Assessing Efficacy and Students' Perception on the Use of Augmented Reality Sandbox in Secondary Geography in Hong Kong

by

TSE, To Fun

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Statement of Originality

I, TSE, To Fun, hereby declare that I am the sole author of the thesis, and the material presented in this thesis is my original work except those indicated in the acknowledgement. I further declare that I have followed the University's policies and regulations on Academic Honesty, Copyright and Plagiarism in writing the thesis. No material in this thesis has been submitted for a degree in this or other universities.

Abstract

Information and communication technologies have been rapidly developing and are currently adopted in many aspects of people's contemporary lives. With the goals to enhance students' interest and motivation in learning as well as their academic performance, the field of education has also been attempting to utilize various forms of modern technologies in and outside of classrooms. Among different forms of technology, interactive technologies, such as AR technology, have been one of the fastest growing and most popular forms, owing to the high level of interaction and the brand-new experiences that can be provided. AR technologies provide the feature of 3D visualization of virtual objects which is highly applicable to high school education in geology and geography.

This study explores using an AR sandbox, an AR technology device designed to help create topography models with sand. In real-time, augmentation can be done to visualize contour lines, simulated water, and elevations to help create physical features within the device. Current studies that explore the use of AR sandbox have focused mainly on the practical applications of the device in terms of design, execution, and implementation, and the effectiveness of the device in enhancing students' learning performance and outcomes has rarely been studied. To measure students' performance, a pre-test and post-test assessment analysis, a questionnaire survey, and a semi-structured group interview were conducted to collect the relevant data. A total of 126 students from 7 local secondary schools were recruited to participate in the study. Students were randomly allocated to classes in two formats and two geographical topics, including a traditional class and an AR sandbox class to compare the traditional and interactive technology approaches in teaching. The two geographical topics were map reading and farming. To further understand how the device may improve students' performance in class, the potential determinants of the enhancement

in students' learning outcomes, the learning attitude, learning motivations, and socio-demographic characteristics were also explored by drawing links between these determinants and students' learning outcomes. An in-depth interview was also conducted with geography teachers of the seven schools to glean the perception of the geography teachers' interests, intentions, barriers, and difficulties in adopting AR sandbox in their classroom teaching.

The comparisons of students' pre-test and post-test assessment performance in the traditional and AR sandbox classes showed that 1) AR sandbox was effective in enhancing students' learning outcome, particularly in the map reading, 2) students generally performed better in the AR sandbox class than the traditional classes in terms of mean scores, and 3) the effectiveness of AR sandbox varies with topics, where AR sandbox was found only to be partly effective in enhancing students' performance for the farming topic. The findings implied that AR sandbox could be an effective technology in teaching. However, it is also essential to take into account its application in terms of the geographical topics to be taught.

In the analysis of the impacts of potential determinants on students' learning outcomes, findings generally indicated that students with more active learning attitudes and motivations by satisfaction and interest performed better in terms of their perceived learning efficacy. It was also found that students with greater motivation for attaining good grades in exams were performing more poorly. Findings in this part implied that the AR sandbox could have bridged the gap between students with varying learning attitudes and motivations. Both students and teachers agreed that the AR sandbox could be a useful tool for the enhancement of geography lessons. However, teachers highlighted a number of barriers and challenges to the implementation of such new technology in classroom teaching. Finally, the current study's limitations were discussed, and relevant recommendations were given for future research.

Keywords: Augmented reality, learning efficacy, geography education, AR sandbox

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CHAPTER 1: INTRODUCTION

In recent decades, information and communication technology has been widely applied into different aspects and areas in the contemporary world due to its rapid development (Al-Qahtani & Higgins, 2013). To enhance the learning experiences and learning outcomes of students, many schools and educational institutions have attempted to use or equipped with these technologies to supplement traditional classroom learning (Al-Qahtani & Higgins, 2013). Technologies in education and learning have also been quickly developing and evolving into various types and forms, where among all the types, instructional technologies and interactive technologies have been the commonly utilized types (Ferrell & Ferrell, 2002; Kennewell, Tanner, Jones, & Beauchamp, 2008). In fact, it has been document by studies that incorporating these technologies into students' learning can help promote their motivation and performance in learning when compared to the traditional classroom learning approach with non-interactive media such as textbooks, but also instructional videos which is a form of instructional technology (Radu, 2014). This showed that the interaction enabled by technology could be the key to promoting students learning experience and academic performance. Likely for this reason, interactive technology have become one of the fast-growing information and communication technology in recent years in learning environment, where it appears in all forms like interactive blackboard, smartphones, or mobile tablets (Chengjie, 2015; Türel, 2011). Various studies have documented the merits of adopting interactive technologies, showing that it can help deliver improved learning experiences, promote engagement, and enhance collaboration in learning (Chengjie, 2015; Radu, 2014). The younger generations of students often find this learning style more interesting and attractive as they are already frequently exposed to different types of interactive technologies outside of schools or classrooms, such as smartphones and iPad which could essentially be the part of many students' everyday life (Chengjie, 2015; Radu, 2014). However, the same phenomenon might have contributed to another issue that students are no longer satisfied or interested by interactions enabled by the regular screens and functions of interactive mobile devices, it was suggested that student started to find technologies in education that allows the full body experience, e.g. virtual or augmented reality technologies, to be much more interesting and stimulating (Radu, 2014).

Augmented reality (AR) technology is one of the key emerging interactive technologies which has caught wide attention of the world in recent years. AR technology offers user a brand new form of experience by visualizing digital contents into virtual objects or scenes that can be projected into and merge with the real life environment (Wu, Lee, Chang, & Liang, 2013; Yuen, Yaoyuneyong, & Johnson, 2011). Through the bridging of the virtual and real life environments, AR technology further enhanced and augmented people's experiences in the physical world (Kesim & Ozarslan, 2012; Wu et al., 2013). The use of AR can even be further extended by the incorporation of other forms of innovative technologies such as audio, video and textual information, etc. (Wu et al., 2013; Yuen et al., 2011). Hence, it can be a powerful tool for augmenting users' interaction and engagement by enriching their perceptions in the virtual and real worlds, and to provide the opportunities for people to experience scenes or phenomena that does not exist in the physical world or those that are not accessible to users with limitations of space and time (Wu et al., 2013; Yuen et al., 2011).

In the applications in education, the visualization of complex spatial features and relationships or abstract concepts can help users to better understand the relevant content that are otherwise hard to illustrate through traditional forms of teaching (Wu et al., 2013). Wu et al. (2013) further suggested that AR has improved the efficiency of education as much as computers and the internet did when those technologies were first introduced to the field of education. AR technology allows the building up of practices and skills that were usually impossible to be developed prior to the emergence of technology-mediated learning environments. A good number of studies indicated that this new approach of teaching could enhance not only the effectiveness of teaching and learning, but also it be an interesting and attractive approach of teaching and learning for students (Kesim & Ozarslan, 2012; Lee, 2012). Apart from that, AR technology has been suggested to provide an array of benefits in teaching and learning, including, to enhance content understanding, improve the learning of spatial structures and functions, to help with long-term memory retention, to improve interaction and collaboration, and to enhance students' motivation. Various forms of AR technologies have been utilized in the teaching and learning of different subjects, for example, mathematic and geography, as well as in STEM education (Chu & Sung, 2016; Vakaliuk, Shevchuk, & Shevchuk, 2020; Yegorina, Armstrong, Kravtsov, Merges, & Danhoff, 2021).

Geography is unique in linking the social sciences and natural sciences and bridging the social sciences with natural sciences and puts the understanding of social and physical processes within the context of places and regions (Royal Geographical Society, 2024). Geographers apply different geographical tools to understand and analyze the relationship between natural systems and human activities. A comprehensive geography curriculum should consists of learning elements from physical geography, human geography and geographical skills. In the HKDSE geography curriculum, physical geography topics comprises of weather and climate, geology, hydrology and ecosystem while the human geography topics include economic geography, urban geography and agricultural study. Students are expected to learn the geographical skills such as map reading, interpretation of aerial photos and satellite images and GIS as embedded across different geographical topics.

Therefore, in the field of geography education, spatial thinking is one of the skills that explores both the virtual and physical environments for discovering problems, finding answers, and presenting solutions (Metoyer & Bednarz, 2017). Therefore, spatial thinking is often a crucial component in the discovery and solving of problems (Woods, Reed, Hsi, Woods, & Woods, 2016). Spatial thinking consists of different cognitive skills such as the understanding of concepts of space, using tools of representation, and the application of processes of reasoning (National Research Council, 2005). Spatial and geographic thinking are especially crucial in geography education as students always need to read and interpret visual information as well as to address complex geographic concepts or problems, such as map reading and interpretation (Giorgis, Mahlen, & Anne, 2017; Metoyer & Bednarz, 2017). Nonetheless, researches indicated that students often find it difficult to understand complex spatial relationship concepts such as understanding scale and how to transform two-dimensional concepts into three-dimensional illustration (Larangeira & Van der Merwe, 2016; Woods et al., 2016). Numerous researches suggested that geospatial technologies (GST), for example virtual globes and geographic information systems (GIS), can address the spatial thinking difficulties and enhance the spatial thinking abilities of learners (Metoyer & Bednarz, 2017; National Research Council, 2005; Schultz, Kerski, & Patterson, 2008). For example, studies have indicated that GIS can be a useful tool to help improve learners' spatial skills and spatial thinking (Lee & Bednarz, 2009; Metoyer & Bednarz, 2017). In this sense, AR technologies that enable the visualization of virtual environments and illustration of complex physical concepts and features could be another tool to enhance students' spatial skills.

Augmented Reality Sandbox (AR sandbox), a recently emerged device in AR technology, is a hands-on sandbox exhibit combined with 3D visualization applications created by Dr. Oliver Kryelos at UC Davis DataLab (UC Davis DataLab, n.d.). It has been suggested to be a powerful tool in bridging the gap between 2D representations of physical features and the real physical world, which can help promote the spatial thinking abilities of learners (Richardson, Sammons, & Delparte, 2018; Woods et al., 2016). AR sandbox allows users to create topography models by shaping real sand, which is then augmented in real time by an elevation color map, topographic contour lines, and simulated water. The system teaches geographic, geologic, and hydrologic concepts such as the reading of a topographic map, the meaning of contour lines, watersheds, catchment areas, levees, etc. (UC Davis DataLab, n.d.). It is especially appropriate for geology and earth sciences education where spatial thinking abilities are often required to interpret abstract concepts and natural phenomena that are not usually visible (Sánchez et al., 2016). Previous studies on AR sandbox have focused primarily on its design, execution and implementation and the introduction of different types of AR devices and their applications in geology education. On the other hand, limited research has been carried out to examine the effectiveness of AR sandbox in geography education in terms of its influence on students learning outcomes.

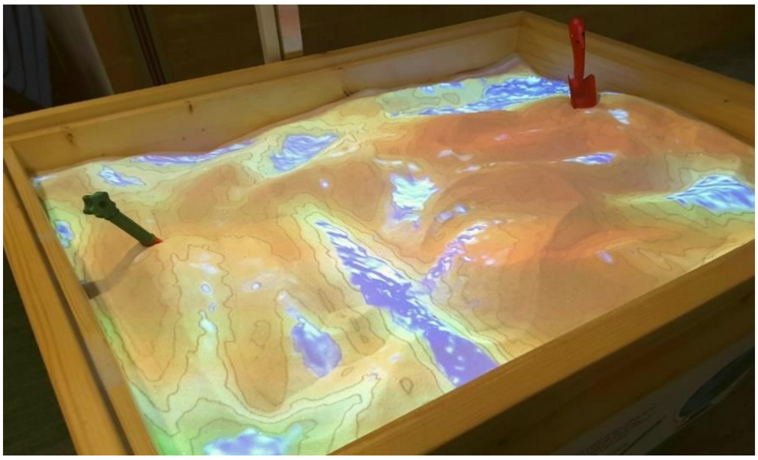

Photo 1.1 An AR Sandbox augmented on a topographic model with a coloured contour map

Photo 1.2 An AR Sandbox real-time augmentation on modifying topography models

Apart from exploring the promotion of students' learning outcome through the application of certain teaching approach or technology, some studies examine students' learning outcome from the individual perspectives of the students' themselves by exploring their socio-psychological states and perceptions. Many socio-psychological and cognitive variables have been suggested to be the crucial determinants of students' performance, such as students' attitudes, knowledge, motivation, interest, belief, personal values, etc. (Chen et al., 2023). Similarly, the socio-demographic characteristics of students, like gender, age, and household income, were also found to shape their performance (Altmyer & Yang, 2010; Hettler, 2015; Rizvi, Rienties, & Khoja, 2019). Therefore, to more thoroughly understand how students' performance can be promoted under the utilization of AR sandbox, it is crucial to take into account the individual perspective of students and explore the associations of their learning outcomes with other potential socio-psychological and demographic determinants.

To address the gaps of research identified in the previous parts, the study aims to examine the effectiveness of the use of AR Sandbox in secondary school geography education, and the determinants that influence the effectiveness of its application. To investigate the impacts of the use of AR technology in improving learning outcomes, secondary school students from local secondary schools in Hong Kong were recruited as participants of the study. All students were invited to attend 2 lessons in different formats and topics respectively. To find out the effectiveness of AR sandbox in geography lessons, in the first part of this study, the change in students' performance before and after classes will be examined. A pre-test assessment and a post-test assessment will be carried out in all classes to find out students' performance before and after the classes and to reflect their improvements in performance with and without the use of AR sandbox. In the second part of this study, the determinants of learning outcome will be explored. A questionnaire survey will be delivered to measure students' learning attitude and learning motivation. The associations between learning attitude, learning motivation, and two socio-demographic variables with the learning outcomes of students will be drawn.

In addition, the essence of geography is an integration of spatial variation over Earth's surface with the distinctiveness of places and interactions between people and their environments (Matthews and Herbert, 2008). Map is one of the most powerful geographical tools to be used as a specific language for showing 3D concepts such as "location" and "place" in graphical or visual form and also for geographical analysis and research. However, research studies showed that it is a complicated task for geography learners to transform spatial information mentally from a 2D view to a 3D view (Ishikawa & Kastens, 2005; Larangeira & van der Merwe, 2016) with spatial thinking skills can be developed by interacting with objects in environments and training (Piaget and Inhelder, 1967; Cohen and Hegarty, 2014) and it is confirmed that the use of information technology could support learning and teaching of spatial concepts (Uttal et al., 2013). Therefore, this study is also aiming to investigate the effectiveness of the AR sandbox in geography lessons, especially students' understanding of the abstract geographical concepts.

Based on the aim of this study and reviewed literature, the following research questions are proposed:

1) Does the utilization of AR sandbox improve students learning outcome?
2) Are there differences in students' performance in the AR sandbox class and traditional class?
3) Are there differences in students' performance in the map reading and farming topics, in both AR sandbox class and traditional class?
4) What are the determinants that can help enhance the learning outcomes of students?
5) Do these determinants vary in their impacts in the traditional class and AR sandbox class?
6) Do these determinants vary in their impacts in the map reading and farming topics?

In order to address the research questions and meet the study goals, a mixed methods approach was taken, combining quantitative and qualitative research methods. The details of the methodology were further explained in chapter 3.

CHAPTER 2: LITERATURE REVIEW

This chapter will first review relevant literature regarding the background of e-learning in terms of its historical development, implementation in secondary school settings, merits, instructional and interactive technology, global successful examples of e-learning implementation, the background of AR, the use of AR in education, and the emerging technology of AR sandbox. Following that, literature on the different measurements of learning outcome will be discussed in terms of pre-test and post-test analysis, self-evaluation, and perceived learning efficacy. The last part of the chapter reviewed studies on the potential determinants of student learning outcome, which include the variables of learning attitude, learning motivation, and socio-demographic characteristics.

2.1. E-Learning

2.1.1. Historical development of e-learning

The concept of e-learning, which is frequently synonymous with online education and virtual learning environments, has been substantially influenced over several decades by the progression of technology and the modifications made to educational requirements. This progression can be broken down into a few essential phases, each distinguished by significant breakthroughs and paradigm shifts in the educational system.

E-learning may be traced back to the 1960s and 1970s when computer-based training (also known as CBT) was first introduced around the same time (Corbeil & Corbeil, 2015). The initial versions consisted mainly of straightforward drill-and-practice programmes executed on mainframe computers. These programmes were utilized in educational institutions and businesses to provide standardized training. PLATO, which stands for

"Programmed Logic for Automatic Teaching Operations," was a system developed at the University of Illinois during this period (Bitzer, Braunfeld, & Lichtenberger, 1961). It was one of the first generalized computer-based teaching systems. Not only did PLATO permit instructional content in topics such as reading and mathematics, it also offered online forums, message boards, and chat rooms, making it a pioneer in many areas of contemporary e-learning.

The transformation brought about by personal computers served to bring in the era of multimedia learning, which began in the 1980s and continued into the 1990s (Alexander, 2001; Bezovski & Poorani, 2016; Corbeil & Corbeil, 2015). Text, graphics, and music were included in the user-friendly interfaces of educational software, which led to the software being more interactive. Learning and gaming were mixed in titles such as "Where in the World is Carmen Sandiego?" to make educational content more exciting and engaging for pupils. The arrival of CD-ROMs resulted in a considerable expansion in the capacity for multimedia content, which made it possible to create more complete educational programmes featuring videos and complex simulations. The instructional design principles that are the foundation of many modern e-learning platforms were developed during this period, which was vital for their development (Segrave & Holt, 2003).

E-learning went from being a standalone instructional software to becoming an interactive and networked phenomenon as a result of the broad use of the internet in the late 1990s and early 2000s that occurred during this period. Blackboard and Moodle are two examples of learning management systems (LMS) designed to enable educators to create, publish, and manage online courses utilizing the internet (Alokluk, 2018; Unal & Unal, 2014). These platforms provided a range of multimedia content and interactive activities, such as forums and quizzes, making it possible for students to engage in asynchronous learning experiences regardless of where they were physically located (Beatty & Ulasewicz, 2006; Croitoru & Dinu, 2016; Rubin, Fernandes, Avgerinou, Moore, & education, 2010).

This era also saw the advent of Massive Open Online Courses (MOOCs), which saw platforms such as Coursera, edX, and Khan Academy begin offering courses from educational institutions worldwide (Hew & Cheung, 2014). These courses were made available to anybody who had access to the internet. This democratization of access to education had a particularly significant impact on secondary education since it made available extra learning resources and courses that could be used to augment regular teaching (De Moura, de Souza, Viana, & Education, 2021; Jung, Lee, & Education, 2018).

Electronic learning has been given a new facet due to the widespread availability of mobile devices (Motiwalla & education, 2007). Thanks to the proliferation of smartphones and tablets, learners could access instructional content from any location and at any time, which made the learning process even more adaptable and individualized. Applications and learning management system interfaces compatible with mobile devices became popular, and educational technology began to emphasize responsive design and mobile-first initiatives (Neffati et al., 2021). This mobility was essential for secondary education since it allowed teachers to cater to students who were becoming increasingly accustomed to mobile technology and considered themselves digital natives (Grönlund & Islam, 2010; Motiwalla & education, 2007; Wu & Chao, 2008).

The most recent advancements in e-learning have been made possible by incorporating artificial intelligence (AI) and machine learning technologies. These technologies have started personalizing learning experiences on a scale that has never been seen before (Gligorea et al., 2023). Platforms that AI powers can change the pace, style, and requirements of individual learners, offering individualized feedback and modifying the level of difficulty of the content based on how well the learner is performing (Fırat, 2023; Potode & Manjare, 2015). Artificial intelligence is used by platforms such as Carnegie Learning and Duolingo to improve learning results by providing students with individualized educational experiences that are responsive to their input dynamically.

Particularly in secondary education, the global COVID-19 epidemic was a defining milestone for implementing e-learning (Poon, Kunchamboo, & Koay, 2024; Xiong, Ling, & Li, 2021). After schools worldwide were forced to close their doors temporarily, e-learning changed from a supplementary or alternative style of education to an absolute requirement overnight. This move not only put the capabilities of the e-learning systems that were already in place to the test, but it also sped up the innovation process within the industry (Ray, 2020; Raza, Qazi, Qazi, & Ahmed, 2022). Educators are forced to incorporate technology into their teaching techniques more profoundly and thoughtfully than ever due to the proliferation of virtual classrooms, live video classes, and online evaluations (Abumalloh et al., 2021; Dangaiso et al., 2023).

E-learning has been a voyage of technology innovation and educational theory adjusting to changing societal needs throughout its history. This journey has contributed to the growth of e-learning. Starting with the earliest computer-based training and progressing to more advanced platforms driven by artificial intelligence, each phase has led to an educational landscape that is more diverse, more accessible, and more efficient. When it comes to secondary education, the development of e-learning has made new opportunities for teaching and learning available, which have the potential to alter the course of events in the future significantly.

2.1.2. Evaluation of the efficiency of e-learning on secondary school students

When it comes to the educational environment of the 21st century, it is anticipated that the introduction of e-learning into secondary education will be one of the major transitions that will take place (Redempta & Elizabeth, 2012; Shraim & Khlaif, 2010). The idea that digital learning environments would improve the accessibility, efficiency, and adaptability of educational learning is probably the most essential element driving this movement(Journell, 2010). In addition to broadening the scope of e-learning, the ongoing development of technology also brings several challenges and opportunities that impact the efficiency of e-learning in educational environments.

Online learning has brought about a transformation in the educational content that is both delivered and consumed. This transformation has resulted in many benefits that solve educational difficulties that have lasted for a considerable time (Journell, 2010). By its very nature, online learning offers students a one-of-a-kind opportunity to participate in educational experiences of the highest possible standard. At this point, the degree of education available to students who reside in rural locations or who require flexible educational schedules due to specific situations is equivalent to the level of education available to students who reside in urban areas (Cheok, Wong, Ayub, & Mahmud, 2017; Mhandu, Mahiya, & Muzvidziwa, 2021). To close the educational inequalities between persons of different socioeconomic backgrounds and geographical regions, this democratic education reform plays a significant role in bridging the gap.

The efficacy of online learning platforms is another aspect that has considerably contributed to enhancing the learning experience. Other factors have also contributed significantly. Students have the opportunity to acquire knowledge that is up to date as a result of digital platforms, which enable the broadcast of content in a widespread manner and allow for rapid revisions (Guragain, 2016). It is beneficial in fields that are constantly expanding, such as science and technology; this is especially true in the case of rapidly growing fields. As opposed to the rigidity of traditional educational models, the freedom to study whenever and wherever one chooses makes it possible to take a customized approach to education that considers a diversity of lifestyles and learning rates. This is in contrast to the rigidity of many traditional educational models (Al-Qahtani & Higgins, 2013; Altmyer & Yang, 2010).

When determining whether or not online learning is effective, one of the most important factors to consider is how it influences students' academic performance. Several studies have been conducted to explore this matter, considering a wide range of factors, such as the course's structure, the material's effectiveness, and the degree to which students participate in the learning process (Alenezi, 2020; Wu & Hwang, 2010). It has been established in several studies that students who took part in well-structured online programmes saw significant academic performance improvements (Johnson, Hornik, & Salas, 2008; MacDonald & Thompson, 2005). The results of these enhancements were reflected in an improvement in performance on standardized exams. When these data are considered, online learning can improve both the knowledge of the subject matter and the command of the subject matter, which could ultimately lead to improved academic accomplishment (Johnson et al., 2008; Shurygin & Krasnova, 2016). However, the fact that the findings were inconsistent draws attention to how essential it is to implement e-learning efficiently. The development of online learning environments that are not only engaging but also educationally sound is of the utmost importance. Through the simplification of complex concepts and the facilitation of increased retention, the incorporation of multimedia, interactive simulations, and real-time feedback into these platforms has the potential to improve learning outcomes significantly (Altmyer & Yang, 2010; Tetteh, 2018).

For online learning to be successful, it is essential to ensure that students continue to express interest and remain motivated throughout the process. Using digital learning technology allows for discovering various dynamic and interactive instructional strategies not often seen in traditional classrooms (Beldarrain, 2006; Hwang, Lai, & Wang, 2015; Zhang & Nunamaker, 2003). Learning is made more engaging and pleasurable by using gamification, which includes points, leaderboards, and badges. This, in turn, encourages students to be more motivated to study. Students can further deepen their learning and remain interested in extended periods when they can use interactive tools such as quizzes and simulations (Haleem, Javaid, Qadri, & Suman, 2022). Therefore, this makes it much simpler for pupils to apply the topics they have learned directly.

On the other hand, the degree to which these technologies are successfully incorporated into the educational programme is frequently a significant factor in determining their effectiveness (Alokluk, 2018; Poon et al., 2024; Wu & Hwang, 2010). It is not appropriate to replace educational goals with them; instead, they should complement the goals that have been established. In addition, incorporating personalized aspects that enable students to learn at their own pace and choose subjects that interest them can significantly boost the level of involvement and satisfaction they experience. If the learning experience is customized to meet the distinctive requirements of each learner, then the learning outcomes can be improved, and the learner's motivation can be preserved (Chou, Chen, & Hung, 2021).

It is essential to consider the perspectives of both teachers and students about electronic learning. For students and teachers to successfully transition to online learning, considerable changes from both parties are required. From the point of view of a teacher, adjusting to e-learning can be a challenging endeavor, particularly for those who need to become more familiar with the tools utilized in digital education. The success of undertakings involving e-learning is frequently dependent upon the provision of adequate encouragement and opportunities for the professional development of educators (Bondar, Gumenyuk, Horban, Karakoz, & Chaikovska, 2020; Klein & Ware, 2003; Modise, 2020). This is a common occurrence. Consequently, there is an increase in the capability to adjust to new technologies and successfully use digital resources in instructional strategies.

From a student's perspective, online learning provides the chance for greater adaptability and a more customized educational experience. The opportunity to interact with contemporary educational technologies and control the pace at which they continue their studies is something that a considerable percentage of students consider beneficial. Some students may feel isolated due to the absence of face-to-face connection in traditional classrooms (Bowers & Kumar, 2015; Erichsen & Bolliger, 2011). This can harm these students' overall learning experience. Online learning platforms need to provide opportunities for students to work together on projects and interact with their classmates to improve student engagement and lessen the likelihood that they will feel isolated (Croft, Dalton, & Grant, 2010; Erichsen & Bolliger, 2011).

Even though a significant number of academic advantages can be obtained via e-learning, there are also a few disadvantages associated with it. Some students have inadequate access to vital technology or internet connectivity, which is one of the most critical hurdles to accessibility that they confront. The technology divide and other obstacles may make it more difficult for all students to participate in online learning and reap the benefits of it.

As an additional point of interest, the total process is significantly impacted by both the construction of instructional resources and the level of content quality. For online learning to be successful, the materials that are utilized need to be correctly crafted and adhere to pedagogical concepts that are considered to be solid. Interacting with high-quality, interactive content that aligns with educational goals and standards typically leads students to interact with the content more profoundly and reach a greater degree of incredible achievement in their learning.

Several factors are taken into consideration when determining the level of success that e-learning projects in secondary school achieve. These factors include the infrastructure for technology, the course design, the level of student participation, and the level of instructor preparedness. Implementing e-learning in secondary education has the potential to bring about a wide range of benefits that could be realized (Guragain, 2016). For e-learning to be successful, it must be deployed with careful planning, receive constant support from educators, and be tailored to meet the specific requirements of each student. On the other hand, E-learning depends on these components to be effective, even though it offers significant benefits such as enhanced accessibility and individualized educational experiences (Alokluk, 2018; Wu & Hwang, 2010). E-learning must continue to be an essential tool for the education of future generations, and the strategies utilized to incorporate it into secondary school must continue to develop in line with the advancements made in technology.

2.1.3. Opportunities and obstacles concerning the implementation of e-learning in secondary education

Electronic learning has emerged as a progressive constraint, bringing almost a move in the standards shaped in instruction and showing a new set of difficulties and opportunities. This is because it has already been incorporated into the secondary school curriculum. This review aims to study the complexities and dynamics that constitute e-learning within the context of secondary education. More specifically, the investigation will concentrate on the progress that has been made and the problems encountered along the way.

Alteration and Challenges to Conquer Through Overcoming

The emergence of e-learning has not only made education more accessible and flexible but has also significantly increased the number of available educational options. Students who reside in rural areas or who have disabilities that make it impossible for them to attend regular schools now have the opportunity to gain access to a wide variety of educational resources through the use of the Internet (Poon et al., 2024). On the other hand, the transition has been challenging. The digital divide is one of the most fundamental challenges that must be conquered. The unequal distribution of access to critical technologies, such as dependable internet and digital gadgets, characterizes it (Obayelu & Ogunlade, 2006). This disparity in communities characterized by low incomes or rural settings is particularly noticeable. To put it another way, it has the potential to exacerbate existing educational inequality, reducing the potential advantages of online education.

It is necessary to overcome several critical challenges, one of which is the preparation of educators for the move from traditional classrooms to digital instructional environments. To determine whether or not online education will ultimately be effective, one of the most important factors to consider is the ability of teachers to integrate technology into their teaching techniques successfully (Ali & Magalhaes, 2008; Modise, 2020). Educators must be more adequately educated and qualified to implement this transformation (Assareh & Bidokht, 2011). Several issues might make the implementation of e-learning more complex, including insufficient training, resistance to change, and varying degrees of comfort with digital tools (Al Gamdi & Samarji, 2016; Astri, 2017). This brings into focus the importance of comprehensive professional development and support systems.

A significant number of challenges are also presented by the involvement and motivation of students in an online setting. The absence of physical presence in traditional classrooms is one of the defining characteristics of these settings, which can lead to feelings of isolation and decreased motivation. To mitigate the detrimental effects that distractions at home and the impersonal nature of online interactions can have on student engagement, it is of the utmost importance to create online learning experiences that are not just interactive but also engaging. There are opportunities, in addition to new developments.

Despite its challenges in this context, e-learning has tremendous prospects that can revolutionize how educational approaches are implemented. There are several benefits, but one of the most significant is the ability to provide individualized teaching. E-learning systems that are integrated with adaptive technology can analyze information on the performance of students as well as their learning patterns. Because of this, it is possible to tailor the material, pace, and learning routes to meet the exact requirements of every individual learner. With the assistance of this high level of personalization, students can learn things in a more effective manner and at their own pace.

Another advantage of e-learning is that it gives students access to a wide array of resources that would be difficult to supply in a traditional learning environment. When students have access to global courses, virtual laboratories, enormous libraries, and multimedia resources, they have the opportunity to engage with learning content that is both comprehensive and comprehensive in scope. Increasing the quality of the educational experience can be accomplished in all of these ways (Croft et al., 2010; Modise, 2020).

E-learning offers several key advantages, one of which is its adaptability. This is an exceptionally advantageous situation for children who may have obligations outside of school or who may perform better at times that are not conventionally considered to be school hours. E-learning can effectively expand educational reach because of its scalability, which enables educational content to be transmitted to a bigger audience at minimal additional expense (Bondar et al., 2020). This highlights the power of e-learning to expand educational reach efficiently.

The Methods of E-Learning That Are Currently Being Improved

This transition has several advantages, one of which is the trend of e-learning, which encourages innovation in the different teaching and learning processes. Educators are actively promoting several other things, including developing creative teaching practices, using contemporary tools, and re-evaluating the overall delivery of education. These kinds of innovations can lead to instructional approaches that are more successful and entertaining (Kennewell et al., 2008), and they can be beneficial to both traditional learning environments and online learning environments.

The quality of the educational information that is being supplied is still a significant factor in determining how successful e-learning will be. Not only should the resources that are accessible online be engaging, but they should also be of high educational quality and conform to the criteria that are utilized in the field of education. The availability of high-quality digital information that is interactive and customized to fit the diverse educational objectives of students is a critical factor in determining whether or not efforts to implement e-learning will be successful (Bartrum, 2018).

The direction that e-learning will take in the future is expected to be significantly influenced by the new technological breakthroughs that are expected to take place. Emerging technologies such as virtual reality, augmented reality, and artificial intelligence are examples of technologies that have the potential to make online education more engaging and immersive (Beckem & Watkins, 2012; Dede, 2009). Others include blockchain technology. This has the potential to assist in resolving the limitations that now exist about the delivery of content and the engagement of students.

The strategic deployment of e-learning in secondary school has the potential to improve educational outcomes considerably; nevertheless, this implementation must be carried out with caution to achieve the desired levels of improvement. There is a need for a paradigm shift in how all parties, including students, teachers, and policymakers, provide and engage with education (Ali & Magalhaes, 2008; Astri, 2017). A fundamental reevaluation of educational practices is required to ensure that they are inclusive, prosperous, and aligned with the requirements of a varied student population. Accepting this shift involves the utilization of new technologies as well as a fundamental reevaluation of educational practices.

Even though e-learning includes a multitude of benefits and has the potential to bring about significant transformations, its success is dependent on the fact that it can overcome challenges via careful planning and continuous improvement. As e-learning continues to develop, it can transform the educational environment by making education more individualized, more easily accessible, and more by the demands of the 21st century. E-learning should be utilized to its fullest potential to traverse the issue sectors and maximize its benefits efficiently.

2.1.4. E-learning and its merits

E-learning can be defined as the utilization of technology in information and communication that helps establish learning experience that allows greater freedom in organization and creation which is not limited by any boundaries (Horton, 2011). It often also refers to the use of internet technologies and digital technologies such as computers, mobile phones, or mobile tablets to supplement traditional learning experience which could enhance learners' knowledge and performance (Ruiz, Mintzer, & Leipzig, 2006). E-learning has been developing for up to three decades, and it has been increasingly utilized as education and technologies, especially the internet, modernize and popularize (Bezovski & Poorani, 2016). Some figures about e-learning may showcase the popularity of this approach and its market, for instance the e-learning market across the world has been suggested to have reached an estimated value of 332.6 billion US dollars in 2022, and it is expected to grow further and reach 686.9 million US dollars by 2030 (StrategyR, 2024). One of the world's largest e-learning markets, the US was estimated at 100 billion US dollars, while the second largest e-learning market of China is also expected growing rapidly by up to 11.6%. Other e-learning markets across the world, such as the markets in Japan, Canada, German were also forecasted to grow over the 2020-2030 period (StrategyR, 2024). By introducing the use of the internet, e-learning enables the use and retrieval of learning content from online platforms, which can often also provide interactive features like the delivery of immediate feedbacks on students' activities and performance by online systems (Bezovski & Poorani, 2016). These types of features in modern e-learning have always been learner-oriented, as users are commonly allowed to control and manager their own learning process, and the virtual elements provided in the e-learning technology (Downes, 2005). The objectives of e-learning usually involve the provision of content and knowledge, and also to help users set up and reach their personal learning objectives (Clark & Mayer, 2008).

E-learning can provide multiple benefits over traditional forms of learning from various aspects of learning. It enables learner centered activities as e-learning is often designed to be learner-oriented, therefore it can promote self-directed and self-paced learning where student would have control over their own progress in learning with a greater level of autonomy (Welsh, Wanberg, Brown, & Simmering, 2003). E-learning can enhance collaboration, interaction, and engagement as the access to online learning material is not restricted by physical, geographical, or temporal limitations and barriers, and users can receive timely revision of materials and feedbacks online so the efficiency of learning can be enhanced (Zhang, Zhou, Briggs, & Nunamaker Jr, 2006). For the same reason, the absence of physical and geographical limitation also allows for greater convenience in learning, as student as well as teachers may not need to be in the same space for teaching and learning to be carried out. As materials are all available online, students may learn anytime and anywhere they find convenient. E-learning is also a more cost efficient and often time lower cost option for schools and students. As e-learning materials and programmes are highly flexible, schools and students may only select and purchase materials that suits their own learning objective or curriculum without the need to purchase all materials at a time (Welsh et al., 2003). The same materials can also be used over time again and again as it is stored online (Guragain, 2016; Welsh et al., 2003). Since many e-learning systems or platforms are available around the world, some may allow users from different parts of the world to interact, which can also enhance students' interaction and engagement with people from different backgrounds (Guragain, 2016).

2.1.5. Instructional technology and interactive technology

There are two common forms of technology use in e-learning, which are instructional technology and interactive technology (Ferrell & Ferrell, 2002; Kennewell et al., 2008). Instruction technology, sometimes also known as educational technology, has received many different definitions from scholars over the years, however, in simple terms, it can be defined as the practice to utilize technology in modern education, and in many case it is the use of computer in education (Earle, 2002). Instruction technology emerged as an alternative for traditional forms of teaching as computer was revolutionized in providing instruction-based tasks (Earle, 2002; Heinich, 1985). It has been served as an educational tool, which was suggested to have changed the scene of education, and have since been widely applied in learning in recent decades (Davies, Dean, & Ball, 2013; Earle, 2002). Instructional technology has now became an ubiquitous tool utilized in classroom, and it was reported that over 70% of both teachers and students utilize instruction technology, mostly in the form of computers and laptops, to help complete their work and tasks inside and outside classroom, and traditional forms of teaching and learning has become less significant (Louisiana State University, 2024). This tool of education was originally introduced to promote the motivation of student in learning, instead of enhancing academic performance (Earle, 2002). Instruction technology can take many forms, depending on the technology that is employed, which can include computers, television, videos and films, audio materials, computer-based programmes and courses, etc., which can provide some kind of instruction for teaching in and outside classes (Heinich, 1985). These technologies are mostly used to supplement and assist the teaching given by teachers, who is taking the leading role in providing and delivering instructions to students (Heinich, 1985).

Instructional technology can help to facilitate learning in several ways such as presentation of content and assessment of achievement (Davies et al., 2013). For example, students can access timely information with the use of internet and instructional videos which they could gain knowledge in a more effective and efficient way (Davies et al., 2013). In terms of presentation of content, multiple technologies are available online nowadays that provide assistance in presentation. For instance, Adobe presenters provides the technology to perform visual and audio presentation as opposed to traditional forms of presentation that relies heavily on text (Indiana University, 2024). Another extremely common example of instruction technology in the current times is the use of video conferencing tools and technology, which has risen in popularity since the time of the pandemic in 2019. Video conferencing technology allows classes to be held online, for example, through the tools of Zoom or Microsoft Teams (Indiana University, 2024).

While instruction technology, or technology in general revolutionized the way of teaching and delivery in classes, one emerging problem for the use of this form of technology is the lack of interactivity. For example, the use of instructional videos limits the way that learners can engage, students may find a particular part of a video or some spatial concepts mentioned in the video difficult to understand, yet this form of technology does not provide any opportunities of interaction that can address the concerns of students (Zhang et al., 2006). Moreover, direct content delivery, which resembles traditional forms of teaching, is still the main feature found in much of the educational software within the realm of instruction technology (Davies et al., 2013). This form of technology is often not learner-centered or oriented, which means that the individual needs and interests of learners cannot be personally address, thus limiting the flexibility of teaching and learning. In fact, educational software are often used only as a supplement material to traditional learning materials, which is usually hard to integrate directly into classroom instruction (Davies et al., 2013). The benefits of instruction technology are limiting under the modern scene of education, therefore it calls for technologies that can provide greater flexibility and level of interaction.

Interactivity has become one of the major element in modern education, together with the appearance of more and more information and communications technologies (ICT) such as digital libraries, Wikipedia, Facebook, a newer form of technology in education, interactive technology has evolved and emerged as an even more popular form of technology, tool, and approach adopted in classes (Guðmundsdóttir, Dalaaker, Egeberg, Hatlevik, & Tømte, 2014; Kennewell et al., 2008). To define interactive technology, the concept of interactivity should first be discussed. Interactivity describes the exchange and interaction between two or more parties, which may in fact refer to two possible interpretations. Interactivity may refer to the interaction between an individual and the technology itself (e.g., a tool, machine, software), on the other hand, it could also describe the interactions and communications between two or more individuals facilitated by technology (Severin & Tankard, 1997). Interactive technology can then be defined as either the technology then enables the interaction between human and technology, or technologies that facilitate the interaction between humans (e.g. between students, or between students and teachers), and in the case of education, also to facilitate teaching or work as a strategy of teaching (Guðmundsdóttir et al., 2014; Kennewell et al., 2008).

Interactivity has been so crucial in education for a few reasons, from the students' perspective, the benefits of it includes the facilitating of the building of knowledge and establishment of cognitive skills (Evans & Gibbons, 2007). Through the use of interactive technology in the classroom, students were found to engage more in learning via interactive videos and other media (Bartrum, 2018; Sánchez et al., 2016). The communication ability of student can also be enhanced through interactive technology as students could be encouraged to share ideas or concepts on the interactive platform (Bartrum, 2018). Interactive teaching was even suggested to be one of the major factors to academic success, along other features like discussion and confidence (Kennewell et al., 2008). Interactive technology often takes form of various kinds of interactive devices, typical examples include interactive whiteboards and interactive tablets (e.g., iPads). The advantages of these tools apart from providing opportunities of interactivity and engagement also includes, great level of flexibility, multisensory presentation, and speed and efficiency, etc. (Smith, Higgins, Wall, & Miller, 2005). In fact, some forms of interactive technology have been very widely adopted, and interactive whiteboard is one of such. It was documented that around 70% of classrooms in Norway have been equipped with interactive whiteboards, and 77% and 67% of teachers in mathematics and in sciences respectively reported that they had been using interactive whiteboards (Guðmundsdóttir et al., 2014; Kennewell et al., 2008).

Interactive technology has been successfully implemented in classes in different ways and as different forms. The widely popular interactive whiteboard would be a good example. Interactive whiteboard has been suggested to help with promoting the motivation, interaction, and engagement of student in class (Türel, 2011). The capabilities of interactive whiteboards to visualize and contextualize lesson contents and to facilitate the participation of student also helped to promote students' learning (Şad & Özhan, 2012). In terms of communication and discussion, interactive whiteboards also help to facilitate cooperation and conversations between students and with teachers (Mercer, Warwick, Kershner, & Staarman, 2010; Warwick, Hennessy, & Mercer, 2011).

Apart from interactive whiteboards, there are also other example of effective implementation of interactive technology. Zhang et al. (2006) found that the use of interactive video increases learner-content interactivity, thus potentially motivating students and improving learning effectiveness. Patterson (2007) indicated that Google Earth is another good illustration of interactive technology used in geography education. It was suggested to facilitate spatial thinking, help develop critical technology and thinking skills, as well as to promote collaboration and communications between students. Its capability to provide dynamic maps for the user together with the information of different place which also enhanced the experience of users (Patterson, 2007).

2.1.6. Global case studies illustrating e-learning success

It is possible to observe the transformative impact of e-learning technology in various educational environments worldwide. The learning experiences of students, as well as the result of their education, have been significantly enhanced by these technologies (McGill, Klobas, & Renzi, 2014). This review will investigate and assess the many techniques and methodologies that have been effectively adopted for e-learning environments. The difficulties encountered during the implementation process in many nations, including Singapore, Alaska, and California, will be investigated.

Singapore's Integrated Online Learning Environment

Implementing a forward-thinking approach to education in Singapore has resulted in the introduction of an integrated online learning environment across all educational levels in the country (Hung, Tan, & Chen, 2003; Wong & Ng, 2020). This was accomplished as a result of such an approach. The Ministry of Education has been making concerted attempts to include technology in the school curriculum in recognition of the significance of developing competency in digital literacy in a society that is becoming increasingly linked (Lam, Alviar-Martin, Adler, & Sim, 2013; Looi, So, Toh, & Chen, 2011). This curriculum, designed to cover a wide range of subjects, offers educational knowledge that is not only interactive and interesting but also designed to cover a wide variety of subjects. This is accomplished through the utilisation of a variety of various platforms.

Students have access to a wide variety of digital tools through these platforms. These tools include interactive simulations, virtual classrooms, and various other digital resources that enhance students' capacity to learn independently (Lim & Weber, 2004). An educational environment that encourages students to be active participants in their academic journey rather than only passive recipients of information is promoted by this setting. This is accomplished by motivating students to manage their learning environments and activities. Utilising digital resources, which are intended to enhance learning in traditional classroom settings, allows for a seamless integration of direct instruction and individual exploration.

According to this strategy, which has proven to be particularly effective in preparing students for future opportunities and difficulties in a digital world, students have been provided with the necessary abilities to navigate and achieve in a rapidly evolving landscape (Lim & Weber, 2004). This method has been credited with providing students with the skills required. As proof that well-integrated e-learning systems can enhance traditional education and nurture an environment in which lifelong learning and adaptability are inherent components of the fundamental educational philosophy, the fact that Singapore's model has been so successful is evidence that this potential exists.

Alaska's Rural Education Initiative

Alaska presents a unique set of obstacles around education. These obstacles are a result of the state's massive and frequently inaccessible landscape, as well as its extreme conditions for weather. The state has implemented innovative e-learning solutions, especially full-time online programmes, essential for reaching students who reside in the most remote areas (Bramble, 1986; Cueva et al., 2019). This is done to resolve the issues that have emerged. Participation in these programmes allows students access to a wide range of educational resources and specialised tuition that would be otherwise inaccessible to them in their particular locations. This access would otherwise be denied to them.

Students get access to an extensive curriculum that comprises live classes, recorded lectures, and a wide variety of interactive learning modules through online programmes, which are all-encompassing and provide students with a full curriculum. This technique offers a flexible learning model that can be modified to each student's specific requirements and situations, which not only overcomes the challenges caused by geographical distance but also considers various situations that each student may be confronting. Using digital platforms allows teachers to provide students with customised attention (Bramble, 1986). Additionally, students can learn at their own pace, focusing on subjects of particular interest or requiring more attention.

These programmes have had an enormous effect, as demonstrated by their significantly improved academic achievement and enhanced student engagement in geographically physically inaccessible locations. E-learning efforts support the levelling of the educational playing field by offering dependable access to high-quality education (Bramble, 1986; Cueva et al., 2019). This is accomplished through the provision of excellent education. This ensures that every student, regardless of where they are physically located, is provided with the opportunity to achieve academic success and achieve in their studies.

California's Khan Academy Partnership

Collaboration between Khan Academy and several school districts in California has brought about a reinvention of how educational institutions employ online resources in their daily operations (Davies, 2012; Williamson, 2018). With Khan Academy's interactive lessons and practice exercises being included in the course material, this collaboration emphasises mathematics. The objective is to enhance students' learning and comprehension of the material.

Utilising the materials that Khan Academy provides, students can work through assignments at their own pace, revisit challenging topics, and receive immediate feedback on their performance. All of these advantages are available to them. This makes it feasible for the teacher and the class to simultaneously participate in a more customised learning experience. Teachers can figure out areas in which their students have difficulty simply by using the data that can be collected through the platform. They can modify the ways they teach based on the findings of this analysis.

The immediate impact of this association, which has led to significant outcomes, has been observed to be a substantial improvement in mathematical achievement across all of the schools that have taken part in the study (Kronholz, 2012). Success is based on how well the pupils perform in the examinations and how they see their mathematical skills. This facilitates a brighter perspective on a subject that many people find challenging. Furthermore, it has resulted in the generation of valuable insights regarding the effectiveness of digital tools that enhance academic performance and engagement, highlighting the potential of customised e-learning resources to supplement conventional teaching methods. Because of these insights, the project has been able to give significant findings.

The vast and profound effects of e-learning across several educational settings are brought to light by the case studies conducted in Singapore, Alaska, and California. These locations are prime examples of how e-learning can transcend physical and psychological barriers to education by embracing technology and purposefully incorporating it into teaching methods. Consequently, they provide pupils with a learning experience that is more successful, interesting, and individualised to their own personalities. E-learning can revolutionise education by making it more accessible and by the requirements and realities of today's digital world, as seen in these examples. With proper consideration, however, e-learning can potentially bring about this revolution.

When it comes to secondary education, the implementation of e-learning has the potential to bring about several transformative effects (Cheok et al., 2017; Redempta & Elizabeth, 2012). It is important to note that these advantages extend beyond the conventional learning paradigms already in place. E-learning has resulted in increased accessibility to a wide variety of educational resources, the personalisation of learning experiences to meet the specific requirements of individual students, and significantly improved levels of student engagement. As a result, the educational landscape has undergone a dramatic transformation, contributing to the introduction of e-learning. On the other hand, these benefits are contingent upon the careful selection of powerful technical tools, the wise deployment of implementation tactics, and the ongoing support for instructors and students as they traverse this transition to digital.

E-learning can potentially transform education into a more democratic process to a significant degree. Eliminating geographical barriers, providing flexible learning schedules, and constructing a platform for interactive and individualised educational experiences are necessary to achieve this goal. Inclusion ensures that everything is feasible by making it possible for every student, regardless of where they come from or their personal circumstances, to have access to a high-quality education (Obayelu & Ogunlade, 2006). Additionally, the adaptability of e-learning platforms enables educators to respond to various learning styles and requirements, engaging students in a manner that stimulates their desire to learn and facilitates their active participation in learning.

Despite this, it is not guaranteed that activities that use e-learning will be successful. It is necessary to have a well-planned strategy in place to incorporate technology into more conventional kinds of educational activities successfully. Educators must provide themselves with continual training and resources for them to successfully adapt to changing teaching approaches (Klein & Ware, 2003; Modise, 2020). Similarly, for students to make the most of the opportunities that digital learning technologies present, they need to be provided with ongoing assistance. Consequently, overcoming possible issues associated with e-learning places a significant emphasis on the role that continuous professional growth and technology support play.

2.2. What is Augmented Reality

Augmented reality (AR) is a cutting-edge technology that combines digital information with the actual world in a seamless manner, hence thereby revolutionising the way in which we see our circumstances (Azuma, 1997). In contrast to virtual reality (VR), which immerses users in a purely digital environment, AR enriches the world that already exists by superimposing computer-generated sensory data such as sounds and sights to the world in real time (Billinghurst & Duenser, 2012). This one-of-a-kind technology makes it possible for elements from the digital world and the real world to cohabit and interact in a dynamic manner, which ultimately results in an enhanced interactive experience.

AR technology combines digital and real-world elements (Carmigniani et al., 2011). Users are able to engage in interactions that go beyond their immediate environment while still maintaining a connection to the real world at the same time. AR builds a composite vision that improves one's experience of reality by combining the real and virtual worlds in a seamless manner (Milgram & Kishino, 1994). Real-time interaction and exact three-dimensional alignment of virtual and physical objects enable AR's seamless integration.

Computer vision, recognising objects, and complex data processing are some of the vital technologies that are necessary for AR to operate properly. AR technologies allow AR devices to accurately understand the physical environment, comprehend spatial relationships, and seamlessly insert digital items into real-world settings for the purpose of facilitating natural interaction. AR games may show a virtual creature lounging on a park bench. Utilising the camera that is built into the device allows it to replicate the physical characteristics of the real world and respond in real-time to changes occurring in the surrounding environment (Dey, Billinghurst, Lindeman, & Swan, 2018).

User interactions and surrounding variables must be recorded (Regenbrecht, Baratoff, & Wilke, 2005). The position and orientation of the device within a physical space can be tracked by AR systems through the use of sensors such as gyroscopes and accelerometers and GPS (Van Krevelen & Poelman, 2010). Despite the fact that the user is moving around, the digital material is able to keep the right alignment with the real world because to this tracking (Azuma et al., 2001). By altering the digital imagery in real time in response to changes in the user's perspective or environment, optical sensors, on the other hand, contributes to the strengthening of the interaction between digital elements and the real world (Kim, Billinghurst, Bruder, Duh, & Welch, 2018).

Three-dimensional registration, which is another fundamental component of AR technology, guarantees that virtual objects are not only positioned within the real environment but also remain rooted in the positions that they have been assigned to, regardless of the user's movement behaviour. It is essential to have this capability in order to keep the impression that digital elements are a part of the real environment, which will ultimately result in a more immersive experience for the user (Azuma et al., 2001).

Through the utilisation of these advanced technological foundations, AR generates an interactive environment in which digital and real-world components are linked (Billinghurst & Duenser, 2012). This enables users to interact with both in a way that is both smooth and intuitive. These core concepts play a critical role in pushing the boundaries of what is possible as AR technology continues to advance. Not only do they make AR apps more robust and intuitive, but they also make them an important part of a wide variety of activities and industries (Carmigniani et al., 2011).

2.3. Practical Uses of Augmented Reality

The adaptability of AR renders it a significant asset in several industries, augmenting both user satisfaction and operational effectiveness (Azuma, 1997). AR is transforming the retail industry by allowing shoppers to preview things in their own environment prior to making a purchase, so enhancing their shopping experiences (Poushneh & Vasquez-Parraga, 2017). Applications such as IKEA's provide consumers with the ability to visualise how a furniture item might appear in their house, so aiding in the process of making more informed purchasing choices.

AR enhances the learning experience by introducing an interactive element in education (Bacca Acosta, Baldiris Navarro, Fabregat Gesa, & Graf, 2014). AR can be utilised by medical students to visually see intricate anatomical structures in three dimensions, hence greatly facilitating comprehension and engagement with intricate subject matter (Kamphuis, Barsom, Schijven, & Christoph, 2014).

AR technology can enhance tourism and museum experiences by providing visitors with layered and contextual information about exhibits or historical places through their devices (Chang et al., 2014). This might encompass the process of animating historical events or restoring ruins to their original state, enhancing the visitor's experience by providing insights that would otherwise necessitate imagination or significant reading.

AR is being incorporated into car windscreens in the automotive sector to present essential driving information, including as speed and navigation cues, right inside the driver's field of vision (Kim et al., 2018). This technology improves safety by reducing distractions and ensuring that important information is easily visible to the driver.

The entertainment and media industries are employing AR to enhance traditional experiences with an additional level of engagement. Sports broadcasts can augment their shows by superimposing real-time statistics and animated replays onto the action, so offering spectators a more comprehensive comprehension of the game (Santos et al., 2013).

Surgical procedures, in which precision is of the utmost importance, are where AR is making major headway in the healthcare industry (Eckert, Volmerg, & Friedrich, 2019). During treatments, surgeons can employ AR to project diagnostic pictures directly onto the patient's body, increasing accuracy and safety by accurately aligning surgical interventions with the underlying anatomy (Van Krevelen & Poelman, 2010).

By incorporating digital information into our regular physical activities, augmented reality is completely changing the way we engage with it (Azuma et al., 2001). With the continued development of AR technology, its incorporation into everyday gadgets is projected to increase, which will result in AR becoming an essential component of digital interactions in the future (Billinghurst & Duenser, 2012). Our sensory experiences are not only improved as a result of this melding of digital and physical realities, but it also offers up new pathways for interaction, learning, and involvement in all aspects of life (Carmigniani et al., 2011). The future potential of AR is boundless, since continuous advancements have the ability to completely transform our utilisation of technology and perception of reality.

2.4. Augmented Reality (AR) in Education

AR is a new trend in interactive technology which excels at improving user interface. One unique feature of AR is that it can provide an immersive participatory simulation, which technology has brought new experience to user and allows them to engage themselves into the physical world (Dunleavy, Dede, & Mitchell, 2009). Studies have shown that AR has strong potentials to provide both powerful hands-on and situated learning experiences and exploration opportunities to users (Lee, 2012; Wu et al., 2013). Recent studies explored the possible application of AR technology in education, which could offer students with 3D presentations and interactive experiences that are specifically tempting for the newer generations of students who are generally raised in an era of interactive media (Yuen et al., 2011). AR can serve as a value-added and engaging component to classroom education and help students overcome some of the limitations of traditional learning methods, allowing students to learn according to their preferred learning style (Antonioli, Blake, & Sparks, 2014; Yuen et al., 2011).

The significant feature of AR is that it can bridge the gap between the real physical world and the virtual world, as well as the gap between practical and theoretical learning practices by enhancing users' perceptions and their interactions with the real world (Kesim & Ozarslan, 2012; Wu et al., 2013). Various studies have proven that the use of AR is more effective in teaching when compared to the application of other media such as books, videos, or PC desktop experiences (Antonioli et al., 2014; Radu, 2014).

Studies have summarized six positive learning effects that AR can bring to learners, including the overcoming of learning difficulties, enhancement of learning experience, enhancement of social interaction and collaboration, enhancement of engagement and motivation, and improvement in long-term memory retention (Kesim & Ozarslan, 2012; Radu, 2014; Wu et al., 2013). First, AR can help learners to overcome learning barriers, especially for subjects that require spatial thinking. Studies have shown that students' spatial abilities can be improved by using immersive and collaborative AR applications (Wu et al., 2013). The sense of authenticity offered by an AR learning environment was found to promote learners' understanding of dynamic representations and complex spatial relationships (Wu et al., 2013). For example, for natural phenomena that are difficult to observe, such as spinning of the earth, ecosystems of wetland or life cycles of wetland creatures, AR can help visualize these phenomena by creating virtual objects and enhance learners' experiences (Kesim & Ozarslan, 2012; Wu et al., 2013). These learning experiences in turn could promote learners' thinking skills and conceptual understandings of these phenomena and clear any misconceptions (Wu et al., 2013). Second, it can enhance learners' learning experience by increasing their content understanding. AR could extend users' perception by integrating the real-world and digital learning resources. The use of AR enables learners to experience scientific phenomena that human generally could not experience. For example, with the use of AR systems, students can observe a virtual solar system, and the process of photosynthesis and chemical reaction (Liu, Cheok, Mei-Ling, & Theng, 2007). Third, it can enhance learners' social interaction and collaboration (Kesim & Ozarslan, 2012). It is observed that the interactive interfaces and immersive features of AR applications can allow students to have face-to face collaboration and discussion other students, unlike other forms of interactive technologies which mostly promote students' interactions with the devices individually (Kesim & Ozarslan, 2012). This learning experience could also maximize the transfer of knowledge between teachers and students (Wu et al., 2013). Fourth, AR can enhance students' learning motivation (Dunleavy et al., 2009; Radu, 2014), where researches indicated that after experiencing the use of AR applications, users reported that they are highly satisfied with this new experience (Radu, 2014). A study showed that GPS-based game increased student motivation, creativity, and exploration more than its paper-based counterpart (Dunleavy et al., 2009). Lastly, AR can help enhance students' long-term memory retention (Radu, 2014). Studies have shown that students' memories on contents learned through AR experiences are stronger than that of non-AR experiences (Radu, 2014).

With the advancement in AR technologies, some significant educational applications of AR technology have been evolved. AR books and AR games have been the most popular tools used by teachers (Klopfer & Sheldon, 2010; Lee, 2012; Yuen et al., 2011). For AR books, they are made to look like regular books, but when a webcam is pointed to the book, the virtual features associated to the book can be visualized as well as the incorporated interactive features (Kesim & Ozarslan, 2012; Lee, 2012; Yuen et al., 2011). In this way, textbooks can be turned into dynamic sources of information (Kesim & Ozarslan, 2012). For example, the Institute for the Promotion of Teaching Science and Technology in Thailand developed a 3D augmented geology textbook which teaches students about the earth's layers, their relationships, differences, and functions (Yuen et al., 2011). For AR game, it presents educators with the opportunities to utilize a new highly visual and highly interactive form of learning (Lee, 2012; Yuen et al., 2011). For example, *Alien Contact!* is a game designed to teach math, language arts, and scientific literacy skills to middle and high school students (Dunleavy et al., 2009). It is a GPS-based AR game which aims to associate the students' real world location to their virtual location in the simulation's digital world (Dunleavy et al., 2009). Narrative, navigation, and collaboration elements as well as academic challenges are incorporated into the game in order to enhance their learning experience and foster multiple higher-order thinking skills (Dunleavy et al., 2009). It holds the potential to be a tremendously effective tool to improve students' interest and attention while teaching a variety of skills (Yuen et al., 2011).

With its development in educational application and various observed benefits, AR technology has been applied in to different subjects for assisting teaching and learning. Novotný, Lacko, and Samuelčík (2013) reported that they designed an AR application for history education, which combines historical maps as the primary context with 3D representation of historical buildings as the secondary context (Novotný et al., 2013). This application was found to improve the understanding of spatiotemporal relations, and users were able to observe the changes in 3D buildings as well as changes in the historical maps (Novotný et al., 2013). In biology, AR can be used to study the anatomy and structure of bodies, teachers can use AR technology to show what organs can be found in the human body and how do they look by displaying 3D computer-generated models in classrooms (Lee, 2012). In astronomy, AR is used by the teachers to demonstrate the relationship between the earth and the sun with the use of 3D rendered planets (Lee, 2012).

2.5 What is AR Sandbox

AR Sandbox was designed by Dr. Oliver Kreylos, a computer scientist specializing on 3D scientific visualization and computational geosciences at UC Davis who also programmed the AR Sandbox software (UC Davis DataLab, n.d.). The first prototype was further developed and designed by a LakeViz3D project team. AR sandbox uses a computer projector and a Kinect 3D camera mounted above a box of sand. Interactivity is allowed when user shapes the sand in the basin. An elevation model with contour lines and a color map could be projected and visualized from an overhead projector onto the surface of the sand. As user move and manipulate the sand, the Kinect perceives changes in the distance to the sand surface, and the projected colors and contour lines change accordingly (UC Davis DataLab, n.d.). The contour lines and colors can be adjusted to convey different principles and/or to be optimized for different physical inputs (UC Davis DataLab, n.d.).

The utilization of mobile devices such as tablets or mobile phones has been the dominant form of AR implementation in education. The screens of devices are the key interface used for these AR tools. As AR sandbox implements its visualization on sand, its interface is different from other AR implementations, and it has been suggested that richer experience can be brought to users when they engage and interact by manipulating the sand by their hands to construct different landscapes (Sánchez et al., 2016).

One study pointed out that AR sandbox is specifically suitable for presenting abstract concepts such as topographic maps and contour lines as it could transform 2D paper topographic map into an interactive and dynamic 3D representation (Giorgis et al., 2017). Learners can construct various landscapes by interacting with and moving the sand, thereby they can view the evolution of the map, such as the change in contour lines as the sand surface changes and it is believed that this could help students to overcome their learning barriers related to spatial concepts (Sánchez et al., 2016). Studies in the application of AR sandbox in education have primarily focused on its implementation and installation of it into geology education (Richardson et al., 2018; Vaughan, Vaughan, & Seeley, 2017; Woods et al., 2016), fewer work has been done to examine the effectiveness of AR sandbox in enhancing students learning in geology or geography education.

2.6 Usage and effectiveness of AR Sandbox in Teaching

AR has become a game changer, in the field of education offering interactive learning experiences that connect knowledge with practical applications. One standout example of this technology is the AR sandbox, which combines a motion sensing camera, a projector with short throw capabilities and an actual sandbox to create models of landscapes that users can interact with. By enabling users to manipulate sand and witness changes in terrain features like lines and elevations the AR sandbox offers a hands on learning experience that is both captivating and effective for grasping complex spatial concepts. This innovative tool has attracted attention for its ability to improve reasoning skills and enhance experiential learning especially in STEM education where understanding spatial relationships is key.

The versatility of the AR sandbox extends to fields. In geosciences, it assists in visualizing formations and manipulating them to deepen students' comprehension of topography and spatial connections. In soil science, it aids students in predicting soil formation based on landscape features enriching their understanding of soil development processes like erosion and water movement through activities. Moreover, the AR sandbox serves as a tool in geo-design by facilitating decision making processes and design discussions, through real time visualization capabilities.

This review consolidates findings from research studies investigating the use and impact of the AR sandbox in environments. These studies collectively illustrate how the AR sandbox shifts learning to an interactive experience significantly enhancing student engagement, understanding and spatial reasoning abilities. Through its application in geosciences, soil science and geo-design in this review underscores the potential of the AR sandbox to revolutionize teaching practices and improve learning outcomes across a variety of fields. The subsequent sections delve into the applications of the AR sandbox in education. Assess its effectiveness as a teaching tool offering insights into its advantages, obstacles and future prospects in educational settings.

2.6.1. Application of AR Sandbox for educational objectives

The AR sandbox represents the use of reality technology that has shown considerable promise in enriching educational experiences across diverse subject areas particularly within STEM disciplines. By combining a motion sensing camera, a short throw projector and a physical sandbox the AR sandbox generates topographical models that enable users to manipulate sand and observe real time changes in contour lines and elevation. This hands-on method promotes a comprehension of spatial concepts and has been effectively applied in educating students, on geosciences, soil science and geo-design.

In the field of geosciences, the AR sandbox has proven to be a tool, for teaching reasoning, which is crucial for comprehending geological phenomena. Elijah T. Johnson's thesis, "Enhancing Spatial Thinking in Geology Students with the Augmented Reality Sandbox" delves into how the AR sandbox can boost thinking skills among geology students. Johnson emphasizes the importance of reasoning in STEM disciplines in geology, where knowledge of topographical and geological features is key (Johnson, 2019). By allowing students to interactively visualize and manipulate these features, the AR sandbox bridges the gap between theory and practical application. This hands-on approach is particularly beneficial for students struggling with concepts and helping them grasp complex ideas more effectively (Johnson, 2019).

The effectiveness of the AR sandbox in geosciences is further validated by research conducted by Woods, Reed, Hsi, Woods, and Woods (2016) who showed that this technology could enhance students understanding of maps and surficial processes. In their study involving geology classes they used the AR sandbox to simulate changes, in topography and water flow offering a way for students to explore these concepts. Woods et al. (2016) has demonstrated that the interactive features of the AR sandbox have a positive impact on students' spatial reasoning skills. These skills are crucial for analysing data and making deductions about subsurface qualities.

Using the AR sandbox in soil science education has produced outcomes in promoting hands on learning experiences. An article, by Karen L. Vaughan and her team titled "Enhancing Soil Science Education through Experiential Learning with an Augmented Reality Sandbox" showcases its implementation in a soil science class at the University of Wyoming. By creating landscapes with the AR sandbox, students could predict soil formation based on terrain features. This method encouraged student engagement leading to a grasp of topics such as soil genesis, erosion dynamics and water movement (Vaughan, Vaughan, & Seeley, 2017). They illustrated how the AR sandbox can revolutionize learning into an interactive venture. Students reported comprehension of erosion processes soil formation mechanisms and water flow patterns as a result of engaging in hands on activities, with the AR sandbox. The ability to visualize and interact with landscapes in time was highlighted as a factor in enhancing their understanding of these intricate phenomena. This discovery is consistent, with theories that highlight the significance of hands on learning and engaging senses to enhance educational achievements (Freeman et al., 2014).

Moreover, the effectiveness of the AR sandbox in soil science education is supported by research studies. Reed et al. (2016) applied the AR sandbox to teach watershed science showcasing its ability to replicate real life scenarios like floods and water flow. The interactive simulations offered by the AR sandbox aided students in grasping the dynamics of watersheds and understanding the factors that impact soil and water interactions (Reed et al., 2016). This practical utilization of knowledge holds importance in earth sciences, where comprehending the interconnection among various natural processes is crucial.

In geo-design the AR sandbox has been utilized as a tool for decision making and design procedures. The research study by Afrooz, Ballal, and Pettit (2018), explores its application in a workshop focused on trial planning. Participants leveraged the AR sandbox to visualize and discuss design interventions illustrating its effectiveness, in facilitating learning and decision making processes (Afrooz et al., 2018). The AR sandbox allowed users to interact with the landscape and design elements in time encouraging discussions and negotiations, among team members. This interactive tool provided an insight into relationships and design compromises which play a vital role in urban planning and landscape architecture (Afrooz et al., 2018). The research revealed that the AR sandbox not only enhanced participants' spatial reasoning abilities but also improved their collaboration skills on design projects.

Incorporating the AR sandbox into geo-design workflows aligns with Steinitz's design framework emphasizing the significance of interactive tools in facilitating effective communication and decision making among stakeholders. By offering a shared platform for exploring design alternatives and their potential impacts the AR sandbox helps participants gain an understanding of issues and make well informed choices.

Apart from its applications in geosciences, soil science and geo-design, the AR sandbox shows promise in settings. Its capacity to generate models in time makes it an invaluable resource for teaching concepts across various disciplines such as geography, environmental science, urban planning, as well as foundational earth science principles, in primary education.

The AR sandbox's versatility in generating simulations such as floods, erosion, and landscape transformations enhances its utility across many educational levels and disciplines. It can be employed in geography classrooms to instruct pupils about terrain formations, water cycles, and the impact of human activities on habitats. The AR sandbox giving students the chance to modify the terrain and witness the outcomes of their actions in time the AR sandbox offers a hands on learning experience that enriches their comprehension of these processes. This method is backed by studies highlighting captivating learning settings as key factors in enhancing student performance (Hake, 1998).

In environmental science courses, the AR sandbox can simulate occurrences such as impacts of climate change, deforestation and urban development. These simulations aid students in grasping how various environmental elements are interconnected and emphasize practices significance. Being able to see and engage with these simulations physically makes the AR sandbox a valuable tool, for promoting knowledge and consciousness (McNeal et al., 2020). While highlighting the benefits, it is essential to acknowledge the difficulties and factors associated with utilising the AR sandbox.

Implementing the AR sandbox requires a lot of setup such as using a motion sensing camera, projector and specific software. It can be quite a challenge to set up and maintain this equipment for schools or organizations with resources. Technical problems like calibration issues and software glitches can sometimes interrupt the learning process.

The AR sandbox is still relatively new in the field of education. There is research on how well it can be adapted to different educational environments. Making sure that students from all backgrounds have access to this tool, including those in schools with budgets or remote locations presents an obstacle. Creating portable versions of the AR sandbox could help make it more accessible.

Assessing how effective the AR sandbox is at improving learning outcomes can be tricky. Traditional evaluation methods might not capture all the benefits it offers in terms of understanding and hands on learning experiences. Establishing evaluation frameworks that accurately measure the impact of using the AR sandbox on student learning is vital for its continued development and success.

The AR sandbox represents an advancement in technology by providing an engaging platform, for teaching complex scientific concepts related to geography, soil science and design. Its versatility has been showcased in fields by enhancing spatial awareness, student involvement and collaborative learning experiences. While there are still challenges to overcome in terms of implementing the technology and ensuring accessibility the potential advantages of this ground-breaking tool are significant.

By turning ideas into hands on experiences the AR sandbox not only boosts educational outcomes but also fosters a greater interest and involvement, in STEM fields. This innovation has the potential to revolutionize learning by making it more engaging, enjoyable and effective ushering in an era of progress. As the AR sandbox progresses further its integration into settings is likely to broaden solidifying its position as a valuable asset, for hands on learning and spatial education.

2.6.2. Effectiveness of AR Sandbox for teaching

The effectiveness of the AR sandbox as a teaching tool is multifaceted, encompassing improvements in spatial reasoning, student engagement, and collaborative learning. This section explores how the AR sandbox enhances educational outcomes across different disciplines, drawing on evidence from several key studies.

One of the primary areas where the AR sandbox demonstrates significant effectiveness is in the enhancement of spatial reasoning. Spatial reasoning skills are critical for success in STEM fields, where understanding and visualizing spatial relationships are essential. Johnson (2019) detailed in his thesis "The Effectiveness of the Augmented Reality Sandbox for Improving Spatial Thinking in Undergraduates," investigates this aspect comprehensively. His study aimed to determine whether the AR sandbox could improve spatial thinking skills among low-scoring students. The results were promising, showing significant improvements in spatial reasoning abilities after students engaged with AR sandbox activities (Johnson, 2019).

Students reported a greater ability to understand and visualize topographical maps and geological features. This improvement is crucial because spatial reasoning is a predictor of success in STEM fields, and enhancing this skill can help retain students in these disciplines. Johnson's findings align with previous research indicating that spatial skills are malleable and can be developed with targeted educational interventions. By providing a hands-on, interactive platform for learning, the AR sandbox helps students build these critical skills in a more engaging and effective manner than traditional teaching methods.

Another critical dimension of the AR sandbox's effectiveness is its impact on student engagement and comprehension. Karen L. Vaughan and colleagues' study, "Experiential

Learning in Soil Science: Use of an Augmented Reality Sandbox," provides substantial evidence in this regard. Vaughan et al. incorporated the AR sandbox into an introductory soil science course at the University of Wyoming, where it was used to create virtual landscapes for students to study soil formation based on topographical features. This experiential learning approach significantly enhanced student engagement and comprehension (Vaughan et al., 2017).

The interactive nature of the AR sandbox allowed students to visualize and manipulate the landscape in real-time, which was cited as a key factor in improving their understanding of complex processes such as soil genesis, erosion, and water flow. Students who participated in the AR sandbox activities reported a more profound understanding of these concepts compared to traditional lecture-based learning. This aligns with educational theories that emphasize active learning and multisensory engagement as crucial for effective learning (Freeman et al., 2014).

The AR sandbox also excels in facilitating collaborative learning and decision-making, particularly in fields that require teamwork and the integration of multiple perspectives. Afrooz et al. (2018) explores the use of the AR sandbox in a geo-design workshop focused on trial planning. Participants in this study used the AR sandbox to visualize and negotiate design interventions, demonstrating its utility in enhancing collaborative decision-making processes (Afrooz et al., 2018).

The AR sandbox provided an interactive platform that enabled participants to engage with the terrain and design elements in real-time, fostering discussion and negotiation among team members. This collaborative environment is essential in fields like urban planning and landscape architecture, where multiple stakeholders must come together to design and implement effective solutions. The AR sandbox's ability to provide a shared, interactive platform for these discussions enhances its value as a pedagogical tool. It helps participants develop a deeper understanding of the issues at hand and make more informed decisions.

Beyond its specific applications in geosciences, soil science, and geo-design, the AR sandbox has broader educational implications. Its ability to create interactive, real-time models makes it a valuable tool for teaching concepts in geography, environmental science, urban planning, and even in primary education for basic earth science concepts. The versatility of the AR sandbox in creating different types of simulations, such as flooding, erosion, and landscape changes, broadens its applicability across various educational levels and disciplines.

In geography education, for example, the AR sandbox can be used to teach students about landforms, water cycles, and the impact of human activities on natural environments. By allowing students to manipulate the landscape and observe the effects of their actions in real-time, the AR sandbox provides a hands-on, experiential learning experience that enhances their understanding of these complex processes. This approach is supported by educational research that emphasizes the importance of interactive and engaging learning environments in improving student outcomes (Hake, 1998).

In environmental science, the AR sandbox can simulate various environmental phenomena, such as climate change impacts, deforestation, and urbanization. These simulations help students understand the interconnectedness of different environmental factors and the importance of sustainable practices. The ability to visualize and interact with these simulations tangibly makes the AR sandbox an effective tool for promoting environmental literacy and awareness (McNeal et al., 2020).

While the AR sandbox has demonstrated significant benefits, it is essential to acknowledge the challenges and considerations associated with its use. Implementing the AR sandbox requires substantial technical infrastructure, including a 3D motion-sensing camera, projector, and compatible software. Setting up and maintaining this equipment can be resource-intensive, posing a barrier for institutions with limited funding. Additionally, technical issues such as calibration errors and software glitches can disrupt the learning experience (Johnson, 2019; McNeal et al., 2020).

The AR sandbox is a relatively new technology, and its scalability across different educational settings is still being explored. Ensuring that this tool is accessible to a broad range of students, including those in underfunded schools or remote areas, remains a challenge. Developing cost-effective and portable versions of the AR sandbox could help mitigate these accessibility issues (Reed et al., 2016). Moreover, the integration of AR sandbox activities into the curriculum requires thoughtful planning to align with educational goals and outcomes.

Measuring the effectiveness of the AR sandbox in improving learning outcomes can be complex. Traditional assessment methods may not fully capture the enhancements in spatial reasoning and experiential learning provided by this tool. Developing robust evaluation frameworks that can accurately assess the impact of AR sandbox activities on student learning is crucial for its continued adoption and improvement. For instance, combining qualitative feedback from students with quantitative measures of academic performance could provide a more comprehensive understanding of the AR sandbox's educational impact (Freeman et al., 2014).

The AR sandbox represents a significant advancement in educational technology, offering a dynamic and interactive platform for teaching complex spatial and scientific concepts. The reviewed articles collectively demonstrate the AR sandbox's effectiveness in improving spatial reasoning, enhancing student engagement, and facilitating collaborative learning. While challenges remain in terms of technical implementation and accessibility, the potential benefits of this innovative tool are substantial.

By transforming abstract concepts into tangible, interactive experiences, the AR sandbox not only enhances learning outcomes but also inspires a deeper interest and engagement in STEM subjects. This technology holds the promise of making learning more immersive, enjoyable, and effective, paving the way for a new era of educational innovation. As the AR sandbox continues to evolve, its integration into diverse educational contexts will likely expand, further solidifying its role as a valuable tool for experiential learning and spatial education.

2.7 Determinants of the Effectiveness Interactive Technology and AR in Education

2.7.1. Learning attitude and learning motivations

To promote the effectiveness of learning and teaching, studies often attempt to explore various determinants of students' learning outcomes. The commonly studied determinants usually concern an array of socio-psychological and cognitive factors, including attitudes, knowledge, motivation, satisfaction, belief, personal values, etc. (Chen et al., 2023). By drawing linkages between the potential determinants of students' learning outcome, researchers have found different factors that may help promote the learning of students, which can be valuable for actual applications in schools and in classes (Chen et al., 2023; Eom, Wen, & Ashill, 2006; Muvawala, 2012).

Among the various factors that have been explored, learning attitude and learning motivation are often found to be important factors that drive the learning outcomes of students. Attitude refers to the recognition, understanding, beliefs, and emotions of an individual towards a certain person, object, or event (Chou et al., 2021; Oroujlou & Vahedi, 2011; Weng, Ho, Yang, & Weng, 2018). Attitude also describes the inclination of action (Chou et al., 2021; Oroujlou & Vahedi, 2011; Weng et al., 2018). Attitude in learning, therefore often studies students' recognition and feeling towards certain types of teaching approach, technology applied, or mode of classes, which would also indicate the preference of students and how willing they are to attend similar classes under these conditions (Chou et al., 2021; Oroujlou & Vahedi, 2011; Weng et al., 2018). As attitude in learning often describes students' recognition and feeling that leads to preference, learning attitude may not always have absolute a positive or a negative side. For instance, Chou et al. (2021) studied the associations between the utilization of the flipped teaching approach, students' attitude, and the effectiveness of learning. The learning attitude in the study measured students' willingness to participate in the class in flipped teaching, their wish for more classes in the same format, and their affective connection to the teaching approach. The findings of the study ultimately indicated that the flipped teaching approach promoted students' learning attitude which in turn enhanced the learning outcome and effectiveness. In a similar study, Cheng and Tsai (2019) studied the application of VR technology and tested studies learning attitude, where attitude was measured by items such as the expectation of student for class that adopts VR technology in the future, which describes students feeling towards the technology as well as their behavioral tendency to participate in such classes in the future.

On the other hand, learning motivation describes the desire and the internal driving force that triggers an individual to carry out an action and indicates a direction of action (Chen et al., 2023). Again, it has been suggested to be an crucial determinant of students' learning effectiveness and outcomes as learning motivation drives students to engage and be more involved in the learning process, which in turn promotes the ultimate result of learning (Chen et al., 2023). Like learning attitude, learning motivation can be measure in different ways depending on the context of the studies. For instance, in the study of Wang, Shannon, and Ross (2013), the authors explored the associations between motivations, learning strategies, learning efficacy, and learning outcomes. Learning motivations were measured in terms of students' confidence in understanding and learning in class, their positive feeling towards performing in class, their interest in the class, and how much they value knowledge gained from the class. While the results indicated that learning motivation was not directly linked to learning outcome as represented their final grade, learning motivation was found to significantly promote students' satisfaction which subsequently improve their final grade. Another study by Garcia and Pintrich (1996) explored learning motivation with reference to the Motivated Strategies for Learning Questionnaire, where motivations were measured in multiple aspects, including intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, etc. Therefore, this also shows that the variable of motivation can have multiple underlying dimensionalities either designed into the scale items, or it can be explored from a set of multiple items that represents a range of motivations in learning.

2.7.2. Socio-demographic variables

To no surprise, socio-demographic factors have been widely documented to be a crucial determinant of students' learning outcomes in class and their academic performance. At a global scale, studies from countries with better socioeconomic status are always the ones that show better learning and academic performance (Hettler, 2015). At the scale of schools, socio-economically privileged students were found to outperform socio-economically disadvantaged students (Hettler, 2015). Socio-demographic factors such as gender, age, household income, grade of study, race, and ethnicity were often explored (Altmyer & Yang, 2010; Hettler, 2015; Rizvi et al., 2019). Socio-economic status of students represents the resources, opportunities, upbringing where all these associated factors influence their ability to learn, their assistance within or outside classes, their chances of involvement, and hence their learning outcome and performance (Altmyer & Yang, 2010; Hettler, 2015; Rizvi et al., 2019; Tetteh, 2018). For instance, Rizvi et al. (2019) found that poverty levels of neighborhoods of student were correlated to their learning outcomes. Alternatively, Hettler (2015) reported that with the introduction of Team-Based Learning, students coming from lower incomes groups and minority background tend to show greater improvements in learning outcome.

At the same time, considering the significant impacts of socio-demographic factors, they are also often considered as the confounding factors in analysis, and would be included in analysis as control variables (Nieuwenhuis & Hooimeijer, 2016).

2.8 Measurements of Learning Outcome

The learning outcome of student were often measured through different variables, and in this study three measurements of learning outcome were utilized, including pre-test and post-test assessment, self-evaluation, and perceived learning efficacy. The following sections provide an overview of the respective measurements.

2.8.1 Pre-test and post-test assessment and self-evaluation

The pre-test (pre-treatment) and post-test (post-treatment) research design has been one of the most common and long established approaches in measuring the outcomes or conditions of intervention and treatment of target groups of population or participants (Bonate, 2000; Dimitrov & Rumrill Jr, 2003; Dugard & Todman, 1995), which resembles experimental designs. This approach of pre-test and post-test assessment benefit from having directionality in research which resembles classical experimental designs (Alam, 2019; Stratton, 2019). A response variable will be employed to reflect the change in the participant (e.g., scores of assessments) before and after the treatment or intervention, and an independent or multiple independent variables can be introduced to represent the treatment or intervention (e.g., use of technology, teaching). The pre-test assessment can also act as a baseline to reflect the original performance or status of participants. The pre-test and post-test approach is often designed to assess a certain group of target participants, e.g., certain types of patients or certain groups of students, so specific information about that specific population can be gathered. Another advantage of this approach is that it can easily and quickly be utilized to assess the treatment or intervention on a target group of participants or to assess the use of a particular form of intervention, e.g., technology (Stratton, 2019). The easy application of this method can therefore be useful for the quick assessment and refinement of newer forms of interventions, such as technology or form of teaching, providing greater flexibility in quickly improving the outcome of the intervention (Stratton, 2019).

The comparison of pre-test scores and post-test results of target participants has been an approach adopted by studies in many different fields, including education, psychology, behavioral sciences, and health sciences, etc. (Castro et al., 2020; Govender & Du Toit, 2002; Shek & Sun, 2012; Twentyman, Heel, Henderson, & Lloyd, 2006). For instance, in behavioral science studies, the behavioral changes of participants in pre-intervention and post-intervention are often observed and studied, on the hand, in medical and health sciences, it is often used to assess the efficacy or effectiveness of certain treatments or medications where the conditions of participants before and after the treatments were compared (Conceição, Pedro, & Martins, 2017; Eheman et al., 2009; Stamatis et al., 2020). It is also common for research in education to adopt the pre-test and post-test research design, particularly to examine the learning outcome of students or the performance of teachers (Dugard & Todman, 1995; Shek & Sun, 2012; Thelen, 2021; Ward, Mandrusiak, & Levett-Jones, 2018). For instance, the study of Putri, Rusdiana, and Rochintaniawati (2019) explored the use flipped classroom approach in junior high school in improving students' engagement, inquiry, problem solving skills in class, and carried out a pre-test and post-test worksheet assessment on students' performance. The findings indicated that the performance of student improved after the implementation of the intervention. Similarly, Alam (2019) studied the effectiveness of lecture-based teaching among a group of medical school students in Pakistan. The study utilized a pre-test and post-test model to explore the change in performance of students before and after the delivery of lectures, and two different topics of lectures were tested. The results indicated lectures were effective in improvement the performance of student reflected by the improvement in learning outcomes in terms of passing rates and marks in the post-test assessment. Studies with similar approach have been carried out in assessing the effectiveness of e-learning too apart from traditional forms of teaching, for instance, Kratochvíl (2014) explored the utilization of e-learning information literacy compared to in-class course among medical students and PhD students in Czech Republic while adopting pre-test and post-test assessments with multiple choice questions. The learning outcome and extend of knowledge gained was determined by the change in number of questions answer correctly by students.

Apart from taking objective measurements of participants performance or conditions for the pre-test and post-test comparisons, some studies utilize another measurement of self-evaluation to also reflect how participants perceive their own performance, which could also be an indicator of their level of confidence, attitude, and skills (Bartlett et al., 2017). Self-evaluation or self-assessment has been widely adopted in the medical education field, where it is often used to examine medical students' training and learning (Bartlett et al., 2017; Zhao & D'Eon, 2020). For instance, Garibaldi et al. (2017) studied the implementation of a medical training programme on Advancing Bedside Cardiopulmonary Examination Skills where students went through the relevant training. Students were then asked to self-assess their performance in terms of their skills and confidence, and such outcome was compared to students who have not taken the training.

2.8.2 Perceived learning efficacy

Apart from the objective measurements by assessing participants through tests and evaluations, the psychological measurement of learning efficacy or self-efficacy are also another commonly adopted variable to examine students' performance in learning (Hayat, Shateri, Amini, & Shokrpour, 2020; Kutuk, Putwain, Kaye, & Garrett, 2023; Tsai, Cho, Marra, & Shen, 2020). Learning efficacy, or sometimes termed self-efficacy, describes the belief of an individual on their own ability in a certain aspect, or their capabilities to do a certain thing (Tsai et al., 2020; Wang et al., 2013), in the case of learning, it could for instance, be the ability of a student in applying knowledge that they learnt. As learning efficacy have been adopted widely by studies in education, different types of scales and items were also developed to measure the variable, which often involve the confirmation of validity and reliability as well (Kutuk et al., 2023; Tsai et al., 2020). Therefore, the variable is also well examined empirically and would be highly suitable for use in the current study. For example, Tsai et al. (2020) has developed a scale that represents five dimensions of self-efficacy in online learning, where the construct validity and reliability were found to be strong. In terms of application of the variable in educational research, Phan (2011) studied the relationships between self-efficacy in learning and learning approaches in university students, where the author measured student learning efficacy through a set of items developed from two self-efficacy scale in previous studies, The items developed inquired students about their perceptions on, for example, their understanding of the subject that was taught, or their ability to do well in the subject that was taught.

2.9 Gap in Knowledge

This study aims to examine the effectiveness of the use of AR sandbox in secondary geography education, and the determinants that influence the effectiveness of its application as existing researches on AR Sandbox mainly focus on technological requirements, potential benefits to educational approaches, instructional design as well as students' and teachers' interests on the AR tool for physical geography or geology at undergraduate level (Jenkins et al., 2014; Offermo, 2016; Nawaz, Kundu & Sattar, 2017; Sanchez et al., 2016; Woods et al., 2016; O'Banion, 2022). In addition, no similar research has been carried out to examine the effectiveness of AR sandbox in secondary geography education in terms of its influence on student learning outcomes. Research studies also suggested that socio-demographic characteristics of students, like gender, household income and age were also found to shape their performance (Altmyer & Yang, 2010; Hettler, 2015; Rizvi, Rienties & Khoja, 2019).

CHAPTER 3: METHODOLOGY

This chapter will start by introducing the overall design of this study, the research questions, and the relevant instruments used. The design of the relevant instrument will be discussed, in terms of the pre-test and post-test assessments, the questionnaire survey, and the semi-structured group interview. The following sections outlines the details on data collection, including the arrangement of classes, the recruitment of participants, and the details on the classes. The last part of this chapter provides an overall description of the data analysis in the study, regarding the analysis of the effectiveness of AR sandbox classes, and the analysis of impacts of the proposed determinants on the learning outcomes of students.

3.1. Research Design and Instruments

3.1.1 Overall research design

This study explores the use of AR technology with a focus, on the AR sandbox to examine its potential as a tool for improving geography education (McNeal et al., 2020; Soltis, McNeal, Atkins, & Maudlin, 2020). The main goal is to determine if AR can have an impact on learning outcomes and identify both the factors that support its use in educational settings and those that may hinder it. The research employs an approach that combines teaching methods and assessment tools to thoroughly evaluate how AR technology influences learning.

This study has two objectives. It aims to assess how AR technology, especially the AR sandbox in enhancing learning outcomes for secondary school students studying geography. Secondly, it aims to understand and analyze the factors that play a role in integrating AR technology into the learning environment. Having this knowledge is crucial for understanding what AR can offer and where its limitations lie as a tool in high school settings.

The study involved students from seven schools in Hong Kong specifically focusing on those in senior grades. This selection was made to ensure that the results are relevant to a group of students who often encounter concepts and could benefit from using interactive learning tools, like AR. At this stage of their education, students are at a point in their journey, where new and creative teaching approaches can greatly influence their learning progress and results.

Participants took part in study sessions that combined teaching methods with those enhanced by AR technology. These sessions focused on two aspects of geography; map reading and farming which are two of the compulsory modules in the Hong Kong Diploma of Secondary Education (HKDSE) geography curriculum. In the HKDSE geography curriculum, physical geography topics comprises of weather and climate, geology, hydrology and ecosystem while the human geography topics include economic geography, urban geography and agricultural study. Students are expected to learn the geographical skills such as map reading, interpretation of aerial photos and satellite images and GIS as embedded across different geographical topics in the HKDSE geography curriculum.

The map reading topic is not only a geographical skill topic but also includes elements of physical geography such as students were learnt to identify and understand the natural landforms from maps. On the other hand, when compare to economic geography and urban geography, farming is more suitable for the use of AR sandbox. For example, farming activities usually occur in natural terrain and the AR sandbox would help to visualize the natural terrain for the task of selecting favorable farming locations in this assessment. Hence, the AR sandbox is less favorable to support the study of economic geography and urban geography as those urban settlements were found in urbanized areas where the visualization impact would be indistinct. In consequence, map reading and farming were selected as the assessment topics in this study for covering the learning elements of physical geography, human geography and geographical skills.

The study followed an experimental design incorporating two different classroom setups for each participant; one using the AR sandbox and the other sticking to a traditional classroom setup. This structure allowed for a comparison of learning outcomes between the AR integrated environments and conventional teaching methods. By rotating students between these formats for the two topics the research aimed to uncover insights into the effectiveness of AR technology, across various educational content.

With the aim of maintain the consistency between the experiment group and control group, all participants conducted the geography lessons in the Department of Social Sciences of The Education University of Hong Kong and all the AR sandbox were conducted with the AR sandbox of the Department to offer standardized intervention to experiment subjects. All the lessons were taught by the same instructors to ensure the teaching style, teacher ability and knowledge were the same in order to minimize the influence of instructor.

In order to address the research questions and meet the study goals, a mixed methods approach was taken, combining quantitative and qualitative research methods. This comprehensive method was chosen to ensure an examination that incorporates both information and personal perspectives from participants.

From a standpoint the study employed pretest and test evaluations to directly gauge how AR influences students learning outcomes. These assessments yielded data on students' knowledge and skills before and after exposure to AR technology providing a foundation for assessing the enhancements brought about by AR.

In the research we conducted group interviews with students to delve deeper into their experiences with AR technology. These discussions allowed us to grasp the details of how students engage and interact with AR, which quantitative methods might not fully capture. This approach provided an understanding of the practical impact of AR in educational settings.

By combining these research methods, we ensured that our study could present a rounded and detailed conclusion on the effectiveness of AR in improving geography education. Our findings offer insights into how AR technology has the potential to transform practices and outcomes for the better.

3.1.2. Research instruments

To tackle these questions and fulfill the objectives, a mixed-methods approach was employed blending quantitative and qualitative research methodologies. This robust approach was selected to ensure a thorough analysis that integrates both statistical data and personal insights from the participants.

Quantitative Measure

A quantitative approach was adopted to evaluate a complete understanding of the effectiveness of AR on educational outcomes within the context of geography education.

Measurement of the direct impacts of AR enhanced teaching methods compared to traditional approaches was the strategy's primary focus, which concentrated on implementing pre-test and post-test after-lesson assessments. It was essential to conduct these assessments to quantify any changes in the student's level of comprehension or performance that could be directly attributed to the instructional strategies that were executed.

With a focus on map reading and farming, the pre-test assessments were carefully designed to provide a baseline measurement of the students' starting knowledge and preparedness for the content of the classes. These subjects were selected based on their physical and human geography significance, ensuring a comprehensive representation of the field's breadth. Multiple-choice questions on the after-lesson assessments were meticulously crafted to objectively assess the students' comprehension of the fundamental ideas and practical knowledge associated with each subject category. Students could reflect on and evaluate their understanding and skills before interacting with the instructional material by incorporating a self-assessment component within the pre-tests. This dual-assessment strategy was crucial in providing a thorough snapshot of the student's initial conditions, laying the groundwork for evaluating the student's educational progress and development during the study.

After the instructional time, which included both traditional and AR enhanced teaching approaches, post-test assessments were given to the students, and the evaluations were designed to replicate the pre-tests, including the same elements of multiple-choice questions and self-evaluation. The intentional replication was essential in facilitating a direct and consistent assessment of educational results before and during the intervention. This study validated the influence of the AR sandbox as an effective teaching tool by ensuring that any observed changes in student performance could be reliably linked to the instructional methods utilised. This was accomplished by preserving uniformity in the assessment's content and structure.

In addition to the formal assessments, the study also included a thorough questionnaire survey to investigate further the factors determining learning efficacy. The quantitative approach included this survey as an essential component. The survey aimed to shed light on the more general attitudes and motivational factors that could affect the learning results. Students' attitudes towards learning in general, their specific levels of motivation while engaging with AR technology, and their overall assessments of the impact that AR has had on their educational experiences were some of the critical areas of attention within the study. Questions were formulated to elicit insights into how these elements influence the student's commitment to the learning process and their level of performance.

The benefits of AR technology on learning processes were seen from multiple angles thanks to this integrative strategy that combined subjective survey data with objective test results. The empirical data derived from the assessments provided tangible proof of advancements or deficiencies in learning. At the same time, the subjective responses obtained from the survey assisted in contextualising these results within the broader range of experiences and perceptions that students held. As a result, analysing these quantitative metrics achieved a comprehensive understanding of AR technology's potential impact on educational practices. This analysis underscored the difficulties and strengths of incorporating these ground-breaking technologies into conventional learning environments. Educators and technologists must comprehensively understand the industry to refine and optimise AR apps for improved academic outcomes.

To explore the use of AR sandbox and its effectiveness, and to find out the potential determinants that shape the learning outcome of student, the current study a few research instruments, in both qualitative and quantitative approaches were developed to help collect the relevant data. In terms of quantitative data, a pre-test and post-test assessment was developed to measure the learning outcome of student as in the scores gained in the test. The self-evaluated performance of students will also be inquired in the pre-test and post-test assessment. Moreover, a questionnaire survey was designed to help measure the potential determinants of learning outcomes of students, including their learning attitude and learning motivation. The questionnaire survey also help to measure a perceived form of learning outcome of students in terms of their perceived learning efficacy. In terms of qualitative measurement, semi-structured group interviews were conducted to capture students' learning experiences and views in the respective classes on AR sandbox and traditional approach as well as in both the map reading and farming topic.

In the pre-test and post-test assessment part, the pre-test assessment aimed to assess students' knowledge of map reading and farming system prior to the delivery of classes. This also serve as a baseline for assessment, to account for the potential discrepancy in level of knowledge between students and help to make a fair comparison in the later stages of analysis. In the map reading class, the pre-test assessment consist of two parts: a) objective assessment of map reading skills and knowledge with eight multiple choice questions, and b) self-evaluation of map reading ability. In the farming class, the pre-test assessment consists of two parts: a) objective assessment of knowledge about farming systems, which student had to evaluate the four proposed sites based on seven given farming factors, and b) self-evaluation of their farming knowledge. The post-test assessment sought to measure the change in knowledge and skills of students in the respective topics and forms of classes. The assessment was developed to be identical to the pre-test assessment to facilitate direct comparison of student learning outcome as in their score they gain. The questionnaire survey will be administered after all classes.

Qualitative Measure

The meticulous use of quantitative and qualitative research tools in this study enabled the creation of a complete dataset, which is crucial for undertaking a detailed inquiry into the impact of AR sandboxes on educational outcomes. The combination of rigorous direct empirical measurement and in-depth personal input in this multimodal method allowed for the possibility of conducting thorough data analysis.

The standardised pre-tests and post-tests yielded quantitative data that clearly and objectively demonstrated the impact of AR technology on students' knowledge and skills. The assessments provided a solid basis for statistical analysis, enabling quantifying the learning improvements promoted by AR-enhanced educational methods compared to traditional approaches. The objective data was critical in determining if the AR implementations significantly affected student learning outcomes. It provided a concrete measure for evaluating the success of the technology in educational contexts.

The qualitative component collected comprehensive student experiences and impressions of AR technology through semi-structured interviews and surveys. The feedback captured the subjective aspects of learning via AR, such as the level of engagement and motivation that students had and their overall happiness with the educational process. By integrating these individual viewpoints, the research acquired a more profound comprehension of AR's pragmatic implementations and potential constraints in academic settings. First-hand student reports gave the numerical data important context while demonstrating how AR affected their learning processes in a more intimate and participatory way.

Several approaches were combined to guarantee that the research could provide a fair and comprehensive assessment of AR technology's function in geography teaching. A thorough knowledge of the influence of AR was made possible by integrating quantitative precision and qualitative depth. This ensured that conclusions were founded on empirical evidence and enriched with human experiences and reactions. A more profound knowledge of the potential for cutting-edge technology to improve educational practices was eventually made feasible by the thorough investigation that allowed for the formulation of well-informed conclusions regarding the efficacy of AR sandbox. These findings are beneficial for educators who are interested in implementing new technologies as well as legislators who are interested in making investments in educational technology.

3.2. Design of Research Instrument

Yani, Mulyadi and Ruhimat (2018) define geography skill as the ability to interpret geographical data in the form of diagrams and maps. In this study, this definition is further contextualized as geography enquiry involving reasoning and decision making through interpreting diagrams and maps. To assess the ability to interpret geographical data in the form of diagrams and maps, Topographic Map Assessment designed by Jacovina et al. (2014) was used for data collection. With map-based geographical tasks involving paths, water flow, slopes, visibility and elevation points are asked. Students are required to identify the best location of farm site through interpreting geographical information of terrains, hydrological system, land availability, market accessibility and road connectivity.

3.2.1. Design of map reading topic assessment

The map reading assessment consists of two parts; the first part is the objective assessment, where eight questions were designed to examine students' knowledge, understanding, and ability to identify physical geography features on maps. All eight questions in this part were multiple choice questions with four answers, of which only one of them was correct, and students were asked to choose only one answer in each question. In questions Qm1 to Qm4, two figures were provided to show different landform features. Landform features, including cliffs, ridges, spurs, and valleys, were shown in the figures to examine students' ability to identify a range of features. In questions Qm5 and Qm8, students' ability to understand and recreate cross-sections from the information provided in a map, including contours and elevation, were tested. Two figures were provided for the two questions, respectively, and students were asked to choose the correct cross-section that represents the slope that shows the shape of the actual land. In questions Qm6 and Qm7, students were tested on their knowledge and understanding of slopes and gradients. Question Qm6 provided a figure, and students were asked to rank three slopes indicated on the map based on their steepness from the gentlest to the steepest slopes. In question Qm7, students were asked to indicate the gradient of one of the paths shown in the same map in Qm6.

In the second part, students were asked to carry out a self-evaluation on their own performance in the test. Students can rate their map reading ability in 0 to 10 marks, where 0 refers to no knowledge, 5 represents a pass, and 10 as a full score. This part measures how the AR Sandbox class and traditional class may influence students' perception on their improvements in ability before and after the class with the respective teaching approaches.

3.2.2 Design of farming topic assessment

The assessment of the topic on farming consists of two parts, the first part covers the objective assessment of student's knowledge, understanding, and ability to identify suitable sites for the development of agriculture. A case of Hong Kong is provided as the background, where a map of Happy Valley in Hong Kong and four potential sites (Site A, B, C, D) agricultural development were proposed. Students were then asked to evaluate based on the information on the map, including the relief of the location and nearby features, whether each site can fulfill the factors needed to be a proper farming location. Each of the four proposed site represents one major question, and within each major question (QfA, QfB, QfC, & QfD), there were seven sub-questions of farming factors that students need to indicate whether the location can attain that requirement for farming. The farming factors include presence of source of irrigation, presence of fertile soil, presence of gentler slope, proximity to market, possibility of soil erosion by flooding, possibility of erosion by landslide, and availability of sunshine. Notably, the four sites proposed each fulfill a different set of farming factors so student would be able to apply their knowledge to assess different situations. Site A represented a location that has high potential and risks for farming, site B represented a location with great physical features and slight risks for farming, site C represented a location with little potential and risk for farming, and site D represented a site with good physical features and geographical locations for farming.

In the second part, students were asked to fill out a self-evaluation to reflect on their performances in the test. Students were asked to rate their knowledge in farming from 0 to 10 marks, where 0 refers to no knowledge, 5 represents a pass, and 10 as a full score. This part measure how the class may influence students' perception on their improvements in knowledge before and after the class with the respective teaching approaches.

3.2.3 Design of questionnaire survey

In the post-test assessment part, a questionnaire survey was also delivered to understand and measure student's learning attitudes, learning motivations, and perceived learning efficacy specifically for the AR sandbox class.

The design of the questions of the questionnaire surveys for collecting students' learning attitude and motivation data were discussed with the geography teachers of the participated schools. Similar questions were used in participants' schools for collecting students' feedback on their lessons for years. Teachers opined that the questionnaire results were reliable and consistency with the lessons observed and student's performance which are useful for enhancing their daily teaching and annual planning of their geography classes. Therefore, no pilot study was carried out for the questionnaire surveys as the questions were tested and used in schools for years with positive comments from the experienced geography teachers.

The questionnaire survey consists of three parts. The first part included a total of 6 questions to explore student attitude in learning. Questions in this part covered a range of attitudes of learning that concern different parts of a lesson. Question A1, A4, and A5 explored students' perceptions of the roles of teachers and their interactions with teachers, including whether teachers should take full control over students' behaviors in class, whether teachers should utilize proper technology to foster students' learning, and whether teachers should take the role to immediately correct students when they make any mistake. Question A2 and question A6 focused on the learning attitude of students in terms of their active involvement and engagement in learning in class. The questions inquired students whether they think discussions and classroom activities are effective in promoting learning, and whether they perceive learning as having the opportunities to explore, discuss, and express personal opinions. In question A3, students were asked if they think traditional classes and method of teaching are the best approach to deliver knowledge, which serves to understand if students prefer a traditional form of lesson or lessons with interactive technology employed. Each question was represented by one statement as described above, and students were asked to indicate their level of agreement with the respective statements. A Likert scale of 1 to 5 was used to quantify students' degree of agreement with the statements, where 5 represented strongly agree, 4 represented agree, 3 represented neutral, 2 represented disagree, and 1 represented strongly disagree. A higher score therefore indicates a more positive attitude towards learning with more interactive approaches with technology applied.

In the second part of the questionnaire survey, students' learning motivations were measured and explored. This part consisted of 6 questions in total, each represented by one statement, and the questions covered aspects of students' learning motivations in terms of their sense of satisfaction in learning, their goals and objectives in learning, and their interests in learning. Question B1 and question B2 gauged the satisfaction of students in learning. In particular, in question B1, students were inquired whether learning brings them a sense of satisfaction, and question B2 asked whether spending effort and building their understanding and personal opinions on a topic is the way for students to gain the sense of satisfaction in learning. Question B3 and question B4 explored the goals and objectives of learning for students, particularly their motivations associated to public exams and classroom exercises. Question B3 captured whether students regard attaining good grades in public examination as their only goal to learn, and in question B4, students were asked if they approach learning and studying exclusively through completing exercises assigned and contents covered in class and in the curriculum. In question B5 and question B6, students' personal interests and motivation in learning were explored. Question B5 asked students if having the interest in the particular subject or content of classes can serve as their motivation to work harder in learning, on the other hand, question B6 asked students to indicate if they think going through and memorizing model answers are the best ways to learn. Similar to the last part, a Likert scale of 1 to 5 was used, and it quantified how often do student feel the same as the scenario described in the statements. In the Likert scale, 5 represented all the time, 4 represented often, 3 represented sometimes, 2 represented rarely, and 1 represented never. A higher score indicates that students were showing more positive learning motivation in modern approaches of learning and felt more aligned with the motivation to learn not just for exams.

In the third part of the questionnaire survey, students' perceived learning efficacy in the AR sandbox class were measured. This part consisted of 7 questions in total, each represented by one statement. Question C1 to question C4 inquired students on their perceptions on how effective the lesson were in promoting their learning and understanding in terms of, their ability in map reading, understanding of contours and landforms and their relationships, farming related knowledge and issues, and their ability and skills in processing data and information. Question C5 asked whether they think the tools utilized in class were helpful in promoting their interests in geography. Question C6 measured how satisfied students were concerning the utilizing of AR sandbox in the lesson. In question C7, students were asked if they would like to have more lesson with the same format with AR sandbox or similar interactive technology adopted. A Likert scale of 1 to 5 was applied to quantify the level of agreement of students regarding the respective statements. In the Likert scale, 5 represented strongly agree, 4 represented agree, 3 represented neutral, 2 represented disagree, and 1 represented strongly disagree. A higher score represented that students were holding more positive perceptions and feelings towards the learning outcome of the lesson and the utilization of AR sandbox.

The last part of the questionnaire survey consisted of 2 questions to collect students' demographic information. In particular, the gender and class and grade of students were inquired in this part.

To encourage students to give their honest opinion and indicate their true feelings and perceptions, it was emphasized in the introduction section of the questionnaire survey that there would be no right or wrong answers in all the questions, and that the survey was used only to understand their personal preferences in learning. It was also clearly indicated in the introduction that all information collected would only be used for research purpose, where no personal information will be disclosed, and individual responses and surveys would not be identified and discussed.

3.2.4. Semi-structured group interview

Semi-structured group interviews were conducted to capture students' learning experiences and their views in the two classes in the respective topics and formats that they took part in. The interview also sought to find out more about students’ tendency towards the use of technology in class. All students were asked the following three questions:

1) What are so impressive/stimulating about the class and why? /How and why do the class interest you, and what are the parts that you find most interesting?

2) How do you compare the AR sandbox class with the traditional geography lessons

you experience in schools?

3) How/In what aspects do you think the use of the equipment and technology help you learn better? (E.g. mastery of abstract concept, 3D representation and visualization, authenticity, hands-on and observed process of change, problem solving, etc.) How helpful they are?

Students were allowed to freely express their views and opinions on the respective questions, and when needed, follow-up questions were asked to find out further details.

3.2.5. In-depth interviews with geography teachers

All geography teachers from these seven secondary schools were invited to participate in a 30-minute in-depth interview about their interests, intentions, barriers and challenges to the adoption of AR sandbox in classroom teaching. The interviewer arranged the in-depth while their students were having the AR geography lessons. Cantonese was used for the interview, and all conversations were recorded for further analysis. All teachers expressed their perceptions of AR sandbox in school and shared their experiences, including their challenges and difficulties.

3.3 Data Collection

3.3.1. Arrangement of classes

Each student was assigned to two classes. One class was in the format of traditional class, and another class was in the format of AR sandbox, where each class will be on a different topic in terms of map reading or farming (i.e., students will not be assigned to traditional and AR sandbox classes both in farming or both in map reading topics). The allocation of students into the classes was done randomly. Students were asked to complete the pre-test assessment individually before the class begun, in the presence of the researchers and their teachers. After finishing the pre-test assessment, students attended the respective classes in the two formats and topics that they were assigned to. At least one researcher was present at each class session. The time taken to complete the pre-test and post-test assessment was approximately 10 minutes, 5 minutes for the post-lesson questionnaire and 10 minutes for the semi-structured interviews.

3.3.2. Participating schools and participants

To recruit participants that are suitable for delivering the relevant geography lessons and to carry out the subsequent pre-test and post-test assessments, local secondary schools in Hong Kong were identified and approached as the first step. The criteria of selecting schools to participate in this study are schools are having geography teachers who are adopting the AR sandbox in teaching of HKDSE geography lessons. The rationale is that all participants are having basic knowledge on what the AR sandbox is and all participants are studying the HKDSE geography curriculum. They were having similar prior geographical knowledge as they are studying the same geography curriculum with same modules. On the other hand, the module selection of the junior secondary geography curriculum is flexible where geography teachers are allowed to select 6 out of 12 modules from the curriculum guide according to their students' needs, subject planning and school context, so there will be a great diversity in students' prior geographical knowledge in the junior secondary level. Therefore, only schools are adopting the AR sandbox in the HKDSE geography are inviting to participate in this study.

A total of seven secondary schools were invited and agreed to participate in and provide support for the study, which include, the Jockey Club Government School, HKFEW Wong Cho Bau Secondary School, Cognitio College (Kowloon), NLSI Lui Kwok Pat Fong College, United Christian College, The HKSYC&IA Chan Nam Chong Memorial College and Pui Ching College. Secondary schools in different districts of Hong Kong with different backgrounds were recruited to allow for a wider representation of students and thus producing a more generalizable outcome. Within the participating school, students in geography classes were then recruited to take part in the lessons and experimentation of AR sandbox teaching. The participation of all students in this study was voluntary. In total, 130 students were invited and participated in the study. The valid student participants and successful samples collected were 126, where 68 students were male and 58 students were female, allowing for a fairly equal distribution. Similarly, 68 students were from Secondary 4, and 58 were from Secondary 5 to represent students of different grades.

3.3.3. Description of classes

Two lesson plans were designed to facilitate the delivery of the map reading and farming system classes. To allow the comparison of teaching with a traditional approach and AR sandbox, both the map reading and farming classes were divided into two groups – the experimental group (learning the topic with the use of AR Sandbox) and the control group (traditional lecture presentation). The same learning contents were designed for both the experimental and control groups, and learning outcomes of both groups were also the same. This allows for the comparison of a traditional teaching approach and a method with AR sandbox. Both map reading and farming classes run in 2 lessons, for a total of around 80 minutes teaching time. The details of each class would be introduced in the following sections.

Lesson plan – Map reading

The learning outcomes of the map reading class include the building of knowledge, techniques, and attitude of students in map reading and active engagement in classes. In terms of the learning outcomes in knowledge, the class was intended to: 1) equip students with the knowledge and skills to interpret 2D and 3D maps, and 2) help students gaining the ability to identify an array of landform features, including concave and convex slopes, cliff, ridge, spur, and valley. In terms of techniques, students were expected to: 1) show the ability to draw a cross section, and 2) calculate the average gradient of a slope after the class. The class also intended to improve students' learning attitude, in terms of promoting their engagement in effective group discussion, and ability to give opinions and to respect others' opinions.

In first lesson, students were first introduced the concepts of relief and vertical intervals and how to illustrate these concepts on maps, which was followed by the identification of landforms features, including concave and convex slopes, cliff, ridge, spur, and valleys on maps. The class proceeded with a group activity that allows groups of students to identify landform features in a few given contour maps. In the traditional class, contour maps provided were in 2D format. In the AR sandbox class, students were introduced to the AR sandbox at this stage instead of 2D maps, and the 3D representation of the landform features of the given contour maps were shown to help them with their identification. The class ended with a discussion and consolidation session on the interpretation of landform features in a group format, and a representative from each group was invited to share the groups' findings.

In the second lesson, an introduction of cross section of a path, vertical exaggeration and gradient of a slope was first given, followed by an activity which student had to complete a worksheet about designing a hiking paths for two different groups of hikers, including university student and elderly persons. 2D maps were provided in the traditional class for the identification of landform features while AR Sandbox was used instead of the 2D maps in the AR sandbox class.

Lesson plan – Farming

For the farming class, the class sought to equip students with the abilities to identify the most suitable farming locations according to the geographical advantages and disadvantages. With regards to the learning content, there were two main parts: a) an introduction of the geography of farmland locations and the farming system followed by an activity which student had to identify the most suitable locations to have farmlands in a worksheet, and b) an identification of alternative farming locations followed by an activity which student had to choose the most suitable locations to have farmlands under the scenario where there were urban development at the river bank area in a worksheet. In the AR sandbox class, the device was set up to help student better understand the topography of the proposed farmland locations by constructing the topography of the sites mentioned in the worksheet while in the traditional class, the same was illustrated using 2D maps.

3.4 Data Analysis

To describe the distribution of participants of this study, the socio-demographic information of student taken part in the study will first be presented and discussed. This will be followed by the description of the post-test questionnaire survey on students' learning attitude, learning motivations, and their comments on the lessons. In this part, the mean scores of the respective statements under the different parts of the survey will be presented and discussed, as well as the average for each construct. All statistical analysis in this study were carried out using the statistical tool of SPSS 27.0.

3.4.1. Analysis of effectiveness of AR sandbox

The presentation and analysis of pre-test and post-test assessment data in this study was carried out in different approaches to address the proposed research questions and hypothesis. First of all, to explore the pre-test assessment and post-test assessment performance of students in the topics on map reading and farming, as well as the traditional class and AR sandbox class, the respective percentage of correct answers for each question in both tests gotten by students were shown and compared under all the different scenarios. Scenarios compared include traditional class with map reading topic, AR sandbox class with map reading topic, traditional class with farming topic, and AR sandbox class with farming topic. To calculate the average percentage of correct answers by students in each question, all correct answers were coded as 1 and incorrect answers were coded as 0, then an average will be taken for each question under each scenario. To compare the pre-test assessment scores and post-test assessment score, in the map reading topic, the mean number of correct answers in the two stages were calculated for all questions answered by each student, to find out the change in performance before and after the classes. For the farming topic, the mean score of each student in the 4 major questions were first calculated and compared, followed by the calculation of overall total mean scores of each student with the scores of the four questions summed. Again, the change in overall mean score was calculated by subtracting pre-test assessment total score of each student by the post-test assessment total score.

Subsequently, to statistically examine the differences in pre-test assessment and post-test assessment mean scores of students under the different scenarios, paired sample t-tests were utilized to find out the statistical significance. Paired sample t-tests were adopted as each sample of the pre-test assessment and post-test assessment was carried out by the same student, which are not independent cases. Paired sample t-test were carried out to compare the mean scores of the pre-test and post-test assessment for all scenarios, with the two forms of classes, and two topics of teaching. In the paired sample t-tests, the differences in mean scores, standard deviation, standard error, confidence intervals, statistical significance (p-value) and other relevant indexes were reported. The paired sample correlation were also tested to indicate whether the pre-test assessment and post-test assessment mean scores were associated, thus if the paired sample approach was adopted correctly. The Cohen's d effect sizes were presented to show to extend of differences that the lesson had made in influencing the pre-test and post-test assessment of students. Finding the effect sizes of each scenario also helped compare the effectiveness of traditional class and AR sandbox class, as well as how different that would be for a map reading topic and farming topic.

3.4.2 Analysis of proposed determinants of learning outcome

Four major determinants were proposed to predict the learning outcome of students in the AR sandbox class and traditional class on the respective topics. The four determinants include, learning attitude, learning motivation, gender, and grade of study. Learning attitude and learning motivations were socio-psychological measurements of student perceptions, and gender and grade of study represented the socio-demographic characteristics of students.

Learning attitude and learning motivation were measured in the questionnaire survey as multiple item variables, to explore any underlying dimensionalities in the two variables, factor analysis were carried out for the two variables respectively. The Kaiser-Meyer-Olkin (KMO) measure of the factor analysis, the eigenvalues of factors, and factor loadings of items were inspected to confirm the proper use of factor analysis. The Cronbach's alpha value of the resulted factors (if any) or the original variable (if it turned out to be a single variable) were also tested to confirm the reliability of the variable and items. Further details on the procedures and other indexes inspected in the factor analysis will be explained in chapter 5.

To find out the associations between the proposed determinants and the learning outcomes of students, multiple regression analysis were performed. The learning outcomes of students were represented by three measurements including, the change in pre-test and post-test assessment mean score, the change in pre-test and post-test assessment self-evaluated score, and the perceived learning efficacy (only for the AR sandbox classes) of students. The proposed determinants were entered into the regression models as independent variables, and the learning outcomes of students were entered respectively into the model as response variables. The details of the multiple regression analysis were further explained in chapter 5.

CHAPTER 4: EFFECTIVENESS OF AR SANDBOX

This chapter will start with an introduction to the background of testing the effectiveness of AR sandbox classes and traditional classes. The methods of this chapter will then be covered, followed by the results section that presents the results of the demographic information of the participating students, the quantitative statistics on the questionnaire survey, the results of the pre-test and post-test assessments in map reading and farming topics, the data analysis of the differences between pre-test and post-test assessments in both map reading and farming, and the self-evaluation of student in their performance. The chapter ends with a discussion of the results and their implications.

4.1 Introduction

This chapter sought to address the research questions on whether AR sandbox can help improve students' learning outcomes, the effectiveness of AR sandbox when compared to traditional teaching, and the differences in effectiveness when the two forms of teaching were applied to the topics of map reading and farming.

Studies in the past have widely adopted the pre-test and post-test analysis approach to measure the learning outcome of students or the effectiveness of the use of certain types of teaching approaches or technology (Bonate, 2000; Dimitrov & Rumrill Jr, 2003; Dugard & Todman, 1995; Nieuwenhuis & Hooimeijer, 2016). Therefore, this chapter utilized the same approach to measure and analyze the differences in students' performance in map reading or farming class in the pre-test assessment before classes were taught and the post-test assessment after the classes were delivered. This chapter discussed the implications of the significant respective findings.

To provide further information regarding the learning experience and views of students on the AR sandbox class and its application, semi-structured group interviews were carried out. The findings of the interviews were presented in this chapter to add to the findings on the effectiveness of AR sandbox and provide relevant qualitative evidence.

4.2 Methods

To explore the effectiveness of the AR sandbox, this chapter employed two measurements of the learning outcome of students: the measurement of pre-test and post-test assessment mean scores and the self-evaluated performance of students. The statistics on students' socio-demographic information were presented, followed by the summary of student pre-test and post-test assessment performance in the traditional class and AR sandbox class in the respective topics of teaching to illustrate the performance of students. Paired sample t-tests were carried out to examine the differences between the pre-test and post-test assessment scores under the four scenarios, traditional class on farming topic, traditional class on map reading, AR sandbox class on farming topic, and AR sandbox class on map reading. The paired sample correlation statistics, and Cohen's effect size of the t-test were also examined and presented.

4.3 Results

The section first described the socio-demographic statistics of the student participants of the current study. The summaries of students' pre-test and post-test assessments in map reading and farming topics were then presented. The paired sample t-test findings in the respective classes were discussed at the end of the section.

4.3.1 Demographic information of students

A total of 132 students were recruited to take part in this study; however, there were only 126 completed samples collected, and 6 samples showed missing data. Therefore, only the information of students with completed samples was reported and used in the analysis in the following sections. Among the participants, 68 were male, and 58 were female, making up 54% and 46% of the total number of students. Students were also recruited from two grades. There were 68 students from Secondary 4, accounting for 54% of the total number of students. On the other hand, the rest of the 58 students were from Secondary 5, accounting for 46% of the total number of students. The number of male and female students, and students from Secondary 4 and Secondary 5 that participated in this study showed fairly equal distributions.

4.3.2 Summary of pre-test and post-test Assessment – Map reading

In the class that took the traditional teaching approach, the pre-test assessment percentage of students giving correct answers in questions Qm1– Qm8 were 95%, 85%, 60%, 83%, 89%, 85%, 69%, and 68%, respectively. The mean number of correct answers by this group of students in the pre-test assessment was 6.32. From the self-evaluation of students on their ability in map reading, students rated on average that their map reading ability was at 5.6 scores. In the same group of students, the post-test assessment showed that in Qm1–Qm8, 92%, 94%, 73%, 92%, 91%, 89%, 72%, and 88% of students gave correct answers. Moreover, the mean number of correct answers this group of students gave in the post-test assessment was 6.88. In terms of the self-assessment of ability, students in the post-test assessment rated themselves to be at a mean score of 6.91. The discrepancy in the proportion of students getting correct answers from the pre-test and post-test assessment showed that apart from Qm1, which showed a drop in percentage, in Qm2–Qm8, the proportion of students answering correctly all increased, which ranged from 3% to 20%. Among the questions, the greatest increase in correct answers were seen in Qm3 and Qm8, for 13% and 20%, respectively. At the same time, the number of questions that students answered correctly in the post-test assessment showed an increase of 0.56. Similarly, students' self-evaluation in terms of the mean scores rose from 5.6 in the pre-test assessment to 6.91 in the post-test assessment.

In the group that employed the AR sandbox in teaching, students achieved 91%, 80%, 46%, 82%, 89%, 78%, 71%, and 71% correct answers in their pre-test assessment in map reading questions Qm1 to Qm8. The average number of correct answers by the experimental group was 6.08. In the self-evaluation of students, they rated their ability to be at a mean score of 5.49. In the post-test results, students in this group got 92%, 95%, 74%, 85%, 94%, 89%, 71%, and 74% correct answers for Qm1 to Qm8. On average, students got 6.72 questions correct in this group, and in their self-evaluation, they determined that their ability to map reading was at 6.6 scores on average. When the pre-test assessment results were compared to that of the post-test assessment, all questions showed an increase in the proportion of correct answers gotten by students except for Qm7 which remained the same at 71%. The increase in percentage of correct answers ranged from 3% to 28%, and the greatest increase were found in Qm2 and Qm3 for 15% and 28% respectively. The average number of correct answers achieved by students increased for 0.64, and the self-evaluated scores increased for 1.11.

Table 4.1 Summary of pre-test and post-test assessments for traditional class in map reading topic

Assessment Items	Pre-test assessment correct answers percentage	Post-test assessment correct answers percentage	Differences in Percentage / score
Qm1	91%	92%	+1%
Qm2	80%	95%	+15%
Qm3	46%	74%	+28%
Qm4	82%	85%	+3%
Qm5	89%	94%	+5%
Qm6	78%	89%	+11%
Qm7	71%	71%	0%
Qm8	71%	74%	+3%
Self-evaluation score	5.49	6.6	+1.11

Table 4.2 Summary of pre-test and post-test assessments for AR sandbox class in map reading topic

Assessment Items	Pre-test assessment correct answers percentage	Post-test assessment correct answers percentage	Differences in Percentage / score
QfA	62%	70%	+8%
QfB	81%	86%	+5%
QfC	73%	74%	+1%
QfD	75%	79%	+4%
Self-evaluation score	4.65	6.56	+1.89

4.3.3 Summary of pre-test and post-test Assessment – Farming

The second part of the assessment concerns the farming topic. The assessment in this part comprised four major questions QfA, QfB, QfC, and QfD, and each major question had 7 sub-questions.

In the pre-test assessment of the traditional class, this group of students achieved 80%, 51%, 34%, 95%, 45%, 71%, and 54% of correct answers for QfA1 to QfA7, yielding an average of 62% of correct answers and a mean of 4.32 correct answers in QfA. Following that, in QfB1 to QfB7, students got 82%, 66%, 83%, 98%, 69%, 100%, and 71% correct answers, respectively; therefore, question QfB had an average rate of correct answers of 81%, and the average number of correct answers was 5.69. For questions QfC1 to QfC7, the percentage of correct answers was 92%, 34%, 92%, 97%, 35%, 85%, and 78%, respectively, and the average percentage of correct answers in QfC was 73%. The average number of correct answers in QfC was 5.13. In QfD1 to QfD7, the percentage of correct answers was 75%, and the average number of correct answers was 5.23. The total average number of correct answers in major questions QfA to QfD was 35.54, and an average of 5.09 for each major question. In the self-evaluation carried out by students, they rated their ability to be at an average of 4.65 scores.

In the post-test assessment of the traditional class, students got 92%, 80%, 25%, 98%, 68%, 74%, and 52% of correct answers for QfA1 to QfA7, respectively, where the average percentage of correct answers in QfA was 70% and the average number of correct answers was 4.89. From QfB1 to QfB7, the proportions of correct answers in the respective questions by students were 86%, 72%, 94%, 95%, 86%, 94%, and 74%. The average percentage of correct answers in QfB was 86%, and the mean number of correct answers in this part was 6.02. In question QfC, student in this group got 94%, 35%, 88%, 97%, 40%, 85%, and 82% answers right for QfC1 to QfC7 respectively. The average percentage of correct answers in QfC was 74%, and on average, 5.2 questions were answered correctly. In the last question QfD, student got 100%, 91%, 85%, 14%, 95%, 85%, and 85% answers correct in QfD1 to QfD7 respectively. The average number of correct answers in QfD was 5.54, and 79% of questions were answered correctly. Students on average answered 37.75 questions right in QfA to QfD, with an average of 5.41 correct answers in each major question. They reported in their self-evaluation that their ability and knowledge on farming was at 6.56 scores on average. The discrepancy in correct answers between pre-test and post-test assessment for QfA, QfB, QfC, and QfD were 0.57, 0.33, 0.07, and 0.31 respectively. The overall change in number of correct answers in the pre-test and post-test assessment in this group of traditional class students was 0.32, and the change in scores in self-evaluation was 1.47.

In the pre-test assessment of the AR sandbox farming class, this group of students achieved 74%, 43%, 34%, 100%, 45%, 54%, and 49% of correct answers for QfA1 to QfA7, yielding an average of 57% of correct answers in QfA. Following that, in QfB1 to QfB7, students got 66%, 65%, 82%, 97%, 72%, 94%, and 58% correct answers, respectively; therefore, question QfB had an average rate of correct answers of 78%. For questions QfC1 to QfC7, the percentage of correct answers was 91%, 35%, 89%, 98%, 32%, 68%, and 69%, respectively, and the average percentage of correct answers in QfC was 69%. In QfD1 to QfD7, the percentage of correct answers was 97%, 88%, 77%, 8%, 97%, 71%, and 37%, respectively, and the average percentage of correct answers in QfD was 68%. The total average number of correct answers in major questions QfA to QfD was 33.05. In the self-evaluation carried out by students, they rated their ability to be at an average of 4.98 scores.

In the post-test assessment of the AR sandbox farming class, students got 82%, 72%, 34%, 98%, 55%, 62%, and 49% of correct answers for QfA1 to QfA7, respectively, where the average percentage of correct answers in QfA was 65%. From QfB1 to QfB7, the proportions of correct answers in the respective questions by students were 74%, 57%, 83%, 97%, 69%, 95%, and 55%. The average percentage of correct answers in QfB was 76%. In question QfC, student in this group got 86%, 17%, 94%, 98%, 28%, 77%, and 52% answers right for QfC1 to QfC7 respectively. The average percentage of correct answers in QfC was 67%. In the last question QfD, student got 97%, 94%, 72%, 17%, 98%, 75%, and 52% answers correct in QfD1 to QfD7 respectively and 72% of questions were answered correctly. Students on average answered 34.05 questions right in QfA to QfD. They reported in their self-evaluation that their ability and knowledge on farming was at 6.25 scores on average. The discrepancy in correct answers between pre-test and post-test assessment for QfA, QfB, QfC, and QfD were 0.8, 0, -0.02, and 0.04 respectively. The overall change in number of correct answers in the pre-test and post-test assessment in this group of traditional class students was 0.03, and the change in scores in self-evaluation was 1.29.

Table 4.3 Summary of pre-test and post-test assessments for traditional class in farming topic

Assessment Items	Pre-test assessment correct answers percentage	Post-test assessment correct answers percentage	Differences in Percentage / score
QfA	62%	70%	+8%
QfB	81%	86%	+5%
QfC	73%	74%	+1%
QfD	75%	79%	+4%
Self-evaluation score	4.65	6.56	+1.91

Table 4.4 Summary of pre-test and post-test assessments for AR sandbox class in farming topic

Assessment Items	Pre-test assessment correct answers percentage	Post-test assessment correct answers percentage	Differences in Percentage / score
QfA	57%	65%	+8%
QfB	78%	76%	0%
QfC	69%	67%	-2%
QfD	68%	72%	+4%
Self-evaluation score	4.98	6.27	+1.29

4.4 Differences in Effectiveness between AR Sandbox & Traditional Class

4.4.1 Effects of traditional class – Map reading

Paired sample t-test were carried out to compare the pre-test assessment and post-test assessment mean scores and self-evaluated scores of students to illustrate the impacts of traditional class and AR sandbox on student's learning outcome in map reading.

In the group of traditional class, a total of 64 samples were tested (Table 4.1). The average score of pre-test assessment was 6.36 (Standard deviation = 1.54, standard error =

0.192), and the post-test assessment mean score was 6.88 (Standard deviation = 1.40, standard error = 0.175). The difference in mean score between the pre-test and post-test assessment was 0.516, and the p-value was 0.002 (Standard deviation = 1.27, Standard error = 0.159, 95% confidence interval = 0.198, 0.833, t = 3.242, df = 63), showing that it was statistically significant. The paired samples correlation coefficient was 0.628 (p-value < 0.001), and the Cohen's d paired samples effect size was 0.405 (95% confidence interval = 0.149, 0.659), showing a moderate level of effect.

Regarding the self-evaluation of students of their ability and knowledge, a total of 64 samples were included in the paired sample t-test (Table 4.1). The self-evaluated pre-test mean score was 5.66 (Standard deviation = 2.10, standard error = 0.263), and the post-test mean self-evaluated mean score was 6.91 (Standard deviation = 1.81, standard error = 0.226). The difference in self-evaluated mean score between the pre-test assessment and the post-test assessment was 1.25, and the p-value was < 0.001 (Standard deviation = 1.48, Standard error = 0.185, 95% confidence interval = 0.88, 1.62, t = 6.757, df = 63), indicating that the test was statistically significant. The correlation coefficient of the paired samples was 0.732 at a significance level of less than 0.001. The Cohen's d effect size of the paired samples was 0.845 (95% confidence interval = 0.556, 1.128), indicating that a fairly strong level of effect.

Table 4.5 Summary of paired sample t-test for traditional class in map reading topic

	Mean	**S.D.**	**S.E.**	**95% C.I.**		**t**	**df**	**Sig.**
				Lower	**Upper**			
Pre-test and post-test assessment	0.516	1.272	0.159	0.198	0.833	3.24	63	0.002
Self-evaluation	1.25	1.48	0.185	0.88	1.62	6.75	63	0.000

4.4.2 Effects of AR Sandbox – Map reading

In the class with AR sandbox employed, 65 samples were included in the analysis of pre-test and post-test assessment scores (Table 4.2). The pre-test assessment mean score was 6.08 (Standard deviation = 1.86, standard error = 0.230), and the post-test assessment mean score was 6.72 (Standard deviation = 1.40, standard error = 0.173). The paired sample t-test showed that the post-test assessment mean score was higher than the pre-test assessment for 0.646 scores on average, and it was statistically significant with a p-value that was less than 0.001 (Standard deviation = 1.14, Standard error = 0.141, 95% confidence interval = 0.364, 0.928, t = 4.578, df = 64). The paired sample correlation coefficient was 0.791, and the significance level was less than 0.001. The coefficient of Cohen's d effect size was 0.568, with a 95% confidence interval of 0.304 and 0.828, which showed that there was a moderate level of effect.

Concerning students' self-evaluation of their own ability in the pre-test and post-test assessment, the pre-test mean score was 5.56 (Standard deviation = 2.42, standard error = 0.342). On the other hand, the post-test assessment mean score was (Standard deviation = 2.68, standard error = 0.379) (Table 4.2). The difference in self-evaluated mean score shown by the paired sample t-test was 1.04, which had a smaller than 0.001 p-value (Standard deviation = 1.43, Standard error = 0.202, 95% confidence interval = 0.634, 1.446, t = 5.15, df = 49). The correlation coefficient of the paired samples was 0.848, and the associated p-value was smaller than 0.001. Cohen's d effect size value was 0.728 (95% confidence interval = 0.413, 1.038), which indicated that the effect size was at a moderate to a strong level.

Table 4.6 Summary of paired sample t-test for AR Sandbox class in map reading topic

	Mean	S.D.	S.E.	95% C.I.		t	df	Sig.
				Lower	Upper			
Pre-test and post-test assessment	0.646	1.138	0.141	0.364	0.928	4.58	64	0.000
Self-evaluation	1.040	1.428	0.202	0.634	1.446	5.15	49	0.000

4.4.3 Effects of traditional class – Farming

In the traditional farming class, 65 samples were included in the analysis (Table 4.3). In the pre-test and post-test assessment, the performance of students was assessed by four questions. Therefore, t-tests were carried out for each question as well as the overall score of the assessment. The pre-test mean score of QfA was 4.32 (Standard deviation = 1.51, standard error = 0.187), and the post-test mean score was 4.89 (Standard deviation = 1.37, standard error = 0.170). The result of the t-test showed that the difference between the pre-test and post-test assessment mean scores was 0.569 scores, and it was statistically significant with a p-value of 0.003 (Standard deviation = 1.47, Standard error = 0.182, 95% confidence interval = 0.205, 0.933, t = 3.13, df = 64). The paired sample correlation between pre-test and post-test assessment in QfA was significant at 0.001 level, and the correlation coefficient was 0.485. The Cohen's d effect size of the t-test was 0.388 (95% confidence interval = 0.134, 0.639), indicating a moderate to low effect level.

In question QfB, the pre-test assessment mean score was 5.69 (Standard deviation = 1.27, standard error = 0.158), and the mean score of the post-test assessment was 6.02 (Standard deviation = 1.23, standard error = 0.153). The difference in mean score between the pre-test assessment and post-test assessment was 0.323, and the result was statistically significant at a p-value of 0.007 (Standard deviation = 0.937, Standard error = 0.182, 95% confidence interval = 0.091, 0.555, t = 2.78, df = 64). The paired sample correlation between the pre-test and post-test assessment mean score was statistically significant (p-value < 0.001), with a coefficient of 0.721. The Cohen's d effect size was 0.345, where the 95% confidence interval was 0.093 and 0.594, indicating that the effect was relatively small.

For question QfC, the pre-test assessment mean score was 5.14 (Standard deviation = 1.09, standard error = 0.135), while the mean score of the post-test assessment was 5.20 (Standard deviation = 1.20, standard error = 0.149). The result of t-test showed the difference on 0.062 score between the pre-test assessment and post-test assessment was not statistically significant (p-value = 0.646, standard deviation = 1.07, Standard error = 0.133, 95% confidence interval = 0.204, 0.328, t = 0.462, df = 64). The paired sample correlation between the pre-test and post-test assessment was significant (p < 0.001), with a coefficient of 0.564. The Cohen's d effect size of the t-test result was 0.057 (95% confidence interval = -0.186, 0.300), indicating that the effect was almost negligible.

In question QfD, the mean score of the pre-test assessment and post-test assessment were 5.23 (Standard deviation = 1.03, standard error = 0.127) and 5.54 (Standard deviation = 0.885, standard error = 0.110) respectively. The difference in mean score between the pre-test and post-test assessment was 0.308, which was found to be statistically significant p-value of 0.045 (Standard deviation = 1.211, Standard error = 0.150, 95% confidence interval = 0.008, 0.608, t = 2.05, df = 64). The paired sample correlation between the pre-test and post-test assessment was not statistically significant (p-value = 0.102), showing that the pre-test and post-test assessment mean scores were not associated. The Cohen's d effect size of the t-test was 0.254 (95% confidence interval = -0.006, 0.500), which is a relatively weak level of effect size.

The total scores of all four questions were further tested by t-test. The pre-test assessment total score was 35.54 (Standard deviation = 6.34, standard error = 0.786), and the post-test assessment total score was 37.75 (Standard deviation = 5.45, standard error = 0.677). The result of the t-test indicated that the difference between the pre-test and post-test assessment total scores was statistically significant (p-value < 0.001), where the difference was 2.215 score (Standard deviation = 4.75, Standard error = 0.589, 95% confidence interval = 1.04, 3.39, t = 3.76, df = 64). The paired sample correlation between the pre-test and post-test assessment total score was significant at p-value of less than 0.001, and the correlation coefficient was 0.686. The Cohen's d effect size was 0.467, which showed that a moderate level of effect was detected.

In the self-evaluation part of the class in farming, students on average reported a pre-test assessment self-rated score of 4.64 (Standard deviation = 2.03, standard error = 0.253), and a post-test mean score of 6.56 (Standard deviation = 2.11, standard error = 0.263). The paired sample t-test result indicated that there is a significant difference between the pre-test self-evaluated score and the post-test score, with a mean difference of 2.215 (p-value < 0.001, standard deviation = 1.63, Standard error = 0.203, 95% confidence interval = 1.52, 2.33, t = 9.454, df = 64). The paired sample correlation between the self-evaluated pre-test and post-test assessment score was statistically significant (p-value < 0.001). The paired sample Cohen's d effect size was 1.182 (95% confidence interval = 0.849, 1.481), which showed that there was a great level of effect.

Table 4.7 Summary of paired sample t-test for traditional class in farming topic

	Mean	S.D.	S.E.	95% C.I.		t	df	Sig.
				Lower	Upper			
Pre-test and post-test assessment: QfA	0.569	1.468	0.182	0.205	0.933	3.13	64	0.003
Pre-test and post-test assessment: QfB	0.323	0.937	0.116	0.091	0.555	2.78	64	0.007
Pre-test and post-test assessment: QfC	0.062	1.074	0.133	0.204	0.328	0.46	64	0.646
Pre-test and post-test assessment: QfD	0.308	1.211	0.150	0.008	0.608	2.05	64	0.045
Pre-test and post-test assessment: Overall	2.215	4.745	0.589	1.040	3.391	3.76	64	0.000
Self-evaluation	1.922	1.626	0.203	1.516	2.328	9.45	63	0.000

4.4.4 Effects of AR sandbox – Farming

In the AR sandbox class, there were a total of 65 samples. Again, the pre-test and post-test assessment scores were examined through paired sample t-test in terms of the four major questions QfA, QfB, QfC, and QfD, as well as the total score of the four and the self-evaluated score by students themselves (Table 4.4).

In question QfA, the pre-test assessment mean score was 3.98 (Standard deviation = 1.64, standard error = 0.187), and the post-test assessment mean score was 4.52 (Standard deviation = 1.51, standard error = 0.187). The paired sample t-test result showed that the difference in mean score between the pre-test and post-test assessment was statistically significant at 0.001 level (Standard deviation = 1.30, Standard error = 0.161, 95% confidence interval = 0.216, 0.861, t = 3.34, df = 64). The paired sample correlation coefficient of the pre-test and post-test mean score was 0.661, and the associated p-value was less than 0.001. A small to moderate effect size level was detected, as indicated by Cohen's d effect size coefficient of 0.414 (95% confidence interval = 0.159, 0.666).

The pre-test assessment mean score of question QfB was 5.34 (Standard deviation = 1.43, standard error = 0.177), and the post-test assessment mean score was 5.31 (Standard deviation = 1.49, standard error = 0.185). The difference in mean score between the pre-test and post-test assessment was -0.031, which showed that students' performance declined after the class. However, the result of the paired sample t-test showed that this difference was not statistically significant (p-value = 0.838, standard deviation = 1.21, Standard error = 0.150, 95% confidence interval = -0.331, 0.261, t = -0.205, df = 64). The paired sample correlation coefficient of was 0.656 (p-value < 0.001), showing that the pre-test and post-test assessment mean score were still correlated within the sample. The Cohen's d effect size was 0.025 (95% confidence interval = -0.268, 0.218), showing that there was almost no effect, which is expected as the difference was insignificant.

In question QfC, the pre-test assessment mean score was 4.83 (Standard deviation = 1.07, standard error = 0.133), and the post-test assessment mean score was 4.66 (Standard deviation = 0.923, standard error = 0.115). Again, a drop in mean score from the pre-test to the post-test was observed for a 0.169 score. Yet, the paired sample t-test result showed that such a change was not statistically significant as the p-value was 0.213, which is above 0.05 level (Standard deviation = 1.08, Standard error = 0.134, 95% confidence interval = -0.438, 0.099, t = -1.259, df = 64). The paired sample correlation coefficient was 0.416, and it was statistically significant (p-value < 0.001). The Cohen's d effect size was 0.156 (95% confidence interval = -0.400, 0.089), indicating minimal effect.

For question QfD, the pre-test assessment mean score was 4.74 (Standard deviation = 1.15, standard error = 0.143), and the post-test assessment mean score was 5.06 (Standard deviation = 1.12, standard error = 0.138). The paired sample t-test result showed that the difference in the pre-test assessment mean score and post-test assessment mean score of 0.323 was statistically significant (p = 0.017, standard deviation = 1.06, Standard error = 0.132, 95% confidence interval = 0.06, 0.586, t = 2.45, df = 64). The paired sample correlation was statistically significant (coefficient =0.561, p-value < 0.001). Cohen's d effect size was 0.304 (95% confidence interval = 0.054, 0.552), which showed that the effect was relatively small.

The mean total score of the pre-test assessment was 33.05 (Standard deviation = 6.30, standard error = 0.781), and the post-test mean total score was 34.05 (Standard deviation = 5.88, standard error = 0.729). There was a 1-score difference between the mean total score of the pre-test and post-test assessments. However, the paired sample t-test result indicated such difference was not statistically significant (p = 0.090, standard deviation = 4.68, Standard error = 0.581, 95% confidence interval = -0.160, 2.160, t = 1.723, df = 64). The paired sample correlation between the mean total pre-test and post-test assessment score was significant (correlation coefficient = 0.706, p-value < 0.001). Cohen's d effect size was 0.214 (95% confidence interval = -0.033, 0.459), indicating a relatively small effect.

Lastly, the self-evaluated mean score of students in the pre-test assessment was 4.98 (Standard deviation = 1.80, standard error = 0.231), and the post-test assessment mean score was 6.25 (Standard deviation = 1.78, standard error = 0.227). The paired sample t-test result showed that the difference in the self-evaluated mean score of 1.26 scores was statistically significant (p < 0.001, standard deviation = 1.40, Standard error = 0.179, 95% confidence interval = 0.903, 1.621, t = 7.04, df = 64). The paired sample correlation between the self-evaluated mean score of the pre-test assessment and post-test assessment was significant (correlation coefficient = 0.694, p-value < 0.001). The Cohen's d effect size of the test was 0.901 (95% confidence interval = 0.593, 1.18), indicating the effect was at a great level.

Table 4.8 Summary of paired sample t-test for AR sandbox class in farming topic

	Mean	S.D.	S.E.	95% C.I.		t	df	Sig.
				Lower	Upper			
Pre-test and post-test assessment: QfA	0.538	1.300	0.161	0.216	0.861	3.34	64	0.001
Pre-test and post-test assessment: QfB	-0.031	1.212	0.150	-0.331	0.269	0.21	64	0.838
Pre-test and post-test assessment: QfC	-0.169	1.084	0.134	-0.438	0.099	1.26	64	0.213
Pre-test and post-test assessment: QfD	0.323	1.062	0.132	0.060	0.586	2.45	64	0.017
Pre-test and post-test assessment: Overall	1.000	4.680	0.581	0.160	2.160	1.72	64	0.090
Self-evaluation	1.262	1.401	0.179	0.903	1.621	7.04	60	0.000

4.5. Feedback from Student in Semi-structured Group Interview

Feedback on the application of AR Sandbox from students was gathered in the semi-structured group interview. As this part was not meant to provide a detailed qualitative analysis of the students' feedback and comments, a brief summary will be provided instead. Students' feedback can be grouped into three categories that suggest the merits of the application of the AR sandbox.

The first benefit of AR sandbox, as reflected by students, was that its application made classes more fun, more attractive, and less boring. Students reported that by making the class activities more fun, they felt more interested in learning about and understanding geographical issues. Also, an AR sandbox was suggested by one student to promote their interest in geography, allowing them to engage in the class more proactively.

The second benefit concerned the ability of the AR sandbox to visualize 3D features. Students indicated that the 3D visualization function of the AR sandbox allows them to experience the landform features, deepening their understanding physically. At the same time, they also indicated that 3D features can more clearly illustrate geographical features than books, which again enhances understanding. One student reported that, through the visualizing of landform features in the AR sandbox, they were able to imagine better how those features actually look inside their mind, which helped them with tests and exams.

The third merit of utilizing AR sandbox concerned the interactions that the technology allowed and promoted in classes. Students indicated that they were more expressive during the class and were more motivated to speak. They reflected that there were more interactions and engagements than regular traditional classes.

4.6. Discussion

The chapter aimed to determine AR sandbox's effectiveness in promoting students' learning outcomes. The mean scores of students' pre-test and post-test assessment and their self-evaluated performance were compared and tested to determine the difference in their performance before and after both classes in traditional and AR sandbox formats.

In traditional classes, the mean scores of students in the post-test assessments were found to be greater than their pre-test assessment in both cases of map reading topic and farming topic. This result indicated that traditional classes were effective in enhancing students' performance, which was fairly expected given that traditional classes that rely on the direct delivery of knowledge have been a long-implemented way of teaching. On one hand, teachers were well trained in this method of delivery and experienced in it. On the other hand, students were also used to this way of teaching. Hence, it would not be too difficult for them to learn in this form of class as well. Therefore, it was no surprise that traditional classes would be an effective way of teaching.

The newer way of teaching – AR sandbox, the approach to be assessed in this study, showed slightly different results. In the AR sandbox class, students were shown to have attained higher mean scores in the post-test assessment than the pre-test assessment in the map reading class. However, the difference in the mean score in the farming class was insignificant. When compared to the traditional class, the improvement in mean score in the post-test assessment for the AR sandbox class was 0.64, and that of the traditional class was 0.52, so the AR sandbox class actually showed a slightly greater improvement. The map reading class focused on teaching students the concepts of gradients and contours, as well as the ability to recognize and understand cross sections and to identify different types of landforms, all through the reading of maps. While these concepts and geographical features have been taught on 2D maps for decades, the ability of the AR sandbox to visualize such features and concepts in the 3D space may give an edge to the teaching of this topic. Through the use of 2D maps, physical and geographical features that can hardly be represented in the 3D space, such as the different types of landforms, can be easily projected and visualized in the AR sandbox, and students were then able to experience and observe in real life. Therefore, this may explain the slight discrepancy in mean score between the traditional and AR sandbox classes in map reading.

On the other hand, in terms of the farming topic, the AR sandbox was certainly not as effective as the traditional class, considering that the result in the AR sandbox class was not significant. Again, this may concern the nature and content of the topic. In the farming class, the student was introduced to the concepts of farming systems, the market effect on farming locations, and other factors to consider when choosing farming locations. While having a tool for visualization of the features that benefit farms, e.g. water sources, may still help students to better understand the topic, the 3D nature of the AR sandbox may play a less significant role in enhancing students' experiences, as this feature to be visualized were more conceptual than physical. For instance, understanding the benefits of choosing a location for farms close to a water source requires students' understanding of the importance of the water source instead of the physical features of the water source. Therefore, while an AR sandbox can still be an interactive experience for the student to stimulate their interest and attention in learning, it may not fit the content of certain topics, in this case, farming, as properly as some other topics like map reading.

To look further into details of the differences in pre-test and post-test assessment of students in the AR sandbox class in farming, the four major questions in the test were also tested individually. In fact, the differences in pre-test and post-test mean scores in QfA and QfD were statistically significant. On the other hand, the differences in mean scores in QfB and QfC were not, suggesting that the relevant content in these two questions was not well delivered and understood by students through the AR sandbox approach. QfB and QfC featured potential farming locations that show risks of soil erosion caused by either flooding or landslides. These processes and the consequences may be more difficult to illustrate in an AR sandbox, especially given the relatively short time of the classes, which in turn makes it harder for the student to understand and reapply their knowledge. Again, this may support the previous suggestion that the topic of farming involves more conceptual knowledge, where AR sandbox may not always be the most suitable approach for such content.

When the effectiveness of the AR sandbox was considered from another perspective, the self-evaluated scores by students in the AR sandbox farming class actually showed a significant difference. This could indicate that students do feel that the use of AR sandbox was achieving some level of success in the delivery of the relevant knowledge. However, they were unable to translate that immediately into the practical assessment. It is still important to consider the use of interactive technology from the students' personal perspective, as the application of such technology was not meant to simply enable students to get higher markers in tests and exams but to develop their interest in learning and stimulate and build their ability to engage, interact, and discuss. Finding which parts within a topic or what kinds of activities are more suitable for the application of AR sandbox, or more broadly, interactive technology could be the key to enhancing students' learning by encouraging them to learn, as well as promoting their learning outcomes in academic terms.

CHAPTER 5: DETERMINANTS OF LEARNING OUTCOMES

The chapter will start with an introduction of the background of the determinants of learning outcomes, and its relevance to the use and application of AR sandbox. The method of this chapter will be described next, followed by the results on factor analysis, reliability testing, and multiple regression analysis. At the end of the chapter, the findings on factor analysis, and the impacts of the proposed determinants will be discussed.

5.1 Introduction

The previous chapter discussed the effectiveness of traditional class and AR sandbox class under different scenarios. This chapter will proceed to address the research question of what factors determine the effectiveness of the respective classes and topics. Previous studies have employed a wide range of variable in explaining the learning outcomes of students with and without the application of interactive technology. Two socio-psychological determinants, learning attitude and learning motivation were selected to examine the learning outcome of students in this study. At the same time, socio-demographic factors of gender and grade of study of student were incorporated in the analysis, on one hand to explore the possible influence of these variables, and also as control variables. To better examine the effect of learning attitude and learning motivations, factor analysis was first carried out to explore any underlying dimensions within the variables. Multiple regression analysis was carried out subsequently to draw links between the proposed determinants and three measurements of students learning outcome, including their change in mean scores in the pre-test and post-test assessment, the change in self-evaluated mean scores, and their perceived learning efficacy. This chapter discussed how the form of teaching, in terms of traditional class and AR sandbox, as well as the topic of map reading and farming may influence the associations between the proposed determinants and the learning outcomes.

5.2 Methods

The proposed determinants of effectiveness in learning, including learning attitude, and learning motivations were measured in part 1 and part 2 of the questionnaire survey. The determinant of learning attitude covered different aspects of students' perception on learning, including their attitude towards of traditional classes and roles of teacher, and their attitude in active engagement and involvement. On the other hand, the determinant of learning motivation measured students' sense of satisfaction and interest in learning, and their goals and objectives in learning. As both determinants covered a range of concepts under the same construct, to further find out any underlying sub-constructs within the determinants, factor analysis will be performed on both determinants respectively.

Factor analysis was performed to explore the potential underlying sub-construct within the variables of learning attitude and motivation in learning of students, which is a commonly adopted technique in exploring the dimensionality of variables in various fields of research (Dunlap, Van Liere, Mertig, & Jones, 2000). The results of the factor analysis can indicate whether the two variables will be treated and further tested as a single factor variable or as a variable with multiple sub-factors. The factor analysis was carried out with principal component extraction and a varimax rotation was specified, and items with factor loading of less than 0.1 was suppressed. Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity was performed along the factor analysis. The KMO measure was obtained to indicate the strength of partial correlation within the factors.

To confirm the factor analysis was carried out in line with commonly suggested standards, a few indexes were considered, including the eigenvalues, individual factor loadings, KMO measure, composite reliability, and the Cronbach's alpha coefficient. The commonly applied standard of eigenvalue of 1 or above, and factor loadings of individual items reaching 0.4 or above were considered (Ferguson & Cox, 1993; Kaiser, 1960). On the other hand, a standard of 0.5 or above will be applied for the KMO measure (Hair, 2009; Shrestha, 2021). The details in the computation and standards applied for the composite reliability and Cronbach's alpha value for variables will be introduced next.

To confirm the reliability of all the variables to be analyzed in the later parts, reliability tests were carried out by obtaining the Cronbach's Alpha values of the respective variables and potential sub-factors from factor analysis. Questions A1, A3 and A5 in part 1 and questions B3, B4, and B6 in part 2 of the questionnaire survey were reverse coded as they measured the opposite effects of the remaining items, in order to ensure that the Likert scale was properly applied. In the test of Cronbach's alpha, the option "scale if item deleted" was chosen in SPSS, in order to find out whether another combination of items may improve the overall reliability of the construct as indicated by an increase in Cronbach's alpha value when an item or items are removed from the variable. Regarding the coefficient of the Cronbach's alpha test, it is generally recommended that the value should reach 0.6, and therefore, this will be applied as the standard for the current study (Taber, 2018). Composite reliability values of factor were also computed to confirm the reliability of the variables to be applied in multiple regression in the later analysis. A standard of 0.7 or above was employed regarding the value of composite reliability (Hair Jr., Hult, Ringle, & Sarstedt, 2021).

To explore the associations between the proposed determinant and the effectiveness of learning in the two types of classes, multiple regression analysis were carried out. Respective multiple regression analysis were performed for the four scenario of classes, including AR sandbox class on farming, AR sandbox class on map reading, traditional class on farming, and traditional class on map reading. In all multiple regression analysis, the variables of learning attitude and motivation in learning (and any potential sub-factors from factor analysis) were entered as the independent variables. The means of all items were calculated for all the respective determinants (and potential sub-factors) used in order to enter the variables into multiple regression analysis. To further explore the potential determinants of effectiveness in learning, two socio-demographic factors, including students' grade and gender were also included as independent variables in the analysis. As these two variables were binary in nature, they were recoded into 0 and 1 for male and female, and grade 4 and grade 5 respectively to facilitate their use in the multiple regression analysis. The effectiveness of learning of students was represented by three measurements, their pre-test and post-test assessment score, self-evaluation scores, as well as their perception of their learning efficacy. The three measurements of performance and learning efficacy were entered as the dependent variables in the multiple regression analysis as the means of all items of the respective variables. It should be noted that as perceived learning efficacy measured specifically the perception of learning outcomes of student in the AR sandbox class but not the traditional class, therefore the multiple regression analysis for this variable will be carried out only for the AR sandbox classes for both topics between the potential determinants and perceived learning efficacy.

5.3 Results

This section will first summarize the statistics of the questionnaire survey items and cover the result of factor analysis and a description of the factors derived. The reliability tests of the variable will then be explained. The multiple regression analysis results in the traditional class and AR sandbox class on map reading and farming topics will be explained respectively. The section will end with the discussion of the implications of the factor analysis and multiple regression analysis results.

5.3.1 Summary of learning attitudes and learning motivations of student

To better understand students' attitude in learning, their learning motivations, a questionnaire survey was delivered to collect the relevant information from all the participated students.

The attitudes of student learning and classes were measured and evaluated by six questions A1 to A6. The mean scores of the six items from A1 to A6 were 3.22, 4.12, 3.23, 4.18, 3.37, and 4.17 respectively (Table 5.1). The average of all items in this part was 3.72, indicating that students were showing generally positive learning attitudes. Three items, A2, A4, and A6 showed similarly high scores. Item A2 described the importance of discussions and classroom activities, item A4 described the importance to adopt technology in helping with teaching and learning and item A6 described that learning is about allowing student to explore, discuss, and present their personal opinions. Therefore, the three items with the top mean scores all showed that students were keen to actively participate and engage in discussions and activities in classes with the use of technology. On the other hand, questionnaire item A1 and A3 received the lowest mean score at 3.22 and 3.23, where the items described that teachers should take the leading role in classrooms and that traditional approaches of direct delivery of materials were the effective way of learning. The lower scores showed that students were not as convinced and motivated by this approach of teaching and learning. Similarly, item A5 also showed relatively lower mean scores at 3.37. Item A5 illustrated that the job of the teacher is to correct student immediately when they make any mistakes, instead of letting them find out the correct answers. The items showed that student may prefer a more interactive style of teaching and learning instead of having to be dominantly led by the teacher.

The learning motivations of students were measured by questionnaire item B1 to B6. The mean scores of questionnaire items B1 to B6 were 3.49, 3.35, 3.14, 3.19, 3.63, and 3.04 respectively (Table 5.1). The average of all items in this part was 3.31. Two questionnaire items B1 and B5 had the highest mean scores in this part, at 3.49 and 3.63. Item B1 indicated that students find that learning can bring them a sense of satisfaction. On the other hand, item B5 described that student would work hard because they are interested in the content of classes. Questionnaire item B6 showed the lowest mean score among all items (mean score = 3.04), the item asked student if they agree that memorizing model answers is the best method to pass exams and to learn. Another item with similarly lower mean score was item B3 with a score of 3.14. The item inquired whether the student think that their goal of learning is to only achieve good grades in public examinations. In general, results in this part may show that students were more likely to be motivated by their interest in the subject and the sense of satisfaction from learning, and that they were less motivation by approaches like memorizing exam questions.

The last part of the questionnaire survey with items C1 to C7 collected students' feedback on the AR class (Table 5.1). The mean scores of C1 to C7 were 3.90, 3.91, 3.98, 3.63, 4.04, 4.21, and 4.06 respectively. The generally high mean scores showed that student were most positive about learning and participating in the AR class. In particular, item C5 showed the highest mean score, which indicated that the use of AR sandbox was effective in promoting students' interest in geography learning. Items C3 and C6 also both showed high mean scores of above 4, indicating that the class helped students to learn about topics on farming, and they were very much satisfied with the application of AR sandbox in the class.

Table 5.1 Summary of statistics in questionnaire survey

	%					Mean	S.D.
Items	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**		
Learning attitude							
A1	9.3	33.3	35.7	14.0	7.8	3.22	1.055
A2	29.7	54.7	14.1	0.08	0.08	4.12	0.728
A3	7.8	27.1	48.8	13.2	3.1	3.23	0.888
A4	33.3	54.3	10.9	0	1.6	4.18	0.744
A5	7.8	34.9	45.0	11.6	0.08	3.37	0.820
A6	34.9	49.6	13.2	2.3	0	4.17	0.741
	All the time	**Often**	**Sometimes**	**Rarely**	**Never**		
Learning motivation							
B1	11.6	36.4	44.2	4.7	3.1	3.49	0.876
B2	7.8	32.0	51.6	4.7	3.9	3.35	0.847
B3	13.2	25.6	33.3	17.8	10.1	3.14	1.164
B4	4.7	28.7	51.9	10.9	3.9	3.19	0.839
B5	17.1	44.2	27.1	7.8	3.9	3.63	0.985
B6	8.5	24.8	38.8	17.8	10.1	3.04	1.085
	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**		
Perceived learning efficacy							
C1	18.8	55.5	22.7	3.1	0	3.90	0.730
C2	21.9	50.8	25.8	1.6	0	3.91	0.784
C3	22.7	53.9	22.7	0.08	0	3.98	0.699
C4	14.8	36.7	46.1	2.3	0	3.64	0.761
C5	32.0	46.1	18.0	1.6	2.3	4.04	0.882
C6	42.2	41.4	14.1	2.3	0	4.21	0.857
C7	37.5	35.9	23.4	1.6	1.6	4.06	0.903

5.3.2 Factor analysis and summary of factors

Factor analysis was carried out for student's learning attitude and learning motivation. The results showed that for both variables, two underlying factors were identified respectively (Table 5.2 & Table 5.3).

Concerning the variable of learning attitude, the eigenvalues of the two factors identified were 2.67 and 1.32, therefore the standard of 1 is reached for both. A total variance of 66.37% was explained (Table 5.2). The first factor identified in this variable included items A2, A4, and A6. The three items in this sub-factor of learning attitude described students' preference for more active forms of learning, including classroom activities, discussions, self-expression, and the use of technology, therefore it was termed "Active learning attitude". This factor explained 44.43% of the total variance, the eigenvalue was 2.67. The factor loadings for items A2, A4, and A6 were 0.785, 0.772, and 0.847 respectively, which all exceeded the recommended level of 0.4. The second factor identified consisted of items A1, A3, and A5. These items represented students' preference on more traditional ways of teaching by having the teacher taking the lead and focus on delivery, therefore this sub-factor was termed "Passive learning attitude". The factor loadings of A1, A3, and A5 were 0.814, 0.839, and 0.683, which are all above the recommended level of 0.4. This factor explained 21.95% of the total variance with an eigenvalue of 1.32. As all factor loadings were shown to be above the minimal limit 0.4, the convergent validity of the factor analysis was confirmed. To further examine the discriminant validity of the analysis, the correlation matrix between all items in the factor analysis was inspected, where a correlation coefficient above 0.7 would indicate that there is a strong correlation between items. The resulted correlation coefficients between all items ranged from 0.084 to 0.520, showing that no items were strongly associated to another item. The KMO value from the analysis was 0.717, which is above the suggested lower limit of 0.5, indicating that partial correlation between was not detected.

Table 5.2 Summary of factor analysis on learning attitudes of students

	Rotated (varimax) components factor loading		Composite reliability (CR)	Cronbach's Alpha
	1	2		
Factor 1: "Active learning attitude"			0.841	0.752
A2	0.785			
A4	0.772			
A6	0.847			
Factor 2: "Passive learning attitude"			0.824	0.710
A1		0.814		
A3		0.839		
A5		0.683		
Eigenvalues	2.67	1.32		
% of variance	44.43	21.95		
Cumulative percentage	44.43	66.38		
KMO	0.717 ($p < 0.001$)			

The factor analysis for the variable of learning motivation also resulted in two sub-factors (Table 5.3). The eigenvalues of the two identified factors were 2.51 and 1.35 respectively, and the total variance explained was at 64.39%. The first factor for the variable consisted of items B1, B2, and B5. The three items in this factor described the motivation of student in learning from satisfaction and interest, therefore it was termed “Satisfaction and interest”. This factor explained 41.84% of the total variance with an eigenvalue of 2.51. The factor loading of the respective items of B1, B2, and B5 were 0.821, 0.816, and 0.850, all exceeding the lower limited recommended at 0.4. The second factor consisted of items B3, B4, and B6, where these items captured the learning motivation of students in the terms of achieving good grade and public examination results. This factor was termed “Grades and exams”. The total variance explained by this factor was 22.55% with an eigenvalue of 1.35. The factor loadings of B3, B4, and B6 were 0.792, 0.561, and 0.783. The factor loading of item B4 was notably lower than other factors, however, it was still above the recommended standard of 0.4. In the inspection of correlation matrix for examining discriminant validity of the analysis, all correlation coefficient among items in this variable were below 0.7, indicating that strong correlations between items were not detected. The KMO value of the analysis was 0.729, which exceeded the suggested limit of above 0.5, showing the partial correlation between items was not an issue.

Table 5.3 Summary of factor analysis on learning motivation of students

	Rotated (varimax) components factor loading		Composite reliability (CR)	Cronbach's Alpha
	1	2		
Factor 1: "Satisfaction and interest"			0.868	0.796
B1	0.821			
B2	0.816			
B5	0.850			
Factor 2: "Grades and exams"			0.759	0.562
B3		0.792		
B4		0.561		
B6		0.783		
Eigenvalues	2.51	1.35		
% of variance	41.84	22.55		
Cumulative percentage	44.43	64.39		
KMO	0.729 ($p < 0.001$)			

5.3.3 Reliability of variables and items

Cronbach's alpha values were tested to indicate the reliability of variables. In additional to that, the composite reliability of the variables was also tested.

In terms of the variable of learning attitude, the Cronbach's alpha coefficient of the factor "Active learning attitude" was 0.752, the result also indicated that the exclusion of any items from the factor would not improve the coefficient. Similarly, the Cronbach's alpha value of factor "Passive learning attitude" was 0.710, and again the deletion of any items from the factor would only result in a drop in a value, therefore all items remain in this factor.

The alpha value of both factors were above the recommended level of 0.6 (Taber, 2018), therefore the reliability of the factors was confirmed. The composite reliability of "Active learning attitude" was 0.841, and that of "Passive learning attitude" was 0.824, which were both above the recommended level of 0.7, further confirming the reliability of the two factors.

In terms of the variable of motivation in learning, the Cronbach's alpha value of the factor "Satisfaction and interest" was 0.796, and the exclusion of any items from the factor would not contribute to an increase in the alpha value. The Cronbach's alpha value of the factor "Grades and exams" was 0.562. The alpha value in this factor was slightly below the suggested level of 0.6, and at the same time, the deletion of any items from the factor would not improve the value. However, given that the questionnaire questions were designed specifically for this study and was not repeatedly tested, such a close value to the recommended level was still considered reasonable and acceptable. On the other hand, reliability was not a concern for the factor of "Satisfaction and interest", and the internal consistency of the factor was confirmed. The composite reliability of "Satisfaction and interest" was 0.868, and that of "Grades and exams" was 0.759, which were above the suggested level of 0.7. The composite reliability of "Grades and Exam" also indicated that the factor could be reliability even though the Cronbach's alpha value was slightly below standard.

<u>5.3.4 Multiple regression analysis of determinants in traditional class – farming</u>

Multiple regression analysis was carried out to explore the associations between the determinants of socio-demographic factors, learning attitude (as two sub-factors), learning motivation (as two sub-factors), and the dependent variables of change in mean score in pre-test and post-test assessment, change in mean score from self-evaluation, and students' perceived learning efficacy.

In the traditional class on the farming topic, students' learning attitude in terms of "Active learning attitude" (p = 0.465, standardized coefficient = -0.246, standard error = 2.135) and "Passive learning attitude" (p = 0.937, standardized coefficient = -0.014, standard error = 1.212) were not significantly associated to their change in mean scores in the pre-test and post-test assessment (Table 5.4). Similarly, students' motivation in learning in terms of "Satisfaction and interest" (p = 0.867, standardized coefficient = 0.052, standard error = 3.067) and "Grades and exams" (p = 0.909, standardized coefficient = -0.050, standard error = 2.526) were not significantly associated to their change in mean scores in the pre-test and post-test assessment too. The socio-demographic profile of student showed no significant impacts on their change in mean score in pre-test and post-test assessment, as the p-value of their gender and grade of study were 0.879 (Standardized coefficient = 0.021, standard error = 2.135) and 0.613 (Standardized coefficient = -0.067, standard error = 1.255) respectively. The R value of the multiple regression model was 0.310, the R square was 0.096, and the adjusted R square was -0.004, showing that the variance explained by the proposed determinants was minimal.

Table 5.4 Summary of multiple regression analysis of potential determinants and change in pre-test and post-test assessment in traditional class in farming topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	-0.246	2.135	0.465
"Passive learning attitude"	-0.014	1.212	0.937
Learning motivation			
"Satisfaction & interest"	0.052	3.067	0.867
"Grades & exams"	-0.052	2.526	0.909
Gender	0.021	1.395	0.879
Grade of study	-0.067	1.255	0.613
R	0.310		
Adjusted R^2	-0.004		

Regarding the change in self-evaluated performance of students, the multiple regression analysis results showed that there was a positive association between students' grade of study and the changes in their evaluation at a significance level of 0.025 (Standardized coefficient = 0.427, standard error = 0.302), indicating that students of secondary 5 showed greater changes in their self-evaluation than students from secondary 4 (Table 5.5). On the other hand, students' "Active learning attitude" (p = 0.296, standardized coefficient = 0.351, standard error = 0.733) and "Passive learning attitude" (p = 0.597, standardized coefficient = 0.091, standard error = 0.412) were not significantly associated to the changes in their self-reported scores. Students' motivation in learning as in "Satisfaction and interest" (p = 0.383, standardized coefficient = -0.273, standard error = 1.050) and "Grades and exams" (p = 0.377, standardized coefficient = -0.383, standard error = 0.860) were also not showing statistically significant associations with their changes in self-evaluated scores. The other socio-demographic variable of students grade of study was not statistically associated to changes in self-evaluated scores with a p-value of 0.809 (standardized coefficient = 0.302, standard error = 0.427). The R value of the regression model was 0.343, the R-square value was 0.118, and the adjusted R-square value was 0.18, indicating that 1.8% of the total variance was explained by the variables in the model.

Table 5.5 Summary of multiple regression analysis of potential determinants and change in self-evaluated performance in traditional class in farming topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	0.351	0.733	0.296
"Passive learning attitude"	0.091	0.412	0.597
Learning motivation			
"Satisfaction & interest"	-0.273	1.050	0.383
"Grades & exams"	-0.383	0.860	0.377
Gender	0.033	0.471	0.809
Grade of study	0.302	0.427	0.025
R	0.343		
Adjusted R^2	0.018		

5.3.5 Multiple regression analysis of determinants in traditional class – map reading

In the topic of map reading in the traditional class, all proposed determinants were not significantly associated to students' change in pre-test and post-test assessment performance as reflect by their change in mean scores. The p-value for the association between "Active learning attitude" (Standardized coefficient = 0.023, standard error = 0.346 and "Passive learning attitude" (Standardized coefficient = 0.103, standard error = 0.279) were 0.871 and 0.510 respectively (Table 5.6). The two sub-factors of motivation in learning, "Satisfaction and interest" (Standardized coefficient = 0.018, standard error = 0.290) and "Grades and exams" (Standardized coefficient = 0.153, standard error = 0.267) yielded p-values of 0.910 and 0.280 respectively. The socio-demographic factors of gender (p = 0.123, standardized coefficient = 0.222, standard error = 0.368) and grade in study (p = 0.610, standardized coefficient = -0.070, standard error = 0.347) of students were also found not to reach the statistical significance level of 0.05. The regression model yielded a R coefficient of 0.268, and a R-square value of 0.072. The adjusted R-square was -0.028.

Table 5.6 Summary of multiple regression analysis of potential determinants and change in pre-test and post-test assessment in traditional class in map reading topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	0.023	0.346	0.871
"Passive learning attitude"	0.103	0.279	0.510
Learning motivation			
"Satisfaction & interest"	0.018	0.290	0.910
"Grades & exams"	0.153	0.267	0.280
Gender	0.222	0.368	0.123
Grade of study	-0.070	0.347	0.610
R	0.268		
Adjusted R^2	-0.028		

In terms of the change in self-evaluated pre-test and post-test mean scores by students, two proposed determinants significantly predicted the response variable, which include the grade of study of students (p = 0.014, standardized coefficient = 0.314, standard error = 0.369), and students' "Active learning attitude" (p = 0.005, standardized coefficient = 0.367, standard error = 0.368) (Table 5.7). The association between the change in students' self-evaluation with the other sub-factor of learning attitude, "Passive learning attitude" (p = 0.527, standardized coefficient = -0.09, standard error = 0.297) was not statistically significant. Likewise, students' motivation in learning as in both "Satisfaction and interest" (p = 0.444, standardized coefficient = 0.110, standard error = 0.308) and "Grades and exams" (p = 0.935, standardized coefficient = -0.01, standard error = 0.284) were also not significantly associated to the change in their self-evaluated performance in the pre-test and post-test assessment. The gender of students not significantly associated to students' pre-test and post-test self-evaluated performance at the significance level of 0.05 too (p = 0.075, standardized coefficient = 0.235, standard error = 0.391). The R coefficient of the multiple regression model was 0.476, hence the R-square value was 0.226. The adjusted R-square value was

0.143, showing that 14.3% of the total variance was explained in the model with all the proposed determinants.

Table 5.7 Summary of multiple regression analysis of potential determinants and change in self-evaluated performance in traditional class in map reading topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	0.367	0.368	0.005
"Passive learning attitude"	-0.090	0.297	0.527
Learning motivation			
"Satisfaction & interest"	0.110	0.308	0.444
"Grades & exams"	-0.010	0.284	0.938
Gender	0.235	0.391	0.075
Grade of study	0.314	0.369	0.014
R	0.476		
Adjusted R^2	0.143		

5.3.6 Multiple regression analysis of determinants in AR sandbox class – farming

Following the same approach, multiple regression was carried out for exploring the associations between the proposed determinants and the three measurements of learning outcome in the AR sandbox classes.

Regarding the farming topic, no proposed determinants showed significant impact on students' change in pre-test and post-test assessment mean scores (Table 5.8). The p-value for the two sub-factors of learning attitude, "Active learning attitude" and "Passive learning attitude" were 0.901 (Standardized coefficient = -0.019, standard error = 0.972) and 0.197 (Standardized coefficient = 0.181, standard error = 1.201) respectively. Similarly, the two sub-factors of learning motivation in terms of "Satisfaction and interest" (p = 0.931, standardized coefficient = 0.013, standard error = 1.027) and "Grades and exams" (p = 0.473, standardized coefficient = 0.098, standard error = 0.943) also showed p-values greater than the 0.05 significance level. The socio-demographic factor of gender showed a p-value of 0.483 (Standardized coefficient = -0.109, standard error = 1.317). On the other hand, the grade of study was found to be marginally significant considering that the associated p-value was 0.060 (Standardized coefficient = -0.255, standard error = 1.227). The R coefficient of the regression model was 0.334, yielding an R-square value of 0.112. The R-square value after adjustment was 0.018, showing that only 1.8% of the total variance was explained by the proposed determinants in the model, which is minimal.

Table 5.8 Summary of multiple regression analysis of potential determinants and change in pre-test and post-test assessment in AR sandbox class in farming topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	-0.019	0.972	0.901
"Passive learning attitude"	0.181	1.201	0.197
Learning motivation			
"Satisfaction & interest"	0.013	1.027	0.931
"Grades & exams"	0.098	0.943	0.473
Gender	-0.109	1.317	0.438
Grade of study	-0.255	1.227	0.060
R	0.334		
Adjusted R^2	0.018		

In terms of the second measurement of learning outcome, by the change in students' self-evaluation of their pre-test and post-test assessment performance, one determinant – learning motivation in terms of "Grades and exams" was found to successfully predict the variable (Table 5.9). Learning motivation of "Grade and exams" was negatively associated to students change in self-evaluated performance (p = 0.031, standardized coefficient = -0.306, standard error = 0.286), indicating that students' more motivated to learn through getting good grades and performing well in exams perceived themselves to make less improvements after the class, on the other hand, students less motivated by good grades and exams feel a greater level of improvement in the AR sandbox class. Learning attitudes of students' as in "Active learning attitude" (p = 0.212, standardized coefficient = -0.191, standard error = 0.297) and "Passive learning attitude" (p = 0.916, standardized coefficient = -0.015, standard error = 0.391) both did not show statistically significant influence over students' change in self-evaluated performance in the pre-test and post-test performance. The other sub-factor of learning motivation in terms of "Satisfaction and interest" was not statistically significance in its association to students' change in self-evaluation (p = 0.221, standardized coefficient = 0.190, standard error = 0.306). Both socio-demographic variables, gender (p = 0.531, standardized coefficient = 0.090, standard error = 0.410) and grade of study (p = 0.084, standardized coefficient = 0.235, standard error = 0.376) of students were not significantly associated to their change in self-evaluated performance in the pre-test and post-test assessment. The R-square for this regression model was 0.400, hence yielding a R-square value of 0.160. The adjusted R-square value was 0.065, meaning that 6.5% of the total variance was explained by the proposed determinants in the regression model.

Table 5.9 Summary of multiple regression analysis of potential determinants and change in self-evaluated performance in AR sandbox class in farming topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	-0.191	0.297	0.212
"Passive learning attitude"	-0.015	0.391	0.916
Learning motivation			
"Satisfaction & interest"	0.19	0.306	0.221
"Grades & exams"	-0.306	0.286	0.031
Gender	0.090	0.410	0.532
Grade of study	0.235	0.376	0.084
R	0.400		
Adjusted R^2	0.065		

5.3.7 Multiple regression analysis of determinants in AR sandbox class – map reading

Regarding performance of students in the map reading topic of the AR sandbox class, the multiple regression analysis showed that students' performance as reflected by their change in mean score in the pre-test and post-test assessment was not associated to any of the six proposed determinants in the models (Table 5.10). In terms of learning attitude, the p-value for "Active learning attitude" and "Passive learning attitude" were 0.814 (Standardized coefficient = 0.042, standard error = 0.296) and 0.890 (Standardized coefficient = -0.024, standard error = 0.258) respectively, indicating that the significance level of 0.05 was not reached. Regarding the learning motivation of students, students' motivation in terms of "Satisfaction and interest" and "Grades and exams" were both not associated significantly to their change in performance in the pre-test and post-test assessment as indicated by their respective p-values of 0.495 (Standardized coefficient = -0.123, standard error = 0.239) and 0.882 (Standardized coefficient = -0.024, standard error = 0.224). Lastly, the two socio-demographic determinants, gender and grade of study of students yielded p-values of 0.336 (Standardized coefficient = -0.135, standard error = 0.336) and 0.223 (Standardized coefficient = -0.169, standard error = 0.306) respectively, again, indicating that the significance level of 0.05 was not reached. The R value of the regression model was 0.255, which resulted in a R-square value of 0.065. However, the adjusted R-square value was -0.039.

Table 5.10 Summary of multiple regression analysis of potential determinants and change in pre-test and post-test assessment in AR sandbox class in map reading topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	0.042	0.296	0.814
"Passive learning attitude"	-0.024	0.258	0.890
Learning motivation			
"Satisfaction & interest"	-0.123	0.239	0.495
"Grades & exams"	-0.024	0.224	0.882
Gender	-0.135	0.336	0.336
Grade of study	-0.169	0.306	0.223
R	0.255		
Adjusted R^2	-0.039		

Regarding the performance of students as reflected by their self-evaluation of their pre-test and post-test assessment, again, no proposed determinants were found to be associated to the response variable significantly (Table 5.11). In terms of the variable of learning attitude, “Active learning attitude” and “Passive learning attitude” resulted in p-values of 0.572 (Standardized coefficient = -0.120, standard error = 0.405) and 0.498 (Standardized coefficient = -0.139, standard error = 0.369) respectively. The two sub-factors of learning motivation, motivations in “Satisfaction and interest” and “Grades and exams” yielded p-values of 0.475 (Standardized coefficient = -0.149, standard error = 0.321) and 0.152 (Standardized coefficient = 0.286, standard error = 0.324) respectively, indicating that the standard of significance level at 0.05 was not reached by either sub-factor. The two socio-demographic variables of gender and grade of study were not significantly associated to students’ change in self-evaluated performance in the pre-test and post-test assessment, with p-values of 0.151 (Standardized coefficient = 0.236, standard error = 0.519) and 0.842 (Standardized coefficient = 0.031, standard error = 0.443) respectively. The R coefficient of the model was 0.319, resulting in a R-square of 0.102. Upon adjustment, the R-square value was -0.030 ultimately.

Table 5.11 Summary of multiple regression analysis of potential determinants and change in self-evaluated performance in AR sandbox class in map reading topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	-0.120	0.405	0.572
"Passive learning attitude"	-0.139	0.369	0.498
Learning motivation			
"Satisfaction & interest"	-0.149	0.321	0.475
"Grades & exams"	0.286	0.324	0.152
Gender	0.236	0.519	0.151
Grade of study	0.031	0.443	0.842
R	0.319		
Adjusted R^2	0.102		

5.3.8. Multiple regression analysis of perceived learning efficacy in AR sandbox classes

Regarding the response variable of perceived learning efficacy of student in the AR sandbox farming class, two determinants, “Active learning attitude” and learning motivation of “Satisfaction and interest” showed significance influence over the response variable (Table 5.12). Students’ “Active learning attitude” positively predicted their perceived learning efficacy ($p < 0.001$, standardized coefficient = 0.434, standard error = 0.111), indicating that student with preference for greater level of interaction and engagement in class perceive themselves to have learnt more from the AR sandbox class. Students’ “Passive learning attitude” was found to show an insignificant result in terms of its association to perceived learning efficacy ($p = 0.157$, standardized coefficient = 0.166, standard error = 0.090). On the other hand, students’ learning motivation as in “Satisfaction and interest” was also positively associated to their perceived learning efficacy ($p = 0.016$, standardized coefficient = 0.293, standard error = 0.095), showing that students that are motivated by the satisfaction gained and interest in the subjects were feeling that they have learnt more from the AR sandbox class. Alternatively, students’ learning motivation of “Grades and exams” was not significantly associated to perceived learning efficacy ($p = 0.267$, standardized coefficient = -0.118, standard error = 0.088). The two socio-demographic variable of gender ($p = 0.910$, standardized coefficient = -0.012, standard error = 0.121) and grade of study (p = 0.219, standardized coefficient = 0.128, standard error = 0.113) also did not show significant impacts on students' perceived learning efficacy. The R coefficient of the regression model was 0.684, which yielded a R-square of 0.468. The R-square value upon adjustment was 0.412, indicating that 41.2% of total variance was explained by the proposed determinants in the model.

Table 5.12 Summary of multiple regression analysis of potential determinants and perceived learning efficacy in AR sandbox class in farming topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	0.434	0.111	0.000
"Passive learning attitude"	0.166	0.090	0.157
Learning motivation			
"Satisfaction & interest"	0.293	0.095	0.016
"Grades & exams"	-0.118	0.087	0.267
Gender	-0.012	0.121	0.910
Grade of study	0.128	0.113	0.219
R	0.684		
Adjusted R^2	0.412		

Regarding the perceived learning efficacy as report by students in the map reading class, the response variable was significantly predicted by two determinants included in the regression model, including "Active learning attitude", and learning motivation of "Satisfaction and interest", where both determinants showed a positive relationship with perceived learning efficacy (Table 5.13). "Active learning attitude" promoted perceived learning efficacy significantly (p = 0.004, standardized coefficient = 0.360, standard error = 0.115), meaning that students with greater level of active learning attitude tend to think that they learnt more and gained greater level of abilities from the AR sandbox class. Similarly, learning motivation of "Satisfaction and interest" also positively impacted students' perceived learning efficacy (p < 0.001, standardized coefficient = 0.431, standard error = 0.093), showing that students more motivated by satisfaction of learning and interests in the subjects tend to perceive themselves to have gained greater level of knowledge and skills from the AR sandbox class. In contrast, the remaining two sub-factors in learning attitude and learning motivation did not show significance influence over students perceived learning efficacy, “Passive learning attitude” showed a p-value of 0.449 (Standardized coefficient = 0.089, standard error = 0.100), while motivation from “Grades and exams” yielded a p-value of 0.855 (Standardized coefficient = 0.020, standard error = 0.087). The socio-demographic determinants included in the model, gender and grade of study were not significantly associated to students’ perceived learning efficacy, with p-values of 0.574 (Standardized coefficient = -0.053, standard error = 0.130) and 0.239 (Standardized coefficient = -0.109, standard error = 0.119). The R coefficient of the regression model was 0.764, which in turn yielded a R-square value of 583. Upon adjustment, the R-square value was 0.537, meaning that 53.7% of the total variance was explained with the proposed determinants of the model.

Table 5.13 Summary of multiple regression analysis of potential determinants and perceived learning efficacy in AR sandbox class in map reading topic

	B	S.E.	Sig.
Learning attitude			
"Active learning attitude"	0.360	0.115	0.004
"Passive learning attitude"	0.089	0.100	0.449
Learning motivation			
"Satisfaction & interest"	0.431	0.100	0.000
"Grades & exams"	0.020	0.093	0.855
Gender	-0.053	0.087	0.574
Grade of study	-0.109	0.130	0.239
R	0.764		
Adjusted R^2	0.537		

5.4 Discussion

The section will discuss the impacts of demographic variables, followed by the findings of factor analysis. The major determinants proposed, learning attitude and learning motivation will be discussed with regards to their impacts on learning outcome under the different scenarios of form of classes and topics.

5.4.1 Impacts of demographic variables

Two socio-demographic variables were tested in this part of the study. The incorporation of socio-demographic factor may help explore any difference in learning outcome and effectiveness that is based on the differences in the profile of students. The differences in impacts between socio-demographic groups may provide crucial information to help prepare for future implementation of the relevant forms of teaching for the relevant groups of students. The inclusion of socio-demographic variables can also act as control variables to ensure that variance caused by these variables on the effectiveness of learning can be accounted for when analyzing other determinants, i.e. learning attitude and learning motivations.

The grade of study of student were found to show significant impacts on the self-evaluated mean score of pre-test and post-test assessment in the traditional class of both the farming and map reading topics. Both associations were positive, indicating students at higher level (i.e. secondary 5) tend to give themselves a higher score in the post-test assessment than the pre-test assessment after they have taken the traditional classes than students at lower level (i.e. secondary 4). This on one hand may indicate that student at the higher grade of study were more used to the traditional form of teaching and delivery that they feel they were able to gain knowledge easier with such way of teaching. But this may also imply that students at higher grade of study show better level of confidence in their learning outcome that they were willing to actually rated their knowledge and abilities with better scores.

The association between grade of study and the change in pre-test and post-test assessment mean score in the AR sandbox farming class was marginally significant. While in strict sense, this relationship may not hold statistically, however, the trend of the relationship might have shown an interesting trend. A negatively relationship between the two variables could have indicated that study in secondary 4 tend to improve more in the post-test assessment than secondary 5 students in the AR sandbox class. As opposed to the situation where student in secondary 5 could be more used to traditional ways of teaching, students in secondary 4 may alternatively be more used to more interactive way of teaching with the application of modern technology.

Apart from the above associations, other regression paths between socio-demographic variables were found to be statistically insignificant, which may not fit with the finding in some other studies in the same area (Altmyer & Yang, 2010; Hettler, 2015; Rizvi et al., 2019). One possible reason could be that the current study included only two socio-demographic variables, while other studies have attempted also to explore influence of other forms of socio-demographic factors of students, e.g. students' household income. For instance, students with higher level of household income could have more frequent access to interactive technology that they may show better outcomes in AR sandbox class, however, that was not accounted for in this study. At the same time, as limited students were recruited in the study, therefore the diversity within the socio-demographic variable were also limited. In terms of grade of study, only students in secondary 4 and secondary 5 were recruited, which they may likely show similar performances as their difference could still be relatively small, as opposed to, for example, the difference between a junior level and a senior level secondary school student.

5.4.2 Factors of learning attitudes and learning motivations

Learning attitude and learning motivations were proposed to be the major determinants of students' learning outcome and the effectiveness of classes in this study. As both learning attitude and learning motivations included a range of items to measure the difference aspects and dimensions within the variable, therefore factor analysis was carried out to explore any potential underlying sub-factors. The results of factor analysis indicated that both variables in fact, did show underlying dimensions within, and each variable yielded two sub-factors. Notably, the items in the sub-factors of "Passive learning attitude" and motivations of "Grades and exams" both consist of all the reverse-coded items in the original variable. In "Passive learning attitude", it was designed to reflect students' attitude and preference towards traditional forms of teaching where teachers take a dominant role of delivery, as opposed to the other 3 items in "Active learning attitude" where engagement, interactions, and discussion was the emphasis. Likewise, in learning motivation of "Grades and exams", the reserve-coded items were designed to measure how students were motivated to learn and study mainly by the desire to achieve good grade and perform well in exam as traditionally expected. The rest of the items in the variable reflected how students were willing to learn and study as they feel interested and satisfied from gaining knowledge in the subjects. It is not uncommon in past studies to employ factor analysis in attempt find out potential underlying dimensions within a variable. It has been shown that even in widely adopted and studied frameworks and scales, different individual studies that employ the same framework may still yield different sub-factors (Dunlap et al., 2000). Therefore, while all items in learning attitude and learning motivations in this study were originally designed to represent the same variable in both ends of the spectrum of the respective variables, the factor analysis result showed that they could be viewed as distinctive sub-factors instead, which may ultimately help provide more detailed findings in the subsequent analysis by multiple regression analysis.

5.4.3 Impacts of learning attitudes

Learning attitudes were found to show influences over the different measurements of performance of students in the multiple regression analysis, hinting that they could be important factors to be accounted for when different formats and topics of teaching are implemented.

In terms of learning attitude, "Active learning attitude" promoted students' self-evaluated performance of students in the traditional class on map reading topic. This finding presented some interesting implications on both the format of classes in terms of traditional class and AR sandbox, as well as the topics that are taught. In the traditional class, students with greater level of active learning attitude showed better self-evaluated knowledge after the class. This indicated not only that more interaction and engagement in class can help improve students' ability and knowledge in map reading, but also that the students were confident to express their feeling of improvements after the class. It is also not surprising that students that prefer more active way of learning would benefit and improve more in the map reading class as the topic inherently provides more opportunities for students to interact and engage, e.g., to handle and read maps and complete relevant tasks that were not simply text based. Alternatively, students who were less active in learning and preferred traditional classes more indicated a lesser level of change in self-evaluated knowledge and ability. This may imply that even when the format of teaching (i.e. traditional class in this case) matches the preference of learning of students, it may not always translate into better performance or greater level of confidence. Therefore, in this case, it is likely that the topic that was taught have greater influence on students' performance than the format of teaching, as the topic of map reading made it easier for students with more active learning attitude to understand and gain knowledge, however, the traditional way of teaching, even though it is the preferred way of learning for some students, it did not help to improve their performance. On the other hand, when compared to the map reading class in AR sandbox format, it may provide another implication. Both active learning attitude and passive learning attitude were not found to impact students' self-evaluation in the AR sandbox class, when compared to positive influence of active learning attitude in the traditional class. This may indicate that the interactive AR technology in AR sandbox could have bridged the gap between more active and more passive learners. The more opportunities and easier access to interactions and engagement that AR sandbox may provide, e.g., to allow students to simply shape sand to create physical landforms instead of having to more abstractly sketch on 2D map may help student even with less active learning attitude to learn as much as more active learners do.

Passive learning not found to influence students' learning outcome in any types of measurements, regardless of the formats and topics of classes. Passive way of learning and teaching is actually still the most common format of delivery, where students should be very much familiar with and be used it. Therefore, it is expected that this variable should induce some level of positive influence on students' performance when compared to AR sandbox, which is an interactive technology that's a lot newer to students that they are generally less familiar with. However, the findings in this part showed a different story.

In terms of students' perceived learning efficacy in both AR sandbox class in map reading and farming topics, students' with more "Active learning attitude" were found to perceive greater level of learning efficacy. This result showed a different situation to the association between active learning attitude and self-evaluated performance in AR sandbox class, where the relationship was not significant. The difference in the measurement of the self-evaluated knowledge and students' perceived learning efficacy may have contributed to that. However, the findings in this part still provided important information for the application of AR sandbox in different topics. Expectedly, students who preferred more interactive and engaging forms of learning tend to benefit more from the AR sandbox classes in both topics than students with lower preference for that. This imply that along the application of AR sandbox or other interactive technology, it is also important to raise students' interest and preference for interactions and engagement for optimize the effects of such technologies.

The findings in this part showed that while learning attitude can be an important variable to shape and predict students' performance in class, it seems to be causing impacts to different forms of class in the same way. Some differences in how students may be driven by their attitude to perform differently in traditional class and AR sandbox class (interactive technology) were suggested based on the differences in "active learning attitude", however differences between the two sub-factors of attitude in the two formats of classes were still not clearly differentiated, hence information to help promote and improve the use of interactive technology may still be lacking. It is possible that including a broader array of attitudinal items may help further distinguish effect of learning attitude in different format of teaching. On the other hand, incorporating other constructs may also help achieve the same goal, for instance, internal psychological and cognitive variables like prior knowledge and personal values, or external variables like learning environments have been utilized by similar studies to explore students' performances (Chen et al., 2023).

The sub-factors of learning attitude of "Active learning attitude" and "Passive learning attitude" have shown varying different impacts on students' learning outcome across measurements. This showed that the factor analysis was helpful in providing more detail findings in multiple regression analysis as previously suggested. If learning attitude was analyzed as a single variable with the "Passive learning attitude" items only reverse-coded, it is possible that the effects from both sub-factors may eliminate and cancel out each other, resulting in an undistinguishable impact of learning attitude. Previous studies have suggested similar issues that if variables are always treated as single constructs, the influence of the variable could easily be masked by the underlying dimensions within the variable (Reio Jr & Shuck, 2015), and the information that can be concluded from such findings would then be very limited. Therefore, the results here indicated that factor analysis was a successful application to help avoid such a situation, but also to provide additional information.

5.4.4 Impacts of learning motivations

Like the situation of learning attitude, learning motivation of students in terms of the two sub-factors "Satisfaction and interest" and "Grades and exams" have shown varying impacts on their learning outcomes.

Learning motivation of "Grades and exams" was the only variable with the sub-factors of learning motivation that showed influence on students' self-evaluated knowledge and ability in the pre-test and post-test assessment across all scenarios with all variables and forms and topics of classes. It was found that motivation by "Grades and exams" was negatively associated to the self-evaluation of student, which meant that students that were more motivated to learn by the desire to acquire good grades and high marks in exams felt that they achieved a smaller improvement after the lesson. On one hand, teaching by AR sandbox may actually be less effective for students that see grades and exams the major objective of learning, as interactive technology emphasize on students' involvement and interaction, however, students' that pay greater attention to grades and exams may have the tendency to prefer learn only about information and knowledge that sticks close to the syllabus and formats of test and exams, or to get "model answers". AR sandbox or other interactive technology may be seen as something that goes outside the "syllabus" as tests and exams would not be carried out in such a format, therefore it is possible that students were not learning as effectively as it is not the way they used to learn. On the other hand, while the use of self-evaluation in assessing performance is not uncommon (Bartlett et al., 2017; Zhao & D'Eon, 2020), it may still sometime show greater level of individual variation subjected to the differences in students' personal standards. Students that paid more attention to "Grades and exams" could in fact, likely be students that are relatively more high-achieving and hence have greater expectations and stricter standards on themselves. Therefore, it is also possible that these students did achieve good learning outcomes, but they tend to underestimate their own achievements.

For students that were more motivated by satisfaction and interest in learning, no significant findings were identified in terms of their change in pre-test and post-test performance or self-evaluation in both AR sandbox classes, which was not entirely expected as apart from the 3D visualization features, AR sandbox was supposed to provide a greater experience and to raise students interest with its cutting-edge technology. It could be possible that this kind of interactive technology was still very new to students that they were still developing an interest for them and hence their level of motivations and satisfaction gained from using them. It could also be possible that students with a lesser level of motivation from satisfaction and interest performed similar to students with a greater level, as again, AR sandbox bridged the gap between the two groups of students with different motivations, and therefore, performances were similar.

Unlike the above situation, students who are more motivated by “satisfaction and interest” showed greater level of perceived learning efficacy in the AR sandbox class in both the farming and map reading topics, indicating that students that were motivated by the satisfaction of learning, discussing and interacting, as well as their own interest in the subject tend to think that they achieved better learning outcomes by the end of the lesson. This would be a more expectable outcome as this group of students would likely be the group that is more open to and be involved the AR sandbox approach of teaching, owing to their personal interest in the topic as well as their preference for interactions in class. On the other hand, the motivation of “Grades and exams” did not show any effects on student perceived learning efficacy may indicate that AR sandbox can enhance students’ performance even when it was not originally a goal or objective for the students, showing that it was not just a fun, but an effective way of teaching. The fact that students that were more motivated by “Satisfaction and interest” also showed greater perceived learning efficacy in AR sandbox classes in both farming and map reading topics may again imply that it is also crucial that students are taught and allowed to enjoy such engagements and develop interest to help promote their learning outcome in these classes regardless of the topics. One possible way to address this issue is to introduce different forms of interactive technology earlier in secondary school or even in primary schools to help students get used to such form of teaching and learning, hence increasing the likelihood that student would show interest in such form of teaching and gain satisfaction from it.

The differences in findings regarding the different measurements of performance and factors of motivation again showed the importance to utilize multiple forms of learning outcome measures and the exploration of underlying dimensions in predictor variables. The effects of “satisfaction and interest” on self-evaluated performance was not found, but in terms of perceived learning efficacy, it was significant, therefore, if only one measurement was used, the possible effects may not be revealed. Similarly, “Grade and exams” induced a negative effect on students’ self-evaluated performance in the AR sandbox farming class, if factor analysis was not carried out, the effects from “satisfaction and interest” may cancel out the effects of “Grades and exams” given that the two would be treated as a single factor.

5.4.5 Different measurements of learning outcome

The learning outcome of students were measured and used as response variables in the multiple regression analysis in three forms, including a change in pre-test and post-test mean score, a change in self-evaluation on knowledge and abilities, and perceived learning efficacy. The three forms of measurements have yielded distinctive results in the analysis, indicating that the proposed determinants influenced the three variables each in different ways, thus providing additional information on what can be done to enhance students’ learning.

The first measurement was the change in students’ pre-test and post-test assessment mean score, which was the key indicator of effectiveness of traditional and AR sandbox classes in the previous chapter. However, in this chapter, none of the proposed determinants, including learning attitude, motivation in learning, and socio-demographic factors were found to be significantly associated to this response variable, indicating that the change in performance of student in this measurement was driven by other underlying factors. Moreover, all the multiple regression tests were found to show minimal percentage of total variance explained, showing that the determinants almost did not contribute to explaining the response variable at all. It was not expected that this variable would show no significant association to any determinants, given that a change in pre-test and post-test scores has been a commonly utilized indicator of performance (Bonate, 2000; Dimitrov & Rumrill Jr, 2003; Dugard & Todman, 1995). A few possible reasons may explain this situation. The first being the actual change in scores in the pre-test assessment and the post-test assessment. The average change in mean scores in the AR sandbox classes for map reading and farming topics were 0.646 and 0.165, while that of the traditional classes for map reading and farming topics were 0.516 and 0.315, the actual differences were relatively small and hence there is a chance that it has led to the failure in detecting and differentiating effect from the determinants. Also, given the limitation on lesson time, each topic was taught for a relatively short period of time, so the relevant questions in the assessment were also designed to be relatively simple and straightforward. Therefore, it is also possible that the relatively simple assessment may not be able to capture the more subtle differences in knowledge and understanding between students. There could be a few ways to potentially improve this measurement and associated analysis. First, as the differences between the pre-test and post-test assessment was relatively small, increasing the number of questions may increase the range and variability of the result and better differentiate students with greater or lesser improvements after the classes. Another approach could be to group questions into different parts or categories so students can be assessed based on their knowledge and abilities in different aspects, which may also help differentiate students' learning outcome.

The second measurement employed in this study was the change in self-evaluated knowledge and abilities. Among all regression paths associating this variable to the proposed determinants, only four were found to be statistically significant. Interestingly, the grade of study of students was the significant determinant in two of regression paths, where students in higher grade tend to report greater differences in self-evaluation. The association between grade of study and self-evaluation in AR sandbox class on farming also showed a similar trend, even though the resulted p-value was 0.084, which was not considered statistically significant. This may indicate that students in higher grade of study tend to be confident with their learning outcome and performance, where they generally tend to indicate a greater level of change in performance. At the same time, it can also be due to the better ability for these students to take in the same information, when compared to less senior students. This indicator of performance enabled the measurement of learning outcome from the students' perspective, but still within context with the pre-test and post-test assessment, providing an alternative way to look at students' performance. However, like the last measurement, the proposed determinants were not the most relevant in explaining this variable, considering the few significant relationships as well as the relatively low percentages of total variance explained in the regression models.

The last measurement utilized in the study was the perceived learning efficacy of student inquired in the questionnaire survey. Unlike the last two measurements, the proposed determinants were able to predict students' perceived learning efficacy relatively more cases where the findings were also within expectation. This variable was not uncommon as a measurement learning outcome in the first place, therefore, similar items to items designed for this study in assessing students learning outcome have been empirically tested by studies in the past (Hayat et al., 2020; Kutuk et al., 2023; Tsai et al., 2020), making the items more reliable. It could also likely be that this variable matched better with the measurement of learning attitude and learning motivation as the items were all inquired in the same questionnaire survey, so students were able to give more coherent answers. Another difference between this measurement and the other two is that this variable clearly measured the learning efficacy of student in different aspects, e.g., in terms of their ability in map reading, understanding of concepts, ability to process data, etc. Therefore, student may give more accurate evaluation of their learning outcome to every aspect, instead of a more ambiguous overall score. It should also be noted that, as this response variable was used only to compare the two AR sandbox class, the information provided was relatively less than the other two response variables where both the formats and topics of classes were contrasted.

The utilization of three different measurements of learning outcome is fairly successful overall. While the measurements of pre-test and post-test assessment mean scores, and self-evaluation were not find to be correlated to learning attitude and learning motivation in most case, making it hardly to understand how teaching can be improved. The two measurement were useful in finding the difference between the traditional class and AR sandbox class in the last chapter. On the other hand, the use of perceived learning efficacy as a measurement of performance helped to draw links between the profile and characteristics of students in order to provide information for implementing the appropriate approaches of teaching under different circumstances to different groups of students.

5.4.6 Difference in topic of classes and form of teaching

The proposed determinants have predicted students learning outcome in different ways regarding the topics of class in terms of map reading and farming, as well as the forms teaching in terms of traditional and AR sandbox classes.

The first difference concerns the learning outcome of students in the traditional class and the AR sandbox class, where student with greater “Active learning attitude” tend to show greater improvements in self-evaluation in traditional map reading class, while those in the AR sandbox class did not report a better perceived learning efficacy. The class in map reading tend to require and provide more opportunities of interactions and engagement, in terms of the handling and reading of maps to learn about landforms, contours, and other physical features where direct delivery of knowledge may not always be the major part of the class. This class could inherently allow students to engage more in activities, handling and reading map, and to discuss with others. In this sense, it is reasonable that students that prefer active learning tend to perform better in the traditional class of map reading as it fits their preferred way of learning. However, the fact that in the AR sandbox class it was not significant showed that AR sandbox could have eliminated the gap between more active and less active students as previously suggested. The engagements and interactions provided and triggered by the use of AR interactive technology could have enabled even the less active students to participate and gain as much knowledge as the more active students, which demonstrated the benefits of AR sandbox or interactive technology in general.

On the other hand, the same result can also be contrasted to the insignificant finding in the traditional class on farming topic. The finding that active learning attitude promoted map reading performance but not farming topic might have shown the difference in nature of the topics. The topic of farming involves relatively more conceptual knowledge, e.g. the farming systems and factors to consider in choosing farming locations. This forms of contents and classes may have less interactions and class activities and more direct delivery of knowledge. The lack of opportunities in interaction may limit the performance more active learners in this topic. However, students with different levels of passive learning attitude were also found to perform similarly in terms of their self-evaluation, which presented another interesting situation. It may imply as previously suggested that even when the more passive nature of the farming topic fits the learning style of more passive student, it does not actually help promote their performance. This may indicate the current way of teaching of the farming topic was not beneficial for different types of students and it is the way of teaching that needs to be changed not the attitudes or motivations of students.

The similarity of the map reading and farming topics was identified in the results from the AR sandbox classes, where "active learning attitude" and motivation of "satisfaction and interest" both promoted students' performance in both scenarios. This showed the benefits of AR sandbox that it can promote the learning of students not only in physical geography, in terms of map reading, where 3D visualization can play a huge part in assisting students learning on the physical features, but also in terms of transforming more conceptual and theoretical knowledge to allow students to learn better in the farming topic. The additional opportunities and experiences in interaction provided by AR sandbox benefited students with greater interests as well as active learning attitude, showcasing the effectiveness of it. However, it also showed that the characteristics of students still play a part in determining whether they can benefit from AR sandbox, which is not the most ideal and optimal outcome of adopting the technology. In the most ideal scenario, students, regardless of the motivation and attitude should be equally promoted in their learning outcome with the application of the technology. Therefore, adjustments in terms of the technology itself, and the way to implement the technology could still be needed.

CHAPTER 6: TEACHERS' PERCEPTIONS OF USING AR SANDBOX FOR TEACHING GEOGRAPHY

This chapter presents the findings from the interviews with the geography teachers of the seven secondary schools who participated in our arranged lessons. The teachers were asked to attend an in-depth interview about their perception of using the AR Sandbox for teaching geography in their schools. They were also asked to share their experiences, effectiveness, challenges, and suggestions for implementing AR technology in geography education (Chen & Tsai, 2012; Santos et al., 2013; Yuen et al., 2011).

6.1. Introduction

AR is at the vanguard of this change, which is characterized by the rising prevalence of the incorporation of cutting-edge technologies into educational settings (Akçayır & Akçayır, 2017). The AR sandbox represents an important step forward in geography education, an interactive tool that visualizes geographical elements and processes in real-world time (Ibáñez, Di Serio, Villarán, & Kloos, 2014). The purpose of this chapter is to look into the viewpoints of seven geography teachers who took part in interviews to discuss their experiences and opinions regarding using the AR sandbox in their individual teaching methods (Billinghurst & Duenser, 2012; Bower, Howe, McCredie, Robinson, & Grover, 2014).

Through these interviews, a detailed picture of the possible advantages and difficulties related with the AR sandbox has been provided (Arvanitis et al., 2009). As a result of the instructors' observations, there is a growing interest in implementing AR technology in order to improve the educational experience (Cheng & Tsai, 2013; Dunleavy et al., 2009). They believed that the AR sandbox can revolutionize how pupils are taught abstract geographical concepts, making them more approachable and exciting to them (Furió, Juan, Seguí, & Vivó, 2015; Huang, Liaw, & Lai, 2016). For example, traditional techniques of teaching map reading, and topographical analysis sometimes fail to pique pupils' interest or sufficiently explain the intricacies of the subjects being taught (Jara, Candelas, Puente, & Torres, 2011; Wu et al., 2013). A viable option that has the potential to bridge this gap is the AR sandbox, which incorporates both dynamic and interactive elements (Akçayır & Akçayır, 2017; Bacca Acosta et al., 2014).

On the other hand, the educators pointed out that the AR sandbox had a number of serious drawbacks, particularly when it came to teaching human geography (Dunleavy et al., 2009). In contrast to the capabilities of the AR sandbox, which are more suited to the study of physical geography, subjects such as economic geography, population studies, and farming do not profit as much from these capabilities (Ibáñez et al., 2014; Santos et al., 2013). In spite of these limitations, the educators noted that the tool was useful in illustrating concepts related to physical geography, such as natural hazards, river systems, and coastal settings. When it comes to these kinds of themes, which entail physical processes and changes in the terrain, the AR sandbox truly shines (Wu et al., 2013).

In the following chapter, we go more into the teachers' intents to use the AR sandbox, as well as the hurdles they face and the solutions they propose to overcome these obstacles (Chou & ChanLin, 2012). The lack of ready-made lesson plans, technical support, and possibilities for professional growth are significant obstacles, despite the fact that there is a demonstrated readiness to utilize this technology (Bower et al., 2014; Kerawalla, Luckin, Seljeflot, & Woolard, 2006). When it comes to successfully incorporating the AR sandbox into geography teaching, addressing these challenges is absolutely necessary.

In general, the purpose of this chapter is to provide a comprehensive overview of the perspectives held by educators on the AR sandbox. Its purpose is to throw light on both the potential of the AR sandbox as well as the practical obstacles that need to be solved in order to effectively capitalize on its educational benefits (Wu et al., 2013).

6.2. Qualitative Results of In-depth Teachers' Interview

Seven secondary geography teachers were interviewed while their students were having either the traditional or AR Sandbox geography lessons. They are asked about their perceptions of the AR Sandbox in teaching geography, their intention to use the AR Sandbox, their barriers to adopting the AR Sandbox in school, and their suggestions to overcome the barriers (Radu, 2014). The interview took around 30 minutes for each teacher, and all conversations were recorded.

6.2.1. Interest in and intention to use AR technology

The teachers interviewed indicated a profound interest in incorporating AR technology, especially the AR Sandbox, into teaching their geography lessons in school (Santos et al., 2013; Yuen et al., 2011). They believe that using such technologies could enhance the educational experience of their students, as AR technology could potentially transform the learning experience of students. This transformation, particularly for a subject like geography, which the content demands a lot of visual and conceptual concepts. One of the primary reasons for the interest in using AR Sandbox is that teachers believe that AR Sandbox can make abstract geographical concepts more tangible and understandable for students (Cheng & Tsai, 2013). Traditional teaching methods like map reading, topographical analysis, and understanding geomorphological processes rely heavily on static maps, diagrams, and textbook descriptions (Ibáñez et al., 2014). These teaching materials can be challenging for students as they need a certain level of spatial thinking and imagination, which some may find very difficult. AR Sandbox, however, offers an interactive and hands-on learning experience with 3-D visual impacts for the students, in which students can see real-time changes in the topography, water flow, and other geographical phenomena that simulate students' understanding of the geographical process (Billinghurst & Duenser, 2012). This visualization impact could facilitate students' understanding of the cause-and-effect relationship that underpins many geographical concepts. For example, students could shape the mountains, valleys, and rivers, see how different coastal geomorphology forms, and understand erosion processes in the coastal environment. This dynamic visualization makes learning more engaging and can significantly improve students' comprehension and retention of complex ideas.

All seven teachers also realized that the AR Sandbox could significantly improve students' motivation and enhance their engagement in class (Di Serio, Ibáñez, & Kloos, 2013). The interactive nature of AR Sandbox transforms entire geography lessons into a more engaging and enjoyable experience of teaching and learning (Jara et al., 2011). The AR Sandbox turns a traditional passive learning approach for students into an active learning process, allowing students to physically manipulate the landscape and instantly visualise the outcome of their actions. Such active involvement can lead to higher levels of student interest and motivation, which leads to an ideal learning environment.

Four teachers highlighted the importance of using AR Sandbox for teaching geography could promote collaborative learning. A teacher said, "*We are aware that students work* *together in harmony to solve the geographical problem through the sandbox exercise, which we can never experience in traditional geography lessons*" Teachers observed that students often work together around the AR sandbox, discussing and debating the best ways to achieve certain geographical effects or solve specific problems. This collaborative learning experience facilitates communication and teamwork, skills that are valuable to them beyond the geography classroom. Building up good communication skills would be an extra benefit for students, which can facilitate these transferable skills for them not only in secondary education but also for their future study and career development (Bower et al., 2014). In addition, a teacher expressed that "*students found it very easy to handle the AR Sandbox trick; some even think about how the sandbox operates. This exposure is important for students to enrich their curiosity in technology*" Teachers generally believed that getting students familiar with the new technology is also valuable in preparing them for a future where such technologies are likely to become increasingly popular. Early exposure and proficiency can give students advantages that could benefit their future development.

Although most teachers responded positively to adopting AR sandbox for teaching geography, a teacher pointed out that AR sandbox is not compelling enough for teaching human geography topics such as urban problems, population, etc. The human geography topics such as economic geography, farming, and population studies do not lend themselves well to the physical and visual capabilities of the AR sandbox (Santos et al., 2013). Many of these topics involved theories which cannot be presented visually with the AR sandbox, and teachers still need a traditional mode to educate students about the concepts and background of these theories.

Regarding their intention to use the AR sandbox in teaching geography in school, all teachers indicated a willingness to use this new technology, provided they have sufficient time to prepare the lessons. They think planning practical geography lessons with a sandbox would be timely (Furió et al., 2015; Wu et al., 2013). They have to identify suitable topics and prepare AR sandbox activities and worksheets for students to facilitate effective learning. Two teachers stated that "*all these lesson plans have to be done by themselves and also need to be well prepared before being implemented in classroom teaching as there aren't any existing teaching and learning resources, such as textbooks, handouts, and worksheets, available in the market for their reference*". Teachers emphasised that while the AR sandbox is a powerful educational tool, its effectiveness is contingent on well-designed instructional materials and activities. Thus, having sufficient time to develop these resources is crucial for its successful implementation. Another teacher expressed that "*they possibly require at least a few days to prepare relevant teaching materials and a few hours to prepare an AR sandbox geography lesson*". The lack of ready-made lesson plans and teaching materials specific to the AR sandbox can be a prominent barrier to the adoption. Such materials would not only save preparation time but also ensure that lessons are pedagogically sound and fully exploit the AR sandbox's potential. The absence of these ready-made teaching materials can eventually drag the intention of geography teachers to implement AR Sandbox lessons for geography teaching in schools (Furió et al., 2015).

6.2.2. Barriers to adopt AR sandbox in school

The function of the AR sandbox demonstrates its potential as a powerful tool for teaching geography (Billinghurst & Duenser, 2012). However, there are several barriers for teachers to hesitate to fully adopt such powerful technology for their lessons. These barriers primarily revolve around the lack of teaching resources, technical challenges, and the need for professional development (Arvanitis et al., 2009).

One of the most significant barriers to adopting the AR sandbox is the absence of custom-made lesson plans and teaching resources. All teachers further emphasised that it is very difficult for them to fully utilize the AR sandbox for their geography lessons in school. Creating these resources from scratch is a time-consuming and challenging task that adds to a secondary school teacher's already substantial heavy workload (Cheng & Tsai, 2013). Teachers are not only willing to invest too much time in creating relevant teaching materials for lessons but also need to keep up with the very tight teaching schedules for the geography curriculum. The schedule is particularly tight for senior form of geography students, who have to complete all necessary topics preparing them for the public examinations.

Another significant barrier is the technical aspect of managing the AR sandbox. Many teachers do not have a strong background in computing or technical skills, making it very difficult for them to handle technical issues that may arise (Ibáñez et al., 2014). This challenge is particularly problematic in school where the IT supports is unavailable or limited. These technical problems can seriously affect and disrupt lessons and cause frustration, deterring teachers from using the AR sandbox (Chou & ChanLin, 2012). All teachers interviewed expressed their concerns in this technical support aspect. They suggested that the fully implemented AR sandbox in classrooms has to be planned well ahead and gain support from the senior management of the school in order to dedicate teaching assistants or IT technicians with relevant computing and technical knowledge to manage the technical aspects of the AR sandbox. Such investment in manpower from students can be the way to alleviate the concerns of geography teachers.

Providing professional development for teachers is another essential factor influencing the adoption of the AR sandbox for teaching. Teachers need training not only on the technical aspects of the AR sandbox but also on its pedagogical applications. Teachers can have an improved grasp of integrating the AR sandbox into their lessons to maximise its educational benefits by implementing effective professional development programmes. The best practices, the preparation of lesson plans, and hands-on experience with the technology should all be covered in these training workshops.

In order to keep up with the latest developments in AR technology and to continuously improve their teaching practices, teachers have highlighted the significance of continued chances for professional development. That training can make teachers feel more confident and competent in using the AR sandbox, ultimately leading to it being used more widely and effectively.

6.3. Discussion and Conclusion

The AR sandbox presents a novel approach to teaching geography. The usage of the sandbox in secondary geography education has been increasingly explored. The perceptions, intentions, and interests of the seven secondary geography teachers about the AR sandbox reveal significant insights into the potential benefits and challenges of integrating this new technology into the classroom (Dunleavy et al., 2009). The following discussion compares the findings from the interviews with previous studies in the current literature on AR in education, emphasising themes such as the enhancement of learning, student engagement, technical challenges, resource availability, and professional development needs (Santos et al., 2013).

6.3.1. Enhancement of learning in geography lessons

The geography teachers who participated in the in-depth interview consistently expressed that the AR sandbox has significantly enhanced students' understanding of abstract geographical concepts (Bacca Acosta et al., 2014). The findings align with much previous research that highlights the capacity of AR to make complex and abstract concepts more accessible and comprehensible for students (Billinghurst & Duenser, 2012). The real-time interactive visualisation functionality of the AR sandbox allows students to effectively comprehend many topics of physical geography, like natural hazards and river and coastal environments. Such interaction offers a more engaging and intuitive learning process, potentially bridging the gap between theoretical knowledge and practical comprehension of geographical knowledge. However, when it comes to teaching areas related to human geographies such as economic geography or population studies, the teachers have mentioned that the AR sandbox is not as helpful as teaching physical geography topics. This limitation is supported by Bacca Acosta et al. (2014), who suggested that AR is primarily effective in learning environments that involve visual and spatial elements. Still, it is less helpful in learning about abstract and non-visual topics (Yuen et al., 2011). The AR sandbox, therefore, holds a great deal of promise for improving the teaching of physical geography topics. In order to provide students with more comprehensive learning experiences, both advanced and traditional methods have to be adopted for effective teaching of geography in secondary schools.

6.3.2. Student engagement and motivation

One of the prominent impacts of the AR sandbox was that it can greatly enhance student engagement and motivation in learning geography (Di Serio et al., 2013). According to Cheng and Tsai (2013), teachers have realised that the participatory aspects of the AR sandbox have the potential to transform geography lessons into experiences that are more fun and intriguing for students (Billinghurst & Duenser, 2012). The AR Sandbox plays an important role in boosting students' interest and enthusiasm by providing them with opportunities to participate in the learning activities actively. Using the AR sandbox, students' learning turns out to be more active than the passively received information from teachers as the conventional teaching approach (Bower et al., 2014). This learning attitude is promoted heavily nowadays, and active participation in learning could generate a habit for students to self-learn and enhance their problem-solving skills. This agrees with the findings of Di Serio et al. (2013), who stated that AR can greatly enhance students' learning attitudes by enhancing the immersion and interactivity of instructional content.

6.3.3. Technical challenges for using AR sandbox

Technical challenges have emerged as one of the critical difficulties for teachers to adopt the AR sandbox, despite the enthusiasm shown for it. The majority of geography teachers claimed that they could not effectively manage the AR sandbox's technical aspects due to their insufficient technical skills (Ibáñez et al., 2014). Dunleavy et al. (2009) identified technological challenges as a primary hindrance to the effective adoption of AR in schools. This is a barrier that has been widely reported in the literature (Arvanitis et al., 2009; Bower et al., 2014). Huang et al. (2016) study suggested similar recommendations as the geography teachers that the presence of dedicated technical support personnel would greatly relieve these issues (Cheng & Tsai, 2013). If teachers had access to such support, they could concentrate on pedagogical matters without being distracted by the need to debug technical issues (Santos et al., 2013). The teachers can solve some minor issues through training on fundamental operation and troubleshooting of the AR sandbox. This will enhance teachers' confidence and willingness to use such technology (Wu et al., 2013).

6.3.4. Teaching and learning resource availability

The teachers highlighted a number of significant barriers, one of which was the absence of individualised lesson plans and instructional materials that were tailored to the AR sandbox (Chou & ChanLin, 2012). In addition, this problem is echoed in the more general literature on incorporating technology in educational settings (Wu et al., 2013). The teachers emphasised the importance of having materials that were already planned and thorough, which could be easily incorporated into their lessons. Without these tools, teachers must spend time and effort creating their own materials, which can be depressing.

Bower et al. (2014) highlighted the need to supply ready-made lesson plans and teaching tools in order to facilitate the implementation of AR technologies. It is essential for the broad adoption of AR sandboxes, in which high-quality teaching materials specifically customised to the AR sandbox can be developed and used (Furió et al., 2015). These resources would reduce preparation time and maximise AR sandbox use, improving student learning.

6.3.5. Professional Development for teachers

It became apparent that professional development was an essential factor that played a role in the adoption of the AR sandbox (Kerawalla et al., 2006). A number of teachers have voiced their desire to have training on both the technical and pedagogical sides of the utilized technology. The significance of continuing one's professional development has been recognized in the research that has been published (Voogt, Erstad, Dede, & Mishra, 2013). It is vital for effective professional development programmes to be developed in order to provide teachers with the knowledge, skills, and confidence necessary for effectively incorporating new technology into their teaching methods.

Cai, Wang, and Chiang (2014) underlined the necessity of opportunities of continuous professional development for teachers to keep them updated on recent developments in e-learning technology and pedagogical practices (Billinghurst & Duenser, 2012). The current study's findings are similar to those of the previous studies in which geography teachers interviewed shared similar feelings. Through professional development training, teachers can keep up with the latest developments in the field and enhance their approaches to teaching. They can then be prepared well to make them feel more confident and competent in using the AR sandbox, and this training can lead to a more broad and successful adoption (Santos et al., 2013).

When it comes to AR in education, the current study's findings confirm and expand upon the existing body of literature (Kerawalla et al., 2006; Yuen et al., 2011). Furthermore, the fact that AR technologies can alter educational experiences is reaffirmed by the fact that they correspond with earlier studies on the advantages of AR for improving knowledge, engagement, and motivation (Billinghurst & Duenser, 2012). New dimensions are added to the conversation as a result of the particular focus on geography education and the thorough insights into the practical issues that instructors face.

The current study provides real-life instances of how an AR sandbox may be utilised to teach specific topics concerning physical geography (Dunleavy et al., 2009). Previous studies have shown the benefits of AR for visual and spatial learning in a general sense.

An in-depth investigation of the barriers that stand in the way of adoption, particularly technological challenges and the requirement for customised resources, brings to light areas that require additional focus (Bacca Acosta et al., 2014). The current study provides a nuanced understanding of how these issues come to fruition in the everyday life of teachers, despite the fact that the literature admits the existence of these challenges. The development of targeted interventions to assist the adoption of AR technologies can benefit greatly from considering things from this practical perspective (Santos et al., 2013).

Previous debates are expanded upon by the emphasis placed on professional development, which underscores the critical role of ongoing, hands-on training that attends to the subject's technical and pedagogical aspects (Voogt et al., 2013). To ensure that teachers not only grasp how to operate the AR sandbox but also know how to incorporate it into their teaching techniques correctly, it is essential that they focus on both of these aspects simultaneously (Bower et al., 2014).

Regarding the AR sandbox, the perspectives of teachers of geography emphasise both the potential benefits of using it and the obstacles that must be overcome in order to incorporate it into the classroom successfully. In addition to providing a more engaging and immersive learning experience, the AR sandbox has the potential to enhance the student's understanding of physical geography and their engagement and motivation (Di Serio et al., 2013). However, related to the availability of resources, the need for professional growth, and the technical hurdles.

In order to maximise the potential of the AR sandbox, it is crucial to address these obstacles by offering tailored support and training (Billinghurst & Duenser, 2012). Educators can cultivate an atmosphere conducive to AR technology's growth by providing comprehensive resources, technical support, and practical professional development courses.

A road map for implementing AR into geography education, revolutionising the learning experience, and improving educational outcomes is provided by the findings of this study, which, when combined with the current body of literature, give significant insights (Bacca Acosta et al., 2014; Santos et al., 2013).

6.4. Conclusion

Perceptions of the AR sandbox by geography teachers show the promise and problems of integrating AR technology into education. The AR sandbox's interactive and immersive learning experiences could help students understand complex geographical concepts (Wu et al., 2013). Educators recognise the importance of this technology as a means of making abstract concepts more concrete and exciting to students, particularly in the field of physical geography.

On the other hand, the adoption of the AR sandbox is not without its challenges. Major challenges are put forward by technical challenges that are associated with the setup and maintenance of the AR sandbox, in addition to the limited knowledge and abilities that the teachers lack. The integration method gets further complicated by the absence of ready-made, high-quality lesson plans and teaching resources. As a result, teachers feel obliged to devote a considerable amount of time to developing suitable materials (Wu et al., 2013). It is necessary to provide teachers with extensive training and opportunities for continuing professional development to equip them with the required skills and knowledge to effectively utilize the AR sandbox (Cheng & Tsai, 2013). This demand for additional resources and assistance highlights the necessity of offering such opportunities.

Teachers can focus on the pedagogical aspects of teaching because of the perspectives provided by the teachers, which also points out the necessity of having technical support personnel to manage and resolve technical issues. By developing collaborative learning settings through the use of the AR sandbox, it can be achieved to increase student engagement and motivation, making geography classes more dynamic and fun (Di Serio et al., 2013; Furió et al., 2015).

In general, the findings show that although the AR sandbox has the potential to transform geography education, successful implementation of this technology is dependent on overcoming the problems that the teachers have raised in terms of both resources and technical challenges (Dunleavy et al., 2009). Schools can facilitate the incorporation of AR technology by offering targeted assistance and resources. This will ultimately end up in an enhancement of the learning experience and outcomes for students (Bower et al., 2014).

In addition, Geography is a specialized subject which requires teachers with academic and pedagogical training in geography. A professional geography teachers should able to make their own geography curriculum in view of the subject resources, subject knowledge and skills and students' experience they have. Therefore, geography teachers play an important role in making their own geography curriculum to enable students understand their world better (Lambert and Morgan, 2010 & Geographical Association, 2024). Teachers' role was important in enhancing students' learning outcomes as they have to choose suitable contents with reference to their students' experience. Teachers were required to design lesson plans and both formative and summative assessment items to monitor students' progress and learning outcomes. Therefore, research findings indicated that there were improvement in students' assessment results in both teaching methods and explained the importance of a professional geography teacher in enhancing student learning experience.

This study contributes to the wider discussion about AR in education by providing teachers, policymakers, and technology developers with recommendations and specific insights that can help them make the most of the potential that AR has to offer in the classroom.

CHAPTER 7: LIMITATIONS AND FUTURE RESERACH

A notable limitation of the study was the focus on map reading and farming as topics. These selections aimed to represent human geography however they did not cover the entire spectrum of geography education. This narrow focus might have hindered the generalizability of findings regarding how interactive technologies like the AR sandbox can enhance geography education (Billinghurst & Duenser, 2012). The specificity of these topics could also lead to varying results regarding the effectiveness of AR sandbox tools as discussed in sections (Azuma, 1997). Different geography subjects may have requirements, for content visualization and student engagement when using technologies (Wu et al., 2013). To address this issue future studies should consider incorporating a range of geography topics. This would not just improve the strength of the results. Also offer an insight into how AR technology could be effectively incorporated into geography teaching (Bacca Acosta et al., 2014; Sirakaya, Kilic Cakmak, & training, 2018).

In addition, it is essential to acknowledge that the field of geography education encompasses both physical and human geography, with each field necessitating a distinct instructional strategy. AR could be of tremendous use in the field of physical geography, which is concerned with natural phenomena such as rivers, mountains, and climate. This would enable students to visualize and interact with these aspects in a simulated world, which would be a significant benefit. Using AR for instance, students could use it to recreate weather patterns or to examine how erosion affects landscapes over time. On the other hand, the field of human geography, which encompasses the study of cultures, economies, and urban development, can call for AR apps that are able to predict demographic shifts, economic trends, and urban planning scenarios. Implementing this dual strategy would guarantee the optimal utilization of AR technology throughout the entire geography curriculum.

Utilizing the AR sandbox in conjunction with several other technical tools has the potential to expand its scope of application. An effective platform for geographical analysis and data visualization, for instance, might be created by fusing AR with geographic information systems (GIS). A more immersive learning environment could be provided by allowing students to view GIS data in 3D via AR. Comprehending intricate ideas like resource management, land use patterns, and geographical distribution may become easier with this integration. Subsequent studies should investigate these comprehensive methods to improve the educational effectiveness of AR technologies.

Furthermore, only the AR sandbox was tested as a tool, in this research. While the AR sandbox is an advancement in technology and different technologies may be more suitable for various subjects. One such instance is VR, which provides a totally immersive environment. This kind of environment could be beneficial for subjects that require in-depth examination of large-scale geographical phenomena, such as the biomes of the Earth or the historical climate change. A hybrid learning experience that is both immersive and interactive could be made possible with the help of mixed reality, which is a combination of aspects of AR and VR. Future studies could explore a range of technologies to compare their effectiveness and determine which ones are most beneficial for educational purposes and subjects (Carmigniani et al., 2011; Radu, 2014).

Another important limitation was the setup used for the AR sandbox classes (Santos et al., 2013). These classes were created specifically for the study which were not fully integrated into the regular geography curriculum. They were also limited to two sessions throughout the term, which may not have been enough to explore the potential of AR technology in education. The short duration and lack of integration, into learning routines might have affected how AR technology was used and its outcomes (Kim et al., 2018). It is possible that a deeper understanding of the influence that AR technology has on student comprehension and participation could be obtained by prolonged exposure to the technology within the regular curriculum. Students would be able to grow more familiar with the technology and potentially gain better educational benefits if, for instance, AR-based classes were implemented continuously throughout the academic year. Studies that occur over a longer period could monitor the improvement of students' abilities and knowledge over the course of several months, providing insights into the ways in which continuous engagement with AR technology effects learning processes and outcomes. To address this future research could involve collaborating with schools to conduct experiments that integrate AR technologies into curricula over an entire term or semester. This approach would allow researcher to observe long-term influence of AR on teaching and learning and facilitate a more accurate assessment of its educational value (Dunleavy et al., 2009). To further provide evidence for comparison on the effectiveness of AR in various learning environments, research could also include a control group that employs traditional instructional strategies alongside with an experimental group that makes use of AR. The use of this method would be helpful when assessing specific advantages and challenges that are linked with integrating the use of AR into typical educational environments.

The integration of technology could offer a precise evaluation of its impact, on learning outcomes and enhance our understanding of how it can be applied effectively in everyday educational settings (Akçayır & Akçayır, 2017; Billinghurst & Duenser, 2012). For instance, including AR technology into regularly lessons could be useful for identifying the best practices for its implementation. This could include identifying the optimal duration of AR sessions, the sorts of AR content that can be most effective, and the most efficient methods to integrate AR with other instructional approaches. By acquiring an understanding of these aspects, it may be possible to establish thorough recommendations for teachers on how to make effective utilization of AR in their classroom teaching.

Regarding the assessment of outcomes the current study focused on pre-test and post-test evaluations, which assessed knowledge and skills at only two time points (Dunleavy et al., 2009). While this method provides insights into the effects of teaching approaches but it lacks the depth to monitor changes in student performance throughout the intervention (Dey et al., 2018; Kim et al., 2018). Future research ought to make use of a longitudinal study design which includes multiple assessment checkpoints throughout the intervention so as gain greater understanding of the evolution of learning. To capture continuing learning and participation, this might involve things like periodical tests, but continuous assessment assignments, and reflective journals. This approach would help identify patterns and fluctuations in learning outcomes over time offering insights into how students engage with and benefit from educational technologies like AR sandbox (Azuma et al., 2001).

Moreover, the study examined a few socio factors like gender and grade level as potential influencers of learning outcomes. This narrow focus may have overlooked socio demographic elements that could impact learning, such as household income, parental education levels or wider cultural influences (Van Krevelen & Poelman, 2010). Students from different socioeconomic backgrounds, for instance, may have different levels of exposure to technology beyond school, which may, in turn, influence their understanding and familiarity level with AR products. In the same way, cultural attitudes towards technology and education may have an effect on how students and their families perceive and communicate with AR-based learning. Future studies should consider including a range of socio variables to gain a more comprehensive understanding of how these factors may affect the effectiveness of AR technology, in education (Kamphuis et al., 2014).

Furthermore, including students from backgrounds and levels in the participant pool could increase the variety of the sample thus enhancing the study findings and their relevance to different student groups (Cheng & Tsai, 2013; Eckert et al., 2019). Incorporating pupils from urban, suburban, and rural schools, for instance, could provide insights into the various ways in which differed environmental contexts impact the utilization and effectiveness of AR technological advances. Moreover, the engagement of students with a broad spectrum of academic skills, including those with difficulties with learning, has the potential to highlight the diversity and accessibility of AR tools in school environments.

To sum up, although this study has shed light on the benefits of using AR technology to improve geography education but also including its limitations by pointing out the areas for further research (Milgram & Kishino, 1994). By addressing these limitations, future studies can expand on existing knowledge. Explore ways in which AR and interactive technologies can be leveraged to enhance educational outcomes across various learning environments and subjects (Poushneh & Vasquez-Parraga, 2017).

CHAPTER 8: CONCLUSION

The purpose of this study was to investigate the effectiveness of placing students in an AR sandbox in order to improve their learning in geography lessons (Billinghurst & Duenser, 2012). This research also attempted to gain an understanding of different factors that influence the learning outcomes of students (Carmigniani et al., 2011; Sirakaya et al., 2018). An assessment methodology consisting of a pre-test and a post-test was employed in the study in order to measure improvements in learning outcomes. Following participation in both AR-enhanced and conventional classroom formats. During the instructional sessions, a wide variety of topics were addressed, which made it possible to assess the performance of students in an array of educational subject disciplines (Azuma, 1997).

In addition, we conducted a survey in order to collect data concerning the students' perspectives on learning, their reasons for learning, and the degree to which they considered their education was successful. We gathered additional socio-details (Akçayır & Akçayır, 2017; Bacca Acosta et al., 2014).

Within the scope of our research, we employed paired sample t-tests to assess the performance of the students following the lessons. Certain findings are brought to light by this study (Santos et al., 2013).

Students exhibited an improvement in their post-test results after participating in map reading sessions that were conducted using the AR sandbox app. The fact that this is the case suggests that the AR sandbox played a significant part in enhancing student learning results by making difficult geographical ideas easier to understand and simple for learners to understand through the use of immersive experiences (Dey et al., 2018; Dunleavy et al., 2009; Kim et al., 2018).

In addition, students' performance in lessons that utilized the AR sandbox was stronger to that of classes (Regenbrecht et al., 2005). Due to the fact that it is both interesting and participatory, the AR sandbox has the potential to be utilized as a teaching tool. This is because it is a good fit for the way that contemporary students prefer to learn (Azuma et al., 2001; Billinghurst & Duenser, 2012).

But the application of the AR sandbox varied depending on the subject matter. To be more specific, it was only successful in some elements of the test evaluation when it involved the farming theme.

This variation of outcomes underscores the fact that although AR technology has the potential to be helpful, its influence can vary depending on the subject matter (Cheng & Tsai, 2013; Kamphuis et al., 2014). Certain subjects are more likely to benefit from the applications of AR than others and vice versa (Eckert et al., 2019).

Based on these findings, it is apparent that the AR sandbox has the potential to be utilized as a teaching instrument to improve geography education (Milgram & Kishino, 1994). Having said that, the research also highlights the significance of taking into consideration how useful AR technology is for certain subjects when implementing it into educational programmes (Poushneh & Vasquez-Parraga, 2017).

Results were obtained through the investigation of the factors that contribute to the outcomes of learning (Azuma, 1997). It is important to note that having a "learning attitude" was found to enhance learning results in traditional map reading lessons; however, this effect was not detected in either AR sandbox classes or traditional farming classes (Carmigniani et al., 2011). A conclusion that can be drawn from this is that although an active learning strategy is typically beneficial to success, its impact may differ depending on the learning environment and the subject matter. The relationship between students' attitudes and motivations, as well as their perceptions of how efficient their learning was, provided additional insightful information. Higher levels of perceived learning efficacy were typically reported by students who exhibited a "learning attitude" and were motivated by "satisfaction and interest" (Billinghurst & Duenser, 2012). On the other hand, students who were predominantly motivated by their anticipation of marks in assessments reported a view of the effectiveness of their learning, which suggests that intrinsic motivation may be more favorable to the perception of academic success than extrinsic motivation. Based on the complex findings, it appears that the utilization of the AR sandbox has the potential to assist in reducing the learning gaps that are associated with various levels of student motivation and attitude. AR technology has the ability to build an educational environment by enabling the creation of an engaging learning setting. This would provide all students, regardless of their original attitude or level of motivation, with the opportunity to improve their learning outcomes.

Furthermore, the limitations of the study provided different points of view. Create the conditions for future research initiatives to take place (Cheng & Tsai, 2013, 2019; Dunleavy et al., 2009). Considering that the research was restricted to individuals and a certain demographic group, it is clear that additional research is required in order to acquire a comprehensive understanding of the potential and constraints of AR in the field of education (Santos et al., 2013). The scope of this research might be expanded in subsequent studies by include a wider range of topics and a more varied student body (Sirakaya et al., 2018). Additionally, AR technology could be incorporated into regular curriculum in a more extensive manner and for longer periods of time in order to better evaluate its effectiveness and durability.

To summarize, this research not only demonstrated that AR technologies have the potential to be used as a teaching tool, but it also shed light on the barriers that are involved in integrating them into more conventional methods of instruction (Carmigniani et al., 2011). The insights that were obtained serve as a foundation for strategies and technical integration initiatives that are targeted at maximizing the benefits that AR offers in terms of improving learning outcomes across a variety of educational settings (Billinghurst & Duenser, 2012).

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Appendix 1

Pre Test and Post Test Assessment Item

Argument Reality Sandbox Project

Pre/post-test – Map Reading

Name of school:

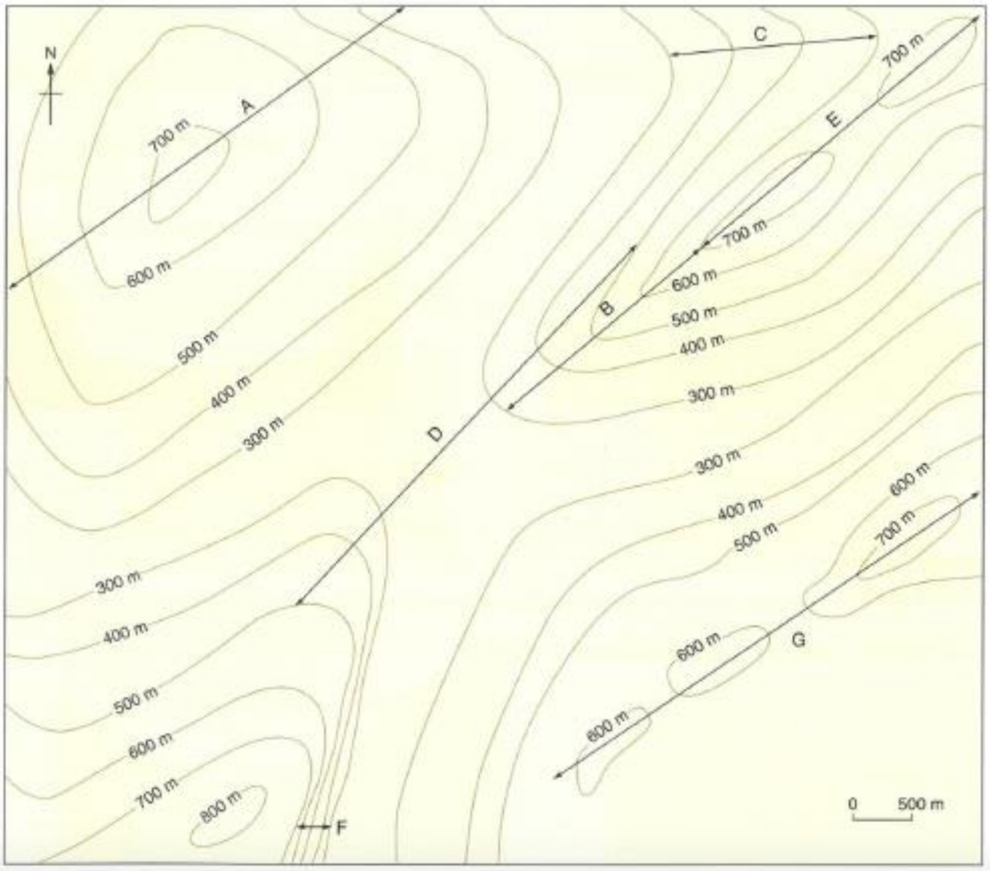
Class: ______________________ Class no: ______________________

Part A: Objective Assessment

Please write down your answer on the following table:

Question no.	1	2	3	4	5	6	7	8
Answer								

Study the figure below and answer Q1 to Q3.



1. What is the landform feature labeled as F?

A. A spur
B. A concave slope
C. A cliff
D. A convex slope

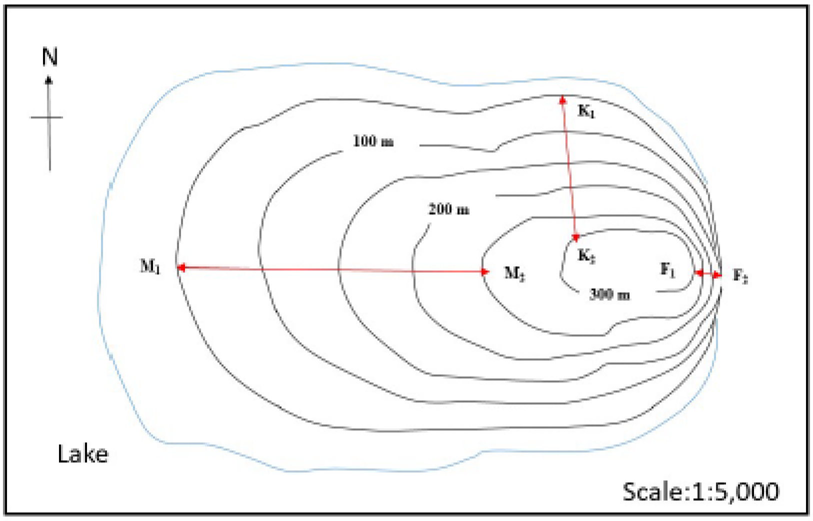
2. What is the landform feature as labeled as G?

A. A valley
B. A spur
C. A cliff
D. A ridge

3. Which of the statement below is incorrect?

A. B is a valley; C is a spur
B. B is a spur; C is a valley
C. B is a convex slope; C is a concave slope
D. B is a concave slope; C is a convex slope

Study the figure below and answer Q4 to Q6.



4. Which landform feature can be found along slope F_1-F_2?

A. A cliff

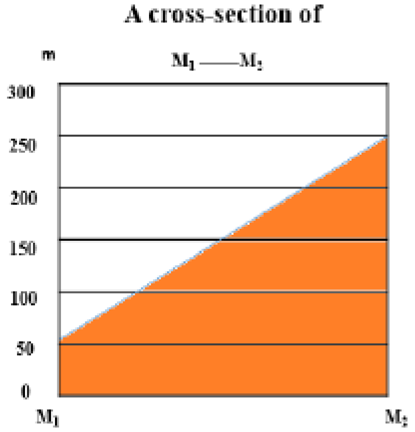
B. A concave slope

C. A ridge

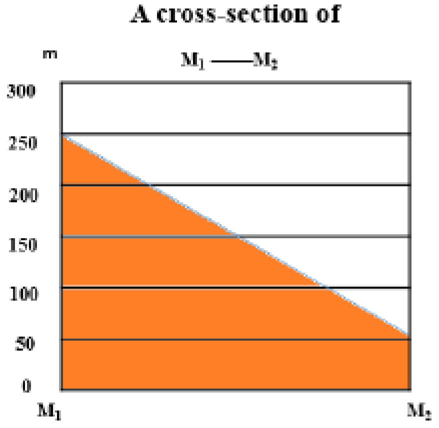
D. A spur

5. Which of the following cross-section of slope M_1-M_2 shows the actual shape of the land?

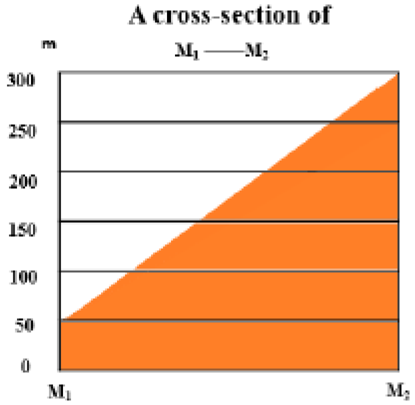
A.



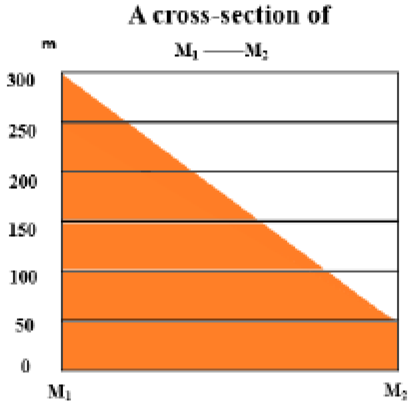
B.



C.



D.



6. The order of slopes F_1-F_2, M_1-M_2 and K_1-K_2 are arranged according to their steepness below, from the gentlest to the steepest. Which of the following is the CORRECT order?

A. Slope F_1-F_2, K_1-K_2, M_1-M_2

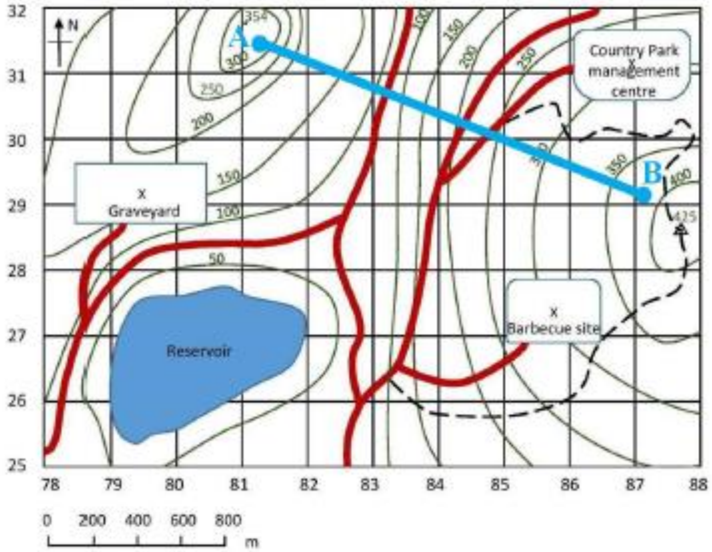
B. Slope K_1-K_2, F_1-F_2, M_1-M_2

C. Slope M_1- M_2 ,K_1-K_2, F_1-F_2

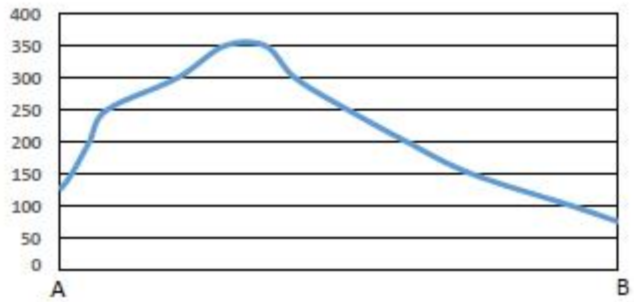
D. Slope M_1-M_2, F_1-F_2, K_1-K_2

Study the figure below and answer Q7.

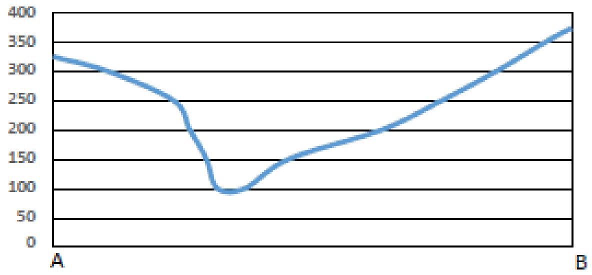
7. Which of the following is the cross section between A and B?



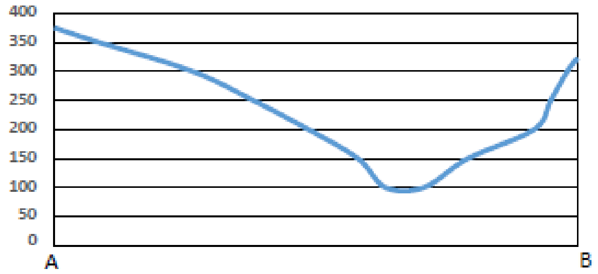
A.



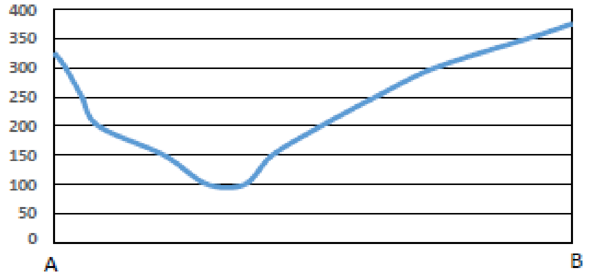
B.



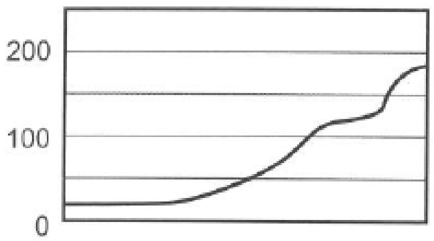
C.



D.



8. What is the average gradient of the following path? (Given the actual horizontal distance is 840 m)



A. 1 in 3.8
B. 1 in 5.6
C. 1 in 6.5
D. 1 in 7.3

Part B: Self-evaluation

I now rate my map reading ability as (10 as full score; 5 as pass score; 0 as no knowledge)

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

--End--

Argument Reality Sandbox Project

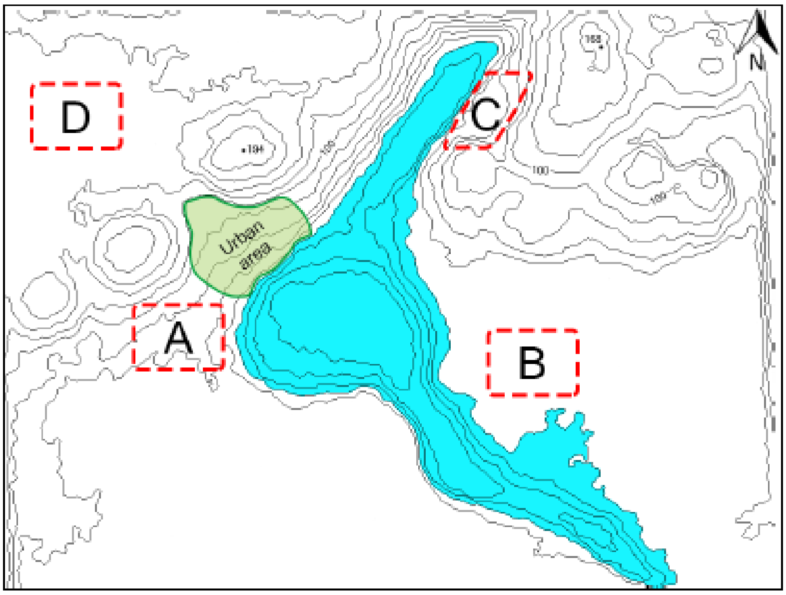
Pre/post-test – Farming

Name of school:

Class: ______________________ Class no: ______________________

Part A: Objective Assessment

The following map shows Happy Valley in the Northern Hemisphere. 4 locations (A, B, C, and D) are selected as proposed sites for agricultural development. Read the map and evaluate the sites based on their location and relief shown in the map. **Put ✓ in boxes if the sites attained the farming factors listed in the table.**



Put ✓ in boxes if the site attained the factor(s).

Factors \ Location		**A**	**B**	**C**	**D**
Closer to irrigation sources					
More fertile soil					
Gentler slope					
Closest to market					
Potential risk of soil erosion	by flooding				
	by landslide				
Favourable aspect for sunshine					

Part B: Self-evaluation

I now rate my map reading ability as (10 as full score; 5 as pass score; 0 as no knowledge)

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

--End--

Appendix 2

Questionnaire Survey

中學地理擴增實境智能沙箱學習問卷調查

學校：

學生編號：________________________
班級: ____________________________

本課程研究問卷分為四部分，目的是了解你們對學科學習及教學的觀念、學習動機及方法的意見。學習方式沒有對錯，只在於該種方式是否適合個人的學習習慣及科目內容。請誠實地回答每一條問題，並以**地理**課程為基礎完成本問卷。註：所有數據只作研究用途，不會公開資料。
請以黑或藍色原子筆，圈出合適的意見。

第一部分：學習的觀念 Part A

	請於下列表格內，表明你對各說法的同意程度。	5－非常同意 4－同意 3－中立 2－不同意 1－極不同意				
A1	1. 老師應全面掌控學生的所作所為。	1	2	3	4	5
A2	2. 有效的教學能鼓勵學生進行更多的討論及課堂活動。	1	2	3	4	5
A3	3. 傳統講授教學法是最好的，因為它能涵蓋較多資訊。	1	2	3	4	5
A4	4. 好老師應該可以運用合適的科技協助學生建立對課題的理解及認識。	1	2	3	4	5
A5	5. 教師的工作應是即時糾正學生學習上的錯誤，而不是由他們自行驗證。	1	2	3	4	5
A6	6. 學習是指學生應有充分的機會去進行探究、討論及表達個人意見。	1	2	3	4	5

第二部分：學習習慣 Part B

	請於下表內，表明這些情景是否經常發生於你身上。	5－總是 4－經常 3－有時 2－好少 1－沒有				
B1	1. 我發現學習會帶給我很大的滿足感。	1	2	3	4	5
B2	2. 我發覺我要在一個課題上做足功夫，建立起自己的觀點，我才會感到滿意。	1	2	3	4	5
B3	3. 我上學的目標是只求公開試成績優異而已。	1	2	3	4	5
B4	4. 我只會認真學習課堂內所要求做的練習，或課程上所提及的內容。	1	2	3	4	5
B5	5. 我努力學習因為我對學習內容感到興趣。	1	2	3	4	5
B6	6. 我發覺通過考試最佳方法是估計可能會問的問題，記住該題目的答案。	1	2	3	4	5

第三部分：地理課堂的意見 Part C

	請在下列各項目內發表意見。	5－非常同意 4－同意 3－中立 2－不同意 1－極不同意				
	課堂完成後，					
C1	1. 加強我對閱讀地圖的能力。	1	2	3	4	5
C2	2. 加強我對等高線及地形關係的理解。	1	2	3	4	5
C3	3. 加強我對有關農業系統課題的理解。	1	2	3	4	5
C4	4. 提升信息處理技巧。	1	2	3	4	5
C5	5. 課堂使用的教學工具, 提高我對學習地理的興趣。	1	2	3	4	5
C6	6. 我很滿意這利用擴增實境智能沙箱 (AR Sandbox)教學的課堂。	1	2	3	4	5
C7	7. 我期望將來有更多這類的地理課堂。	1	2	3	4	5

第四部分：背景資料 Part D

D1	1. 性別	1	男		2	女		
D2	2. 水平	就讀年級	1	中四	2	中五	3	中六
			4	初中				

～問卷完，謝謝！～