Intelligence Augmented Reality Tutoring System for Mathematics Teaching and Learning

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Abstract

This study developed an interactive Intelligence Augmented Reality Tutoring System (IARTS) for mathematics teaching and learning. IARTS consists of learning aid, virtual tutor, and guiding mechanism for mathematics problem solving. One hundred thirty-seven eighth grade students from four classes of a southern Taiwan junior high school participated in this study. Two classes were set as the experimental group with 67 students using the IARTS. Two classes were the control group with 70 students using multimedia material with a QR code that linked to a YouTube channel. A set of questionnaires was administered to evaluate students' learning motivation and system acceptance. Also, a semi-structured focus group interview of both students and teachers was conducted. The results showed that learning motivation and system acceptance of the experimental group were not significantly better than the control group. The theoretical implications of using augmented reality for teaching and learning are discussed and practical implications are proposed.

Keywords: Augmented reality, Intelligent tutoring system, Interactive learning environment, Learning motivation

1 Introduction

Many educational institutions have developed computer-based systems, software, and applications to facilitate teaching and learning. A variety of emerging technologies such as internet of things, tablet computing, gamification, virtual reality (VR), and augmented reality (AR) have been developed in recent years. Previous researchers have pointed out the application of AR and VR as teaching aids or as instructional strategy to facilitate teaching and learning [1-3]. AR and VR have enriched educational strategies. For example, Billinghurst, Mark, Belcher, Gupta, and Kiyokawa [4] empirically supported that using AR as a teaching aid helped the interaction between teachers and students. AR has also been shown to be effective in improving academic achievement compared to traditional teaching methods [5-6].

In Taiwanese junior high schools, students often encounter many setbacks and difficulties in learning mathematics and do not perform very well on tests. Thus, this study pioneered an interactive Intelligence Augmented Reality Tutoring System (IARTS) for mathematics teaching and learning. IARTS consists of learning aid, virtual tutor, and guiding mechanism for mathematics problem solving. If students did not understand contents in the class, they could use the IARTS system to learn by themselves at home. It is a novel application with visual effects and simple intuitive interaction that combines virtual teaching materials and the guidelines for problem solving. With the help of IARTS and interactive guidance in their learning process, students learn the fundamentals of the content more effectively, improving their learning outcome and achieving a better understanding of mathematics.

2 Literature Review

2.1 Characteristics / Classification of Augmented Reality (AR)

Augmented Reality (AR) is an emerging technology used as a teaching aid in many aspects of education. AR has three characteristics: (1) the combination of real and virtual objects in a real environment, (2) real time interaction, and (3) virtual objects registered in 3D [7]. AR allows virtual objects to be seamlessly overlaid onto views of the real world [8]. In addition, there are two methods of displaying AR: (1) See-Through AR and (2) Monitor-Based AR. See-Through AR allows users to directly view the surrounding environment through the monitor. The monitor also displays the virtual image, which merges elements of a physical real-world environment with virtual computer-generated imagery such as images, photos, 3D objects or scenes. The Monitor-Based AR combines images captured by the webcam with virtual

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images, permitting their viewing on Head Mounted Display (HMD) or a computer monitor [9].

Milgram and Kishino [9] consider the real environment and the virtual environment as a continuum, as shown in Figure 1. They represent the two ends of the continuum, respectively. The left shows a real environment which is inwardly contracted to form Augmented Reality (AR), while the right depicts a virtual environment from which Augmented Virtuality is formed when contracted inwardly. Mixed Reality (MR) is located in between the real environment and the virtual environment. Mixed reality is a combination of AR and AV, the real world and the virtual environment to create a virtual image which in line with human vision, so that people can instantly interact with virtual objects.

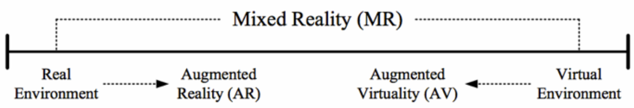


Figure 1. Schematic diagram of real and virtual performance [9]

AR technology works by identifying the target object and then tracking the identified objects. The imposed virtual images are then tacked onto the object which is then presented on the display device. At present AR is divided into three categories [10], (1) marker-based AR: using the black box as a marker for better identification and tracking; (2) markerless AR: identifies and tracks natural patterns, like photos, wedding invitations, greeting cards, posters, business cards, credit cards, brochure and so on, as image processing technology has advanced, the most common form of AR is markerless; (3) location based services (LBS) AR or “mobile location service,” “geo location service” and “location service.” Geographic location is the basic application of value-added services. LBS is the mobile device GPS positioning function to provide the current location.

2.2 AR Applications

Billinghurst, Kato, and Poupyrev [8] exploited AR to design a set of books called “Magic” book. AR books look like common paper books, but they are presented by AR with 3D animation to visualize the contents of the book. Therefore, learners can use the handheld HMD to experience the AR scenes in Magic books. Such reading method can help users turn their imaginary world into reality and then inspire more imagination when reading. In addition, Dünser and Hornecker [11] observed the condition of students’ reading AR textbooks from tablets and found that students’ reaction and engagement with AR textbooks was higher than traditional textbooks. Moreover, Liarokapis, Petridis, Lister, and Liarokapis, Petridis Lister, and White [12] proposed a Multimedia Augmented Reality Interface E-Learning (MARIE), which was later successfully implemented to transform education in order to enhance teaching and learning methods. Likewise, with the wide use of smart phones, AR is set to become a ubiquitous commodity for mobile learning. For example, Specht, Ternier, and Greller [13] indicated AR applications on smart mobile phones have created interactive experiences for users.

Furthermore, Fjeld, Juchli, and Voegtli [14] reported that tangible interaction of AR could be brought to chemistry education and described a Tangible User Interface (TUI) and Augmented Chemistry (AC) by giving details on basic and specialized interactive tools working in this system and outlining the educational context. Soga, Matsui, Takaseki, and Tokoi [15] developed AR guidance and diagnosis function of constellations’ shapes in learning astronomy with the Wii remote controller. Likewise, Sunyoung, Junhun, Yeongmi, and Ryu [16] proposed a preliminary AR system framework for ‘Sil-Gam’ book where users could experience virtual contents through haptic interaction. It provides readers with realistic or abstract experiences of contents through virtual and augmented reality technologies.

There has been a rapid adoption of AR in wider educational fields. One mathematical-based application is Construct3D. It offers a three-dimensional geometric construction tool specifically designed for mathematics and geometry education. It is based on the mobile collaborative augmented reality system, “Studierstube,” which is a system for improving spatial abilities and maximizing the transfer of learning [17]. Also, Juan, Beatrice, and Cano [18] presented an AR system for learning the inner human body. This system could be improved by adding new organs. They tested the systems with children from the Summer School of the Technical University of Valencia. They also analyzed whether the use of a Head-Mounted Display or a typical monitor influenced the experience of the children. AR can further be applied in music teaching. Feng, Yu, Yao, Ziqiang, and Sidan [19] presented a novel markerless augmented reality based on a piano teaching system, tracking the actual keyboard of a piano. Following the virtual hands augmented teaching on the keyboard, beginners can practice playing the piano naturally. Moreover, AR has applications in learning Chinese. Chen et al. [20] proposed a prototype of AR learning system that enabled school children to have a better understanding in the pronunciation and memorization of Chinese. This evidently enhanced the learning motivation and interest of school children. This study showed an interesting way to promote Chinese phonetic alphabet learning via AR environment. The project revealed that AR did make the interaction and interface more user-friendly so that the children became more immersed in the learning scenario.

Although AR has been applied widely in education curriculums, most studies have concentrated on a one-sided study, either teacher's teaching or student's learning. However, they have neglected that teaching and learning is closely intertwined. Above all, AR, which turns abstract ideas into concrete concept, is not necessarily utilized in all researches. As a result, this research, focusing on mathematics, probes into not only the teacher's teaching but also the students' learning.

3 Intelligence Augmented Reality Tutoring System (IARTS) Learning Environment

This study established an IARTS for mathematics teaching and learning. The IARTS consists of learning aid, virtual tutor, and guiding mechanism for mathematics problem solving. The development of IARTS was based on the software development kit (SDK) Vuforia and the Unity game engine. Students used a smartphone camera to preview a textbook on the display to present a view of the real world. The interactive user interface and menu were then superimposed on the smartphone camera preview in real-time. The virtual tutor, learning materials, and virtual objects appear to be overlaid on the textbook. The development of IARTS processing procedure consists of the following: (1) designing markerless pattern: designing pictures as the AR markerless pattern in order to recognize IARTS; (2) creating tracking: creating identifiable features used for system recognition and tracking; (3) designing learning materials: designing and modelling the learning content that include virtual tutor model, learning contents, pictures, and video materials; (4) designing user interface (UI): using Photoshop and Illustrator to design the interactive menu and import to Unity; (5) building AR environment: designing and creating AR learning environment in Unity; (6) programming C# script: programming interactive function script; and (7) publishing application: compiling the application and generating the Android Package (apk). The final IARTS for mathematics teaching and learning is now available on Google Play (Figure 2).

Figure 2. IARTS for mathematics teaching and learning on Google Play

On the main screen of IARTS, there are four interactive buttons: (1) course units, (2) course descriptions, (3) exit system, and (4) acknowledgement as shown in Figure 3.

Figure 3. IARTS main screen

The learning materials were based on an 8th grade, junior high school, textbook that was assigned from Ministry of Education in Taiwan. The IARTS lesson units in this study focused on arithmetic progression and arithmetic series and geometric figure and geometric construction (Figure 4).

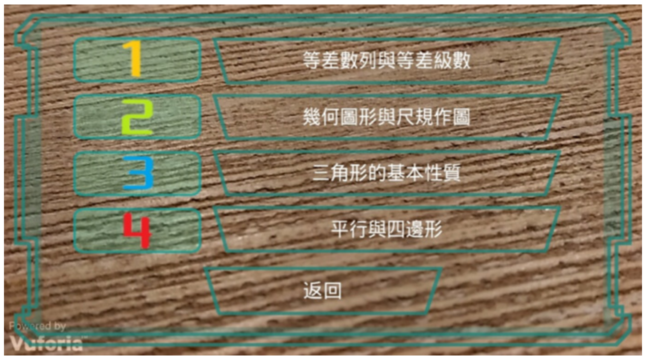


Figure 4. IARTS lesson units

Figure 5 shows the practice session menu. Users click on a cell and the equal progression menu is presented. The first unit's chapter sub-menu include 1-1 equal difference columns, 1-2 equal progression series, Chapter 1 comprehensive exercises, and Return to previous page button. Figure 6 shows the second practice session unit, Geometry and Ruler Drafting menu. Users click on the menu button, which brings up 2-1 Life Plane, 2-2 Vertical, Bisection and Line Symmetry, 2-3 Ruler Drawing, Chapter 2 Comprehensive Exercise, and Return to Previous Page Buttons.

4 Experimental Design

4.1 Participants

There were 137 eighth grade students from four classes of a southern Taiwan junior high schools in this study. The average age of those students were between 13 and 14 years old. All students possessed a smartphone

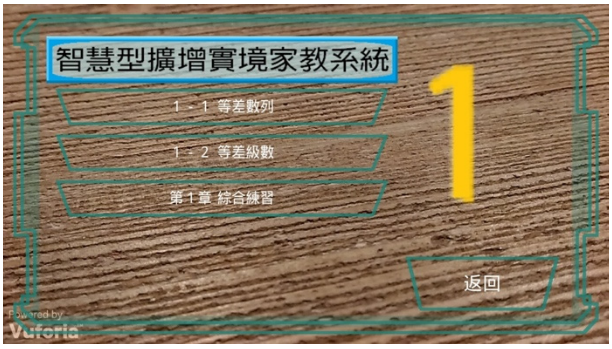


Figure 5. IARTS Chapter 1 subunits

Figure 6. IARTS Chapter 2 subunits

as a requirement. Two classes were set as the experimental group with 67 students using the Intelligence Augmented Reality Tutoring System (IARTS). The other two classes were set as the control group with 70 students using multimedia material with QR code that linked to a YouTube channel. The same instructor was responsible for these four classes. Figure 7 shows an experimental group's student using IARTS. Figure 8 is IARTS processing the contents. There are two buttons in Figure 9, the return button and share button. The return button returns to the course content list and the share button shares the learning content screen with other students via Line, Facebook messenger, WeChat, and other communication apps. Figure 10 illustrates the student operation process, Chapter1 - Arithmetic sequence and Arithmetical progression, and Chapter 2 - Geometry and ruler drawing, respectively.

Figure 7. Experimental group's student using IARTS

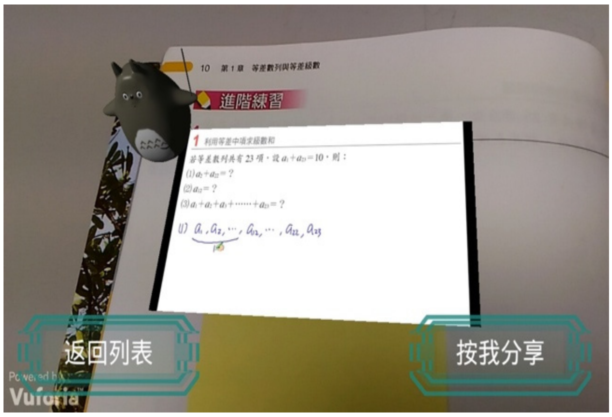


Figure 8. Student learning content

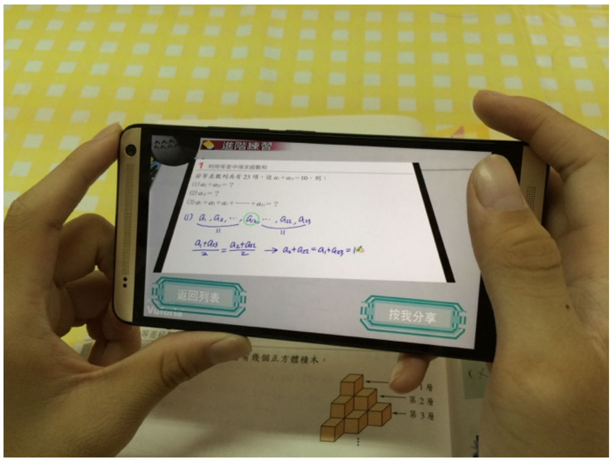


Figure 9. Student operation process (Chapter1 - Arithmetic sequence and Arithmetical progression)

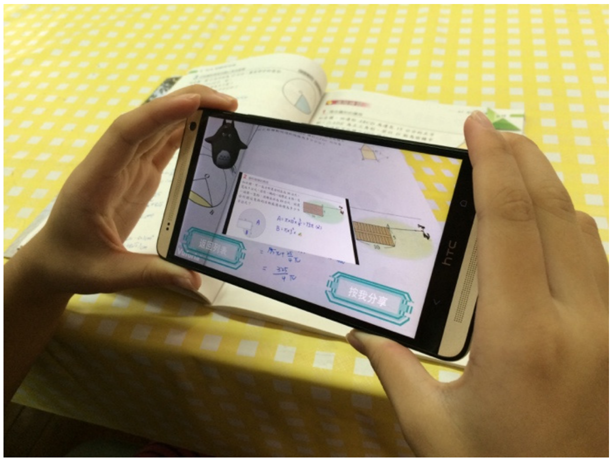


Figure 10. Student operation process (Chapter 2 - Geometry and ruler drawing)

4.2 Procedure

The experimental procedure is illustrated in Figure 11. This study first assigned students into groups. The random sampling technique was used to assign students into either the experimental or control group. Next, teachers introduced the learning activity and task, which included the purpose and importance of this study. After the introduction to the learning activity and task, both the experimental and control groups spent 100 minutes to participate in either IARTS approach or multimedia learning with QR code that linked to a YouTube channel. For the experimental group, students first setup their smart phones in the classroom. This preliminary procedure included linking to the wireless network, downloading the app, and installing IARTS. The IARTS learning materials included the arithmetic progression and arithmetic series and the geometric figure and geometric construction. After the experiment finished, a set of questionnaires was administered to both groups to evaluate students' motivation and system acceptance. After the questionnaire, interviews were conducted with both students and teachers to gather their opinions and suggestions for future improvement.

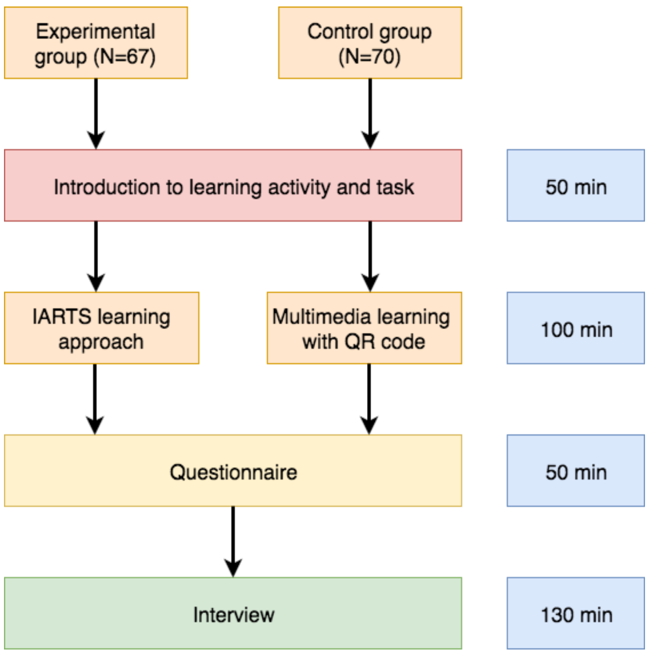


Figure 11. Experimental procedure

4.3 Instrument

A set of questionnaires was developed based on previous studies to evaluate students' learning motivation and system acceptance. In addition, the questionnaires were reviewed by two experts to ensure content validity of the instrument. First, the Instructional Material Motivational Survey (IMMS) (Figure 12 and Figure 13) was conducted to assess students' learning motivation. The IMMS instrument is based on the ARCS motivation model [21-22] and was slightly modified for the AR content to meet the purpose of this research. IMMS consisted of 36 questions measured on a five-point Likert-scale. The response of 1 represented "strongly disagree" and 5 stood for "strongly agree." The Cronbach's α values of the four dimensions were 0.80, 0.78, 0.65 and 0.82, respectively.

教材動機量表

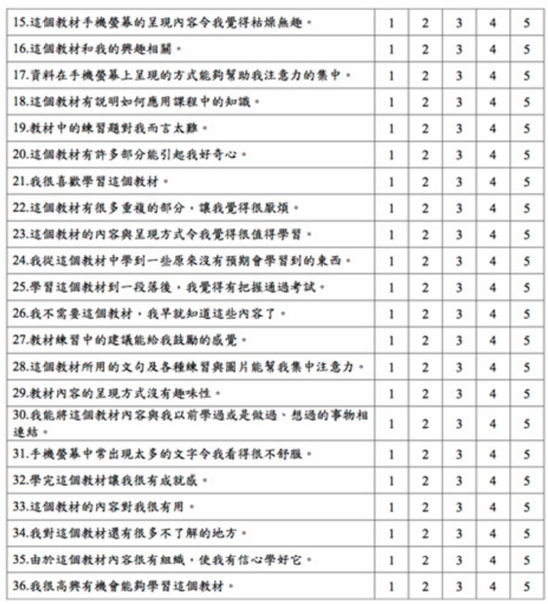
班級：＿＿＿＿＿＿ 姓名：＿＿＿＿＿＿ 座號：＿＿＿＿

【作答說明】

1. 主要為瞭解學生使用智慧型手機操作擴增實境教材後的動機。動機只是程度上的不同，並無好壞之分，也沒有標準答案，請安心作答，本問卷共 36 題。
2. 您的回答很重要，這份量表將會對學術研究與老師教學有所幫助，請務必認真作答，而問題的回答並沒有對錯之分，請依據您對每個題目的「第一個反應」來回答問題，不需要考慮太久。
3. 請依照您對下列各題敘述內容的符合程度，圈選出最代表自己情況的數字，每題只圈一個數字。
4. 請不要遺漏任何一個題目。
5. 務必寫上你的班級、姓名、座號。

教材動機量表	非常不符合	不符合	符合	大多符合	非常符合
1.這個教材對我而言剛剛好，不會太難也不會太簡單。	1	2	3	4	5
2.這個教材的每個部分都有一些引人注意的內容，吸引我的注意力。	1	2	3	4	5
3.這個教材比我本來想像中更難。	1	2	3	4	5
4.當我聽完老師最前面的介紹之後，我知道我會在這個教材學到什麼。	1	2	3	4	5
5.當我學完這個教材的全部內容，我感到很滿足。	1	2	3	4	5
6.我明白這個教材的內容和我以前學過的知識連貫起來。	1	2	3	4	5
7.手機螢幕出現太多東西，害我捉不住重點。	1	2	3	4	5
8.這個教材有許多部分看起來非常吸引人。	1	2	3	4	5
9.教材中有圖片或例子說明這個課程的重要性。	1	2	3	4	5
10.這個教材的內容對我而言非常重要。	1	2	3	4	5
11.這個教材的呈現方式能幫助我集中注意力。	1	2	3	4	5
12.這個教材的內容太抽象了，讓我很難集中注意力。	1	2	3	4	5
13.當我再學習這個教材的時候，我有信心能夠學好它。	1	2	3	4	5
14.我很喜歡這個教材，希望有機會再多學習這方面的知識。	1	2	3	4	5

Figure 12. The questionnaire of IMMS page 1

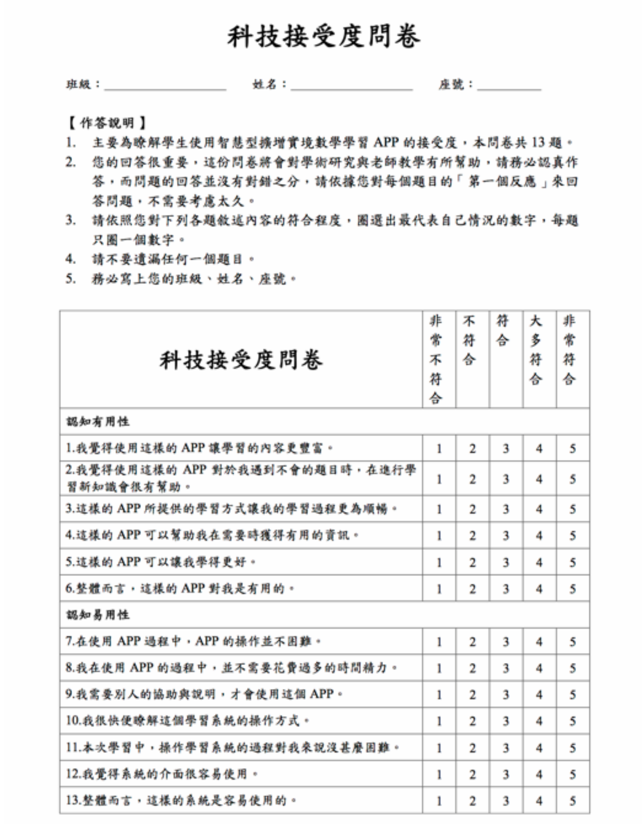


15.這個教材手機螢幕的呈現內容令我覺得枯燥無趣。	1	2	3	4	5
16.這個教材和我的興趣相關。	1	2	3	4	5
17.資料在手機螢幕上呈現的方式能夠幫助我注意力的集中。	1	2	3	4	5
18.這個教材有說明如何應用課程中的知識。	1	2	3	4	5
19.教材中的練習題對我而言太難。	1	2	3	4	5
20.這個教材有許多部分能引起我好奇心。	1	2	3	4	5
21.我很喜歡學習這個教材。	1	2	3	4	5
22.這個教材有很多重複的部分，讓我覺得很厭煩。	1	2	3	4	5
23.這個教材的內容與呈現方式令我覺得很值得學習。	1	2	3	4	5
24.我從這個教材中學到一些原來沒有預期會學習到的東西。	1	2	3	4	5
25.學習這個教材到一段落後，我覺得有把握通過考試。	1	2	3	4	5
26.我不需要這個教材，我早就知道這些內容了。	1	2	3	4	5
27.教材練習中的建議能給我鼓勵的感覺。	1	2	3	4	5
28.這個教材所用的文句及各種練習與圖片能幫我集中注意力。	1	2	3	4	5
29.教材內容的呈現方式沒有趣味性。	1	2	3	4	5
30.我能將這個教材內容與我以前學過或是做過、想過的事物相連結。	1	2	3	4	5
31.手機螢幕中常出現太多的文字令我看得很不舒服。	1	2	3	4	5
32.學完這個教材讓我很有成就感。	1	2	3	4	5
33.這個教材的內容對我很有用。	1	2	3	4	5
34.我對這個教材還有很多不了解的地方。	1	2	3	4	5
35.由於這個教材內容很有組織，使我有信心學好它。	1	2	3	4	5
36.我很高興有機會能夠學習這個教材。	1	2	3	4	5

Figure 13. The questionnaire of IMMS page 2

Second, perceived usefulness and perceived ease of use were used to assess students' system acceptance toward using IARTS or multimedia learning (Figure 14). This questionnaire was based on previous studies [23-26]. The 13 questions with a five-point Likert-scale measurement: 1 represented "strongly disagree" and 5 signified "strongly agree." The Cronbach's α of the entire questionnaire was 0.87. The value indicated sufficient internal consistency for assessing the students' acceptance of using IARTS or multimedia learning.

After completing the questionnaire, interviews were conducted to gather opinions and suggestions from both students and teachers. A semi-structured focus group interview [27] was conducted with 67 students from the experimental group. Each focus group interview with six to eight students lasted around eight to fifteen minutes. Teachers were also interviewed to gather their opinions and suggestions of using IARTS.



科技接受度問卷

班級：＿＿＿＿＿ 姓名：＿＿＿＿＿ 座號：＿＿＿＿

【作答說明】

1. 主要為瞭解學生使用智慧型擴增實境數學學習 APP 的接受度，本問卷共 13 題。
2. 您的回答很重要，這份問卷將會對學術研究與老師教學有所幫助，請務必認真作答，而問題的回答並沒有對錯之分，請依據您對每個題目的「第一個反應」來回答問題，不需要考慮太久。
3. 請依照您對下列各題敘述內容的符合程度，圈選出最代表自己情況的數字，每題只圈一個數字。
4. 請不要遺漏任何一個題目。
5. 務必寫上您的班級、姓名、座號。

科技接受度問卷	非常不符合	不符合	符合	大多符合	非常符合
認知有用性					
1.我覺得使用這樣的 APP 讓學習的內容更豐富。	1	2	3	4	5
2.我覺得使用這樣的 APP 對於我遇到不會的題目時，在進行學習新知識會很有幫助。	1	2	3	4	5
3.這樣的 APP 所提供的學習方式讓我的學習過程更為順暢。	1	2	3	4	5
4.這樣的 APP 可以幫助我在需要時獲得有用的資訊。	1	2	3	4	5
5.這樣的 APP 可以讓我學得更好。	1	2	3	4	5
6.整體而言，這樣的 APP 對我是有用的。	1	2	3	4	5
認知易用性					
7.在使用 APP 過程中，APP 的操作並不困難。	1	2	3	4	5
8.我在使用 APP 的過程中，並不需要花費過多的時間精力。	1	2	3	4	5
9.我需要別人的協助與說明，才會使用這個 APP。	1	2	3	4	5
10.我很快便瞭解這個學習系統的操作方式。	1	2	3	4	5
11.本次學習中，操作學習系統的過程對我來說沒甚麼困難。	1	2	3	4	5
12.我覺得系統的介面很容易使用。	1	2	3	4	5
13.整體而言，這樣的系統是容易使用的。	1	2	3	4	5

Figure 14. The questionnaire of perceived usefulness and perceived ease of use

5 Results

5.1 Quantitative Data Discussion

Students' learning motivation was conducted after the learning activity. Table 1 shows descriptive statistics of learning motivation of the two groups. The t-test result shows that the learning motivation of the experimental group was not significantly better than the control group ($t = 1.155$, $p \geq .05$). This implies that both the IARTS approach and the multimedia with QR code that linked to YouTube were both helpful in enhancing students' learning motivation.

Table 1. Descriptive statistics of learning motivation of the two groups

Group	N	Mean	SD	*t*	Sig.
Experimental group	67	3.44	1.09	1.155	.567
Control group	70	3.31	1.07		

$^{*}p \geq .05$

In addition, system acceptance was conducted after the learning activity. Table 2 shows descriptive statistics of system acceptance of the two groups. Perceived usefulness and perceived ease of use were the dimensions for the measurement. The t-test result shows that the system acceptance of the experimental group was also not significantly better than the control group ($t = 1.415$, $p \geq .05$). This supports the conclusion that both IARTS and multimedia were accepted system for students' learning.

Table 2. Descriptive statistics of system acceptance of the two groups

Group	N	Mean	SD	*t*	Sig.
Experimental group	67	4.13	0.93	1.415	.488
Control group	70	4.08	0.92		

$^{*}p \geq .05$

5.2 Interview with Students

Each focus group interview was around eight to fifteen minutes with six to eight students (Figure 15). During the interview phase, students expressed their opinions and suggestions regarding using IARTS. In general, students felt IARTS was interesting, convenient, interactive, and easy to use. They further expressed they could use IARTS anytime and anywhere they encounter problems or difficulties. In addition, IARTS could increase their learning motivation because they could use IARTS repeatedly to improve their learning performance, especially the memorization of mathematical formulae. They also described some improvements for system design and usability. For example, the app could improve the design of user interface in order to reduce the reading tiredness from the small screen. Moreover, students recommended that IARTS could add some functions in the future, such as subtitles, timing control, solutions scales, and speed adjustments of virtual tutoring explanations.

Figure 15. Interview process picture

Students' opinions and feedback were collected and summarized after interview as shown below.

- When difficulties are encountered, I can check the solution immediately, instead of spending too time looking for someone for help.
- It is easy to learn at home, even I don't understand, I don't need to work to find someone to ask.
- This can allow people who cannot afford to go to tutoring class, but still have the opportunity to study independently within their own academic progress.
- This changes the way of many children's learning.
- When curiosity occurred, I found it's more interesting to learn.
- For those students who are interested in modern technology but do not want to learn simply, the integration of AR would help with students' learning.
- This is a very useful APP for those students who don't go to tutoring class
- I like the function without access to internet after downloading.
- It is easy to use and understand, repeat play could help me to understand deeply and enhancing learning from boring to fun.
- I hope I can use it from textbook directly in the future.
- This APP allow me to learn mathematics more accessible, and the user interface was very simple and easy to use.
- Very useful and help me a lot when I encounter the question I don't know.
- It helps us to learn more easily and learning is not as boring as it used to be.
- This App let me think there is a virtual tutor there who can help me to understand deeper question in mathematics.
- This APP helps me to learn independently at home before going to school.
- Using mobile app could enhance my learning and increase my willingness to learn.
- Having this app could save some money and time going to tutoring school, and I can review the topic taught by the teacher alone.
- This app makes our learning more efficient, and I feel I become smarter, which could reduce my stress of learning and I think it helps teacher's frustration in teaching too.
- This App is very useful when I don't understand teacher's lecture, and very helpful to prepare exam could I can self-taught at home.

Opinion and suggestions for future improvement.

- I hope there is a quickly or reversely feature, cause use in a long time, users may feel tired on their hands.
- I hope other subject's textbook could have this app too.
- The latter on the screen may be too small for some people.
- Perhaps use tripod for additional accessory.
- If there is a cause-and-effect reason function after calculation would be great, not just the process of formulating calculation.
- I hope there is a tablet app version in the future, cause the screen is too small.
- I hope that I can adjust the speed based on my own learning paced.
- The user interface is not complete, and easy to use, but the voice explanation is not really clear.
- It is very easy to use, but only limited to students who have cell phone.
- If there is much virtual game that embed in the app or change the character from carton to a current movie star, a real-life person, or a bunch of selections, would increase the relevant, interested, and motivation.
- I think this app somehow lacks reality and real teaching.
- I wish there is a function that I can add my own text descriptions.

5.3 Quantitative Data Discussion

In the teacher interview phase, two mathematics teachers who participated in this study were interviewed. They described the advantages of using AR in their teaching and how helpful IARTS was. With the implementation of smartphone and AR, they could provide more interactive learning materials to students. Students could then learn anytime and anywhere they chose, motivating them to engage and participate in further classroom activities.

6 Conclusion and Discussion

This paper presented the results of an interactive Intelligence Augmented Reality Tutoring System (IARTS) experiment for the mathematics curriculum. Participants positively accepted the IARTS for mathematics teaching and learning.

The findings show IARTS could be used as virtual tutor with virtual materials for mathematics teaching and learning. Although there were not significant differences between the experimental and control groups, they remarked that guidance and personalization is a key to enhance the learning motivation and engagement. With the help of IARTS, teachers can make students' learning environment more interactive and pleasurable. IARTS not only provide the power to engage learner in a variety of interactive ways, but also provides each individual with unique rich content from three-dimensional learning environments.

A further contribution is the extension of the study by Kaufmann and Schmalstieg, which looked at 3D geometric construction tool specifically designed for mathematics and geometry education [17]. In addition, this study extended previous research by Keller which examined the motivational design for learning and performance and incorporated this with augmented reality to facilitate and enhance teaching and learning [21-22].

IARTS also supports the theory of constructivism where students construct their own understanding and knowledge and take control of their own learning. IARTS can provide motivating, entertaining, and engaging environments for mathematics teaching and learning. Students can further construct and integrate their knowledge and skills with 3D simulations generated by mobile devices. Finally, IARTS provide a cost-effective educational tool for students whose parents may be worried about finances.

In the view of many previous researches that has applied AR in their context, AR could probably be focused on further AR textbook design and development in terms of simplicity and ease of use. In addition, researchers can collaborate with publishers in Taiwan or other countries to create an IARTS-based, learning material, in various subjects such as English, Science, and History.

For future research, this study will further integrated AR learning material into different levels of mathematics courses, not only focused on secondary schools, but also primary school textbooks.

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References

[1] D. Pérez-López, M. Contero, M. Alcaniz, Collaborative Development of an Augmented Reality Application for Digestive and Circulatory Systems Teaching, *10th IEEE International Conference on Advanced Learning Technologies (ICALT 2010)*, Sousse, Tunisia, 2010, pp. 173-175.

[2] K. R. Bujak, I. Radu, R. Catrambone, B. Macintyre, R. Zheng, G. Golubski, A Psychological Perspective on Augmented Reality in The Mathematics Classroom, *Computers & Education*, Vol. 68, pp. 536-544, October, 2013.

[3] M. Bower, C. Howe, N. McCredie, A. Robinson, D. Grover, Augmented Reality in Education: Cases, Places and Potentials, *Educational Media International*, Vol. 51, No. 1, pp. 1-15, March, 2014.

[4] M. Billinghurst, D. Belcher, A. Gupta, and K. Kiyokawa, Communication Behaviors in Colocated Collaborative AR Interfaces, *International Journal of Human-Computer Interaction*, Vol. 16, No. 3, pp. 395-423, November, 2003.

[5] M. C. Hsieh, F. R. Kuo, H. C. K. Lin, The Effect of Employing AR Interactive Approach on Students' English Preposition Learning Performance, *Journal of Computers and Applied Science Education*, Vol. 1, No. 1, pp. 45-60, May, 2014.

[6] H. C. Chu, J. M. Chen, K. H. Yang, C. W. Lin, Development and Application of a Repertory Grid-Oriented Knowledge Construction Augmented Reality Learning System for Context-Aware Ubiquitous Learning, *International Journal of Mobile Learning and Organisation*, Vol. 10, No. 1-2, pp. 40-60, April, 2016.

[7] R. T. Azuma, A Survey of Augmented Reality, *Teleoperators and Virtual Environments*, Vol. 6, No. 4, pp. 355-385, August, 1997.

[8] M. Billinghurst, H. Kato, I. Poupyrev, The Magicbook-Moving Seamlessly Between Reality and Virtuality, *IEEE Computer Graphics and Applications*, Vol. 21, No. 3, pp. 6-8, May/Jun, 2001.

[9] P. Milgram, F. Kishino, A Taxonomy of Mixed Reality Visual Displays, *IEICE TRANSACTIONS on Information and Systems*, Vol. E77-D, No. 12, pp. 1321-1329, December, 1994.

[10] M. C. Hsieh, K. Y. Huang, *Augmented Reality is So Fun! A New Technology Application Combining Virtuality and Reality*, Sung Gang, 2016.

[11] A. Dünser, E. Hornecker, An Observational Study of Children Interacting with an Augmented Story Book, *International Conference on Technologies for E-Learning and Digital Entertainment*, Hong Kong, China, 2007.

[12] F. Liarokapis, P. Petridis, P. F. Lister, M. White, Multimedia Augmented Reality Interface for E-Learning (MARIE), *World Transactions on Engineering and Technology Education*, Vol. 1, No. 2, pp. 173-176, January, 2002.

[13] M. Specht, S. Ternier, W. Greller, Dimensions of Mobile Augmented Reality for Learning: A First Inventory, *Journal of the Research for Educational Technology (RCET)*, Vol. 7, No. 1, pp. 117-127, January, 2011.

[14] M. Fjeld, P. Juchli, B. M. Voegtli, Chemistry Education: A Tangible Interaction Approach, *The Human-Computer Interaction (INTERACT 2003)*, Zurich, Switzerland, 2003, pp. 287-294.

[15] M. Soga, K. Matsui, K. Takaseki, K. Tokoi, Interactive Learning Environment for Astronomy with Finger Pointing and Augmented Reality, *Eighth IEEE International Conference on Advanced Learning Technologies (ICALT 2008)*, Santander, Spain, 2008, pp. 542-543.

[16] S. Park, J. Lee, Y. Kim, J. Ryu, A Preliminary System Framework for "Silgam" Book, *2009 International Symposium on Ubiquitous Virtual Reality (ISUVR 2009)*, Gwangju, South Korea, 2009, pp. 64-67.

[17] H. Kaufmann, D. Schmalstieg, Mathematics and geometry education with collaborative augmented reality, *Computers & Graphics*, Vol. 27, No. 3, pp. 339-345, June, 2003.

[18] C. Juan, F. Beatrice, J. Cano, An Augmented Reality System for Learning the Interior of the Human Body, *Eighth IEEE International Conference on Advanced Learning Technologies*

(ICALT 2008), Santander, Spain, 2008, pp. 186-188.

[19] F. Huang, Y. Zhou, Y. Yu, Z. Wang, S. Du, Piano AR: A Markerless Augmented Reality Based Piano Teaching System, *The 2011 International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC 2011)*, Zhejiang, China, 2011, pp. 47-52.

[20] C. H. Chen, C. C. Su, P. Y. Lee, F. G. Wu, Augmented Interface for Children Chinese Learning, *The Seventh IEEE International Conference on Advanced Learning Technologies (ICALT 2007)*, Niigata, Japan, 2007, pp. 268-270.

[21] J. M. Keller, Development and Use of the ARCS Model of Instructional Design, *Journal of Instructional Development*, Vol. 10, No. 3, pp. 2-10, September, 1987.

[22] J. M. Keller, Strategies for Stimulating the Motivation to Learn, *Performance and Instruction*, Vol. 26, No. 8, pp. 1-7, October, 1987.

[23] F. D. Davis, Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology, *Management Information Systems Quarterly*, Vol. 13, No. 3, pp. 319-340, September, 1989.

[24] H. C. Chu, G. J. Hwang, C. C. Tsai, A Knowledge Engineering Approach to Developing Mindtools for Context-Aware Ubiquitous Learning, *Computers & Education*, Vol. 54, No. 1, pp. 289-297, January, 2010.

[25] P. H. Wu, G. J. Hwang, C. C. Tsai, Y. C. Chen, Y. M. Huang, A Pilot Study on Conducting Mobile Learning Activities for Clinical Nursing Courses Based on the Repertory Grid Approach, *Computers & Education*, Vol. 31, No. 8, pp. e8-e15, November, 2011.

[26] Y. J. Chang, C. H. Chen, W. T. Huang, W. S. Huang, Investigating Students' Perceived Satisfaction, Behavioral Intention, and Effectiveness of English Learning Using Augmented Reality, *2011 IEEE International Conference on Multimedia and Expo*, Barcelona, Spain, 2011, pp. 1-6.

[27] C. E. Basch, Focus Group Interview: An Underutilized Research Technique for Improving Theory and Practice in Health Education, *Health Education & Behavior*, Vol. 14, No. 4, pp. 411-448, Winter, 1987.

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