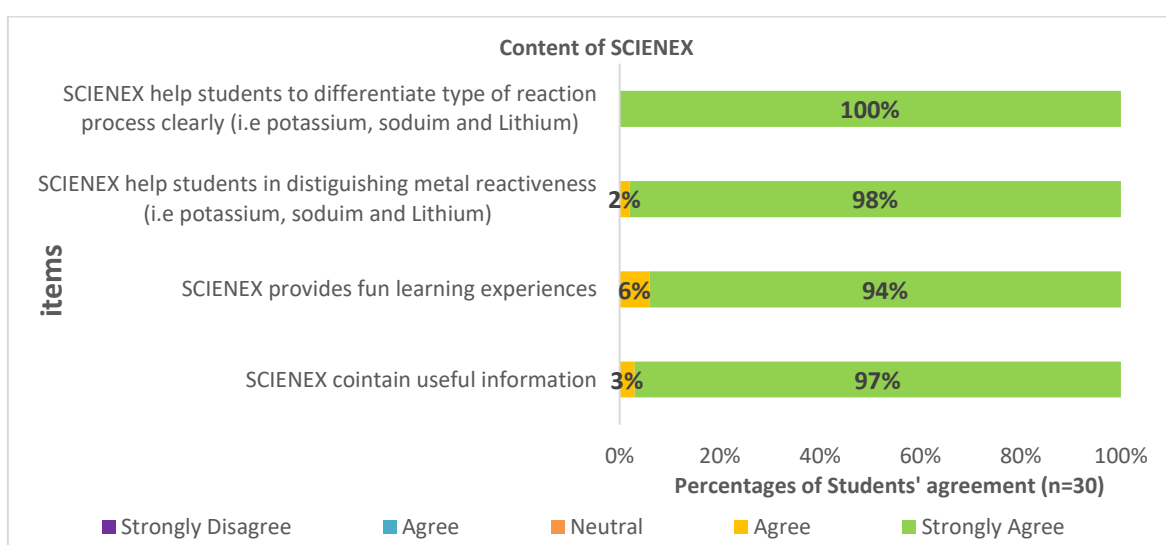

Figure 13. Result of usability testing for the content of SCIENEX

3.2.5. Ease of use of SCIENEX

The ease of use of SCIENEX was evaluated as seen in Figure 14. All (100%) of the students strongly agreed that SCIENEX used simple language. This helps students to become faster, better, and smarter in understanding the content they are learning [66]. In addition, 96% of the students strongly agreed and 4% agreed that SCIENEX used simple words. Stahl and Nagy [67] strongly supported that the use of simple and meaningful words can help students to understand the learning content. Meanwhile, 98% of the students strongly agreed and 2% agreed that they felt happy when using SCIENEX. Kasinathan *et al*. [68] revealed that AR promotes interactive learning that is interesting and enjoyable with easy navigation. Finally, 95% of the students strongly agreed and 2% agreed that they could remember how to use SCIENEX. The interface used in SCIENEX helped students utilize it and they could easily remember how to use it.
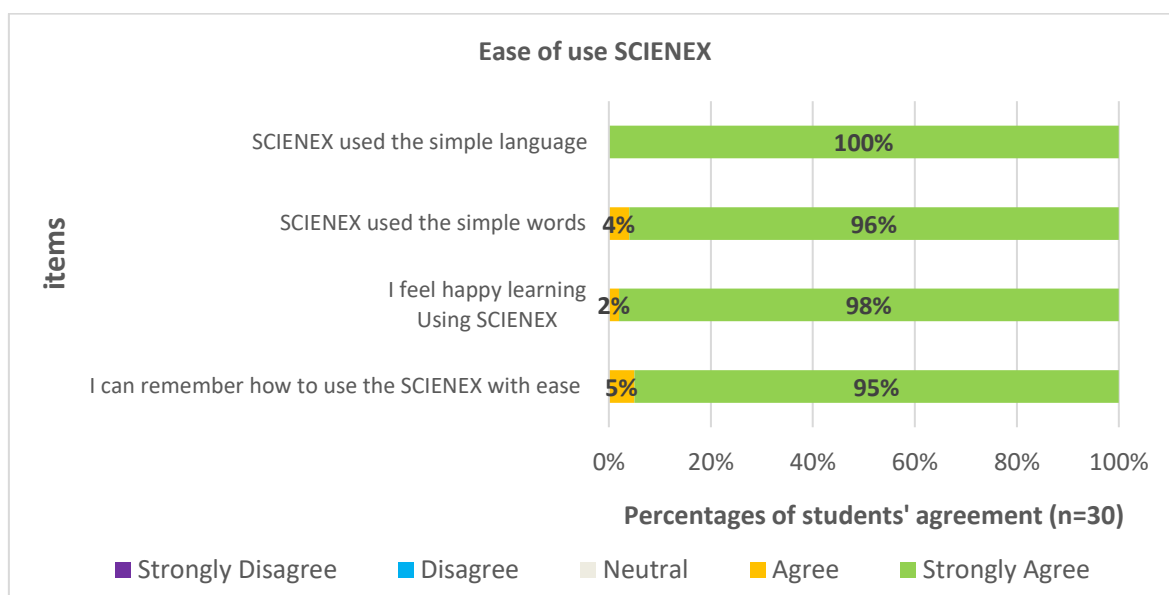

Figure 14. Result of usability testing for the ease of use of SCIENEX

3.3. The results of the effect of SCIENEX on students' performance

This section discusses the evaluation of the students' performance before and after using SCIENEX. The result indicates that students' marks increased from the pre-test to the post-test as shown in Figure 15. Thus, all the students improved their marks after learning the reaction for potassium (*kalium*), sodium (*natrium*), and lithium (*litium*) with water using SCIENEX. After that, a t-test was conducted to examine the effect of SCIENEX on students' performance. Normality tests need to be conducted before proceeding to the t-test analysis. Kolmogorov-Smirnov and Shapiro-Wilk tests were conducted to test the normality data. The results of both tests revealed that p>0.005, due to Kolmogorov-Smirnov (pre-test; p=0.182, post-test; p=0.200) and Shapiro-Wilk (pre-test; p=0.555, post-test; p=0.268). Thus, the data for the pre-test and post-test are normally distributed. Table 3 shows the result of the normality test. Both the pre-test and post-test had correlation which is 0.750 and significant as presented in Table 4. In order to assess the effect of SCIENEX on students' performance, a paired sample t-test was used. The result revealed that t=21.754, p=.000, which is less than 0.005 as seen in Table 5. Thus, the null hypothesis was rejected. Based on the result found, it can be concluded that using SCIENEX increased students' performance.

This study finding is in accordance with several studies, which found that using an AR application can help students by improving students' performance. Several studies, such as Estapa and Nadolny [69], found the effect of an AR-enhanced mathematics lesson on student achievement; Ibáñez *et al*. [70] revealed the impact of AR technology on the increased academic achievement of students from public and private Mexican schools; Fidan and Tuncel [71] revealed that applying AR to problem-based learning increased the learning achievement in physics students. Thus, it supported the claim that using AR helps students' learning. This is due to the powerful technology of AR, which makes it possible to visualize the learning for abstract topics or subjects in an interesting manner [33], [72]–[78].
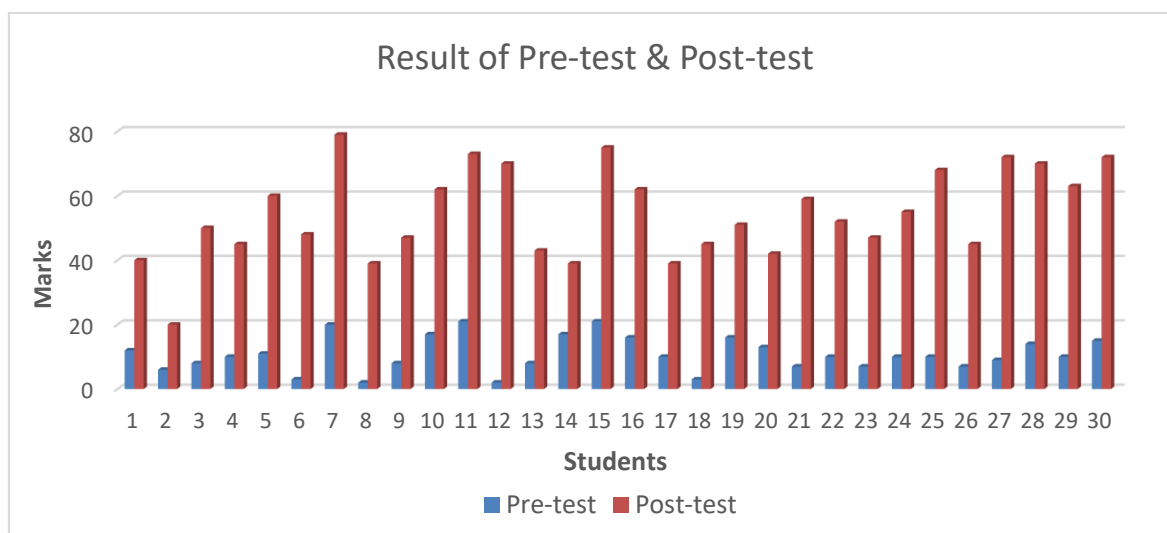
Figure 15. Pre-test and post-test

Table 3. Normality test

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig
Pretest	146	30	103	967	30	466
Posttest	109	30	200*	954	30	216

*. This is a lower boundary of the true significance.
a. Lilliefors significance correction.

Table 4. Paired samples statistics

	Mean	N	Std. Deviation	Std. Error Mean	Correlation
Pre-test	10.5333	30	4.62179	84382	750
Post-test	54.4000	30	14.07762	2.57021	

Table 5. Paired samples t-test

	Paired differences							
	Mean	Std. Deviation	Std. Error mean	95% confidence interval of the difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Posttest-pretest	43.86667	11.04453	2.01645	47.99076	39.74257	21.754	29	000

4. CONCLUSION

This study has proposed an augmented reality tool, namely science exploration (SCIENEX), for studying the chemistry subject for secondary school students. SCIENEX is a technology tool, which was developed using mobile augmented reality, to teach chemistry to secondary school students. It is an established and valid tool for learning chemistry based on the experts' evaluation. The usability testing of SCIENEX has proven that it can be used in learning chemistry based on the users' perspective. In addition, SCIENEX has also increased students' performance in learning chemistry. The findings from this study indicated that students provided positive feedback and agreed that this application helps them to get a better understanding of chemistry. The findings also provided insights into the integration of technology in teaching and learning, specifically augmented reality.

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