

**ENHANCING COLLABORATIVE LEARNING IN AN AUGMENTED
REALITY SUPPORTED ENVIRONMENT**

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Abstract

In this research project, effort had been made into the application of collaborative augmented reality technology (AR) to mediate traditional collaborative learning process. The objective is to study how collaborative AR as a relatively new technology could mediate the collaborative learning process. A server-supported mobile collaborative system was built to simulate the phenomena on 'elastic collision', a topic selected from the physics textbooks of Singapore's junior high school. The end user software client was implemented on mobile platform to give collaborator more freedom in collaborative task. Technologically, server based architecture has been implemented to facilitate the central control on the multi-person collaboration and also allow mobile client to offload computational intensive tasks. User experiment had been conducted with sixty students from National University of Singapore who did not possess prior knowledge on the topic of 'elastic collision'. Results empirically verified that the influence of AR could effectively foster better collaborative learning. Participants had also reported substantial stronger learning interest. As a conclusion, AR appears to be a promising technology for education community as instructional tools in the future. It is the mission of both technical and educational research communities to work

together to build AR application that shape the future of AR as promising educational technology.

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Chapter 1. Introduction & Literature Review

1.1 Overview

Advances in computer technology have been rapidly and revolutionarily broadening the scope of activities on teaching and learning. In late 20th century, electronic revolution, particularly the development of multimedia technology, had brought along the concept of electronic learning (e-Learning) to the education community. In general, e-Learning exhibits advantages of supporting learning in a personalized, portable, on demand and flexible manner (Zhang, Zhao, & Jr., 2004). Together with the growing of communication technology, connecting computing devices was becoming ever easier. As a result, there were opportunities in developing collaborative e-Learning software that can engage multiple learners in learning activities simultaneously.

Learning activity had been explained by various past literatures. Generally, it had been broadly classified into one of six categories (Naismith, Lonsdale, Vavoula, & Sharples, 2004) based on the characteristic of the activities. Among which, collaborative activities in learning had been identified as one of the major category of learning activities. The driving mechanism of collaborative learning was explained by social interaction theory. Collaborative learning involves multiple individuals engaged in knowledge building (Hiltz, Coppola, Rotter, Turoff, & Benbunan-Fich, 2000), usually in a face-to-face setting. Through technological enhancement, field of computer supported collaborative learning (CSCL) had attracted attentions. The concept of collaborative learning can be extended such that we can make use of the technology to mediate traditional face-to-face discussion based learning activities or to construct technological environment for remote collaboration.

Intensive researches on CSCL had been carried out due to the growing interest in employing computer technology to improve collaborative learning effectiveness (Dillenbourg & Fischer, 2007).

On the other hand, with the growing demand of computer simulation on education which requires richer visual presentation, classic 2-dimensional (2D) multimedia was insufficient to deliver the required level of visual presentation in some occasions. Virtual reality (VR) has become a new approach to deliver educational content. However, its disadvantages have also been revealed. Firstly, it is difficult for immersive VR to support natural way of communication where collaborators could interact in face to face. In addition, many people like to “stay in control” by seeing the reality at the same time while performing learning task. Augmented reality (AR) is a technology that overlay computer generated virtual graphic into real world reality and it had demonstrated its great potential on creating a shared mixed reality workspace for effective collaborative learning (Wichert, 2002). Its major difference from VR is that AR only mixes virtual scene with reality but not replaces it. More specifically, VR built a virtual world that completely removes the sense of reality from users whereas AR integrated the virtual world with real world in a nice way so that it makes it possible for both worlds to interact. Technology of AR has been developed for several decades and it focused on vision tracking, interaction technique and display technology (Zhou, Duh, & Billinghurst, 2008). The strength of AR lies on its capability of integrating 3-dimensional (3D) object into the real world reality captured by camera. In educational context, AR is able to simulate the educational content (e.g. scientific phenomena described in physics, chemical textbook, etc) in a high degree of realism which is beyond the capability of classic multimedia tools (e.g. 2D flash technology). Although classic 2D and 3D multimedia tools can simulate the scientific phenomena to certain degree, they are incapable to present

the simulated scene integrated in real world. On the other hand, comparing to traditional physics and chemical experiment, AR can easily simulate the scientific phenomena that is technically difficult or dangerous to present in classroom or laboratory. For instance, it is not an easy task to produce physical object with precisely defined mass and velocity. Moreover, it is also dangerous to conduct certain chemical experiment in school.

In this research project, the effectiveness of AR on physics education has been investigated. A specific scenario was chosen and implications of application of AR in mediating traditional face-to-face collaboration was studied empirically with comparing to the same scenario carried out in traditional face-to-face case as well as with the help of classic 2D multimedia tool. The primary objective was to measure three main aspects of learning outcomes mediated by AR environment, namely learning outcome, motivational effect as well as the usability issues. Firstly, the learning effectiveness was measured from objective learning outcome that indicates the actual learning effect mediated by the AR environment. Secondly, the measurement on whether AR environment could induce motivational effect on facilitating learners' interest was carried out. This measurement could be obtained from perceived learning effectiveness and user's preference. Lastly, usability issues had also been observed insight as an effort to explore and investigate the room of improvement for delivering a better user experience.

The remaining section of this chapter provides literature reviews reporting founding on past researches that we concerned as follow: Firstly, augmented reality (AR), as the technology we had chosen to adopt in collaborative learning process, had been reviewed briefly. This covered the information about research areas and trends in AR as well as some famous past works about collaborative AR. In addition, theory and research practice on

collaborative learning had been reviewed. The objective was not only to give readers some fundamental knowledge if he/she was not familiar with the field previously but also to provide an overall theoretical framework for this project on which research method we are adopting and the reason of choosing it. Thereafter the research practices could be adopted as the tool to be used in this research work. With the background information presented in this chapter, next chapter would step into the details of this research work.

1.2 Technology of Augmented Reality

1.2.1 Introduction to Augmented Reality

Virtual reality refers to computer generated 3D simulation that users can enter and interact. Users are able to immerse into the artificial environment as a simulated reality and manipulate the virtual objects in that world (Louka, 1996). In particular, the real world is not visible to users involve into VR. VR enables rich visual experience on computer simulation and is good for presenting complex phenomena. Different from VR where the entire virtual scene is generated by computer, AR only generate part of virtual imagery and have those scenes registered into the real world scene. Users of AR could see the virtual world and real world registered nicely and simultaneously.

As relatively young technology, AR has been developed and researched for more than forty years. The technology allows overlaying of computer-generated 3D virtual images into the real physical environment in real time and users interact with those virtual images seamlessly on a display device. Figure 1 (Gu, Li, Chang, & Duh, 2011) have shown a good example of an augmented reality application where virtual cube and virtual block are drawn on top of the physical pattern (i.e. fiducial marker). It is a field of multidisciplinary research. Apart from the researches merely on technological aspects like tracking, interaction and

display technology, there are also researchers studying the implication of AR towards humanity and human computer interaction (HCI) issues, such as its usability and design issue. The existing literatures provided greater detail on AR researches for reader to obtain more information on AR. But nevertheless, since we had chosen AR as a new media to deliver a representation of learning phenomena (i.e. physical phenomena appears in the textbook) so as to mediate collaborative learning, it is necessary and worthwhile for us to provide a brief introduction into the backgrounds and various relevant researches over this field to the readers of this dissertation.

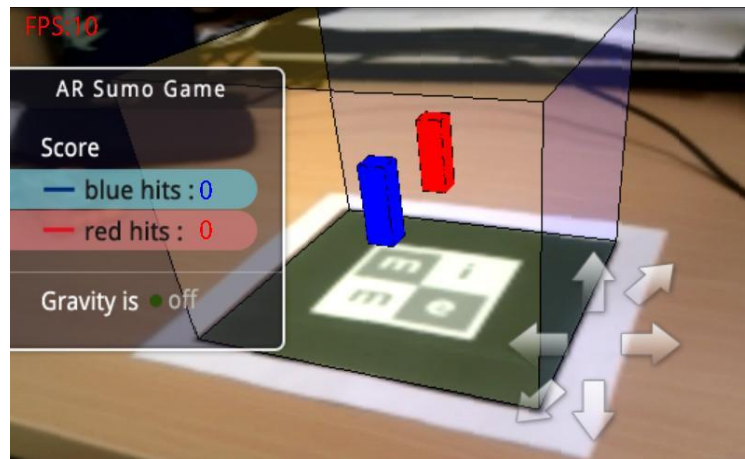


Figure 1 Vision-based AR



Figure 2 GPS-based AR

Over years (1998-2008), most researches on AR have fallen into five main areas. According to Zhou, Duh & Billingham (2008), there are:

1) Tracking techniques

Tracking technique ensures that any change in viewing perspective would be reflected in the rendered graphic. According to these, there are two basic

approaches. Firstly, vision-based techniques use computer vision techniques to estimate the camera pose. Early technical papers suggested using marker-based tracking (Fig 1). Fiducial markers are specially designed square patterns that facilitating the computer visual recognition process. One good example is the famous ARToolkit library (Kato & Billinghurst, 1999) developed at 1999 that facilitates programmers to develop marker-based AR applications. Second type of tracking technique is known as sensor-based (Fig 2) tracking (Rolland, Baillot, & Goon, 2001). This technique suggested using various sensors like inertia sensor, magnetic sensor, GPS receiver and so on. Each type of sensors is good at detecting certain information. So if used wisely, a number of different sensors could provide sufficient information for tracking task. Besides, sometime it is also useful to use hybrid information from GPS receivers, inertia sensors and computer vision techniques interchangeably since each approach exhibit its own advantages. Integrating information from each source helps to make the AR applications more robust especially for outdoor AR applications (Azuma, et al., 1998).

2) Interaction techniques

Interaction techniques define how end users interact with AR system. Thus, it is an important objective to facilitate an intuitive interacting experience to end users. Tangible AR interface is one of the main objectives in AR interaction researches. It enable end users to manipulate virtual AR contents just like manipulating real objects. The challenges of tangible AR is: how to detect the real objects and identify their motions reliably so that we could identify inputs from end users (through hand gesture, fingers, etc) and make response. Different past researches have been proposing various solutions on hand gesture recognition, finger recognition and so

on (Malik, McDonald, & Roth, 2002), (Dorfmüller-ulhaas & Schmalstieg, 2001) (Irawati, Green, Billingham, Duenser, & Ko, 2006) .

3) Calibration & registration

Tracking device calibration technique and registration algorithm ensures virtual contents to be aligned exactly with the real content. A good calibration technique with registration algorithm could estimate correspondences between 3D and 2D scenes (i.e. homography) and register the virtual content onto the real scene precisely.

4) AR application

The researches in this area concerns how could development of AR application that brings value to human. AR has exhibited great potential to be applied in areas like education, advertisement, entertainment and so on. Later in this section, some famous AR applications were introduced.

5) Display techniques

From past researches in virtual reality (VR) and AR, the display techniques concentrate on mainly three aspects: see-through head-mount displays (HMD), projection-based displays and handheld displays. See-through HMD is wearable devices (Fig 3) that allow users to see the real world augmented by virtual imagery. On the other hand, projection-based display doesn't require users to wear devices but to project virtual imagery directly onto the real objects in daily world (Ehnes, Hirota, & Hirose, 2004). Researchers have been studying the possibilities and techniques to operate camera and video projector simultaneously (Bimber, Grundhöfer, Grundhöfer, & Knödel, 2003) (Cotting, Naef, Gross, & Fuchs, 2004) and obtained promising findings.



Figure 3 See-through HMD display
(Broll, et al., 2004)

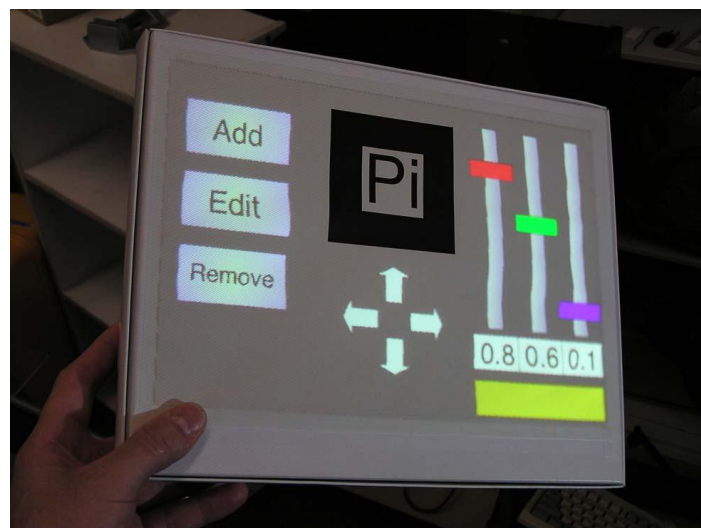


Figure 4 Projection-based displays
(Ehnes, Hirota, & Hirose, 2004)



Figure 5 Mobile AR on Cell Phone

(Möhring, Lessig, & Bimber, 2004)

While see-through HMD based display and projection-based display involve expensive hardware investments (generally not for personal use), handheld display could potentially be the most popular display because handheld devices such as mobile phones, personal digital assistants (PDA) are ubiquitous nowadays. Particularly, mobile phone is becoming a necessary device for most people nowadays. First self-contained AR application on mobile phone (Fig 5) was presented at 2004 (Möhring, Lessig, & Bimber, 2004) in which mobile phone was fully responsible for performing paper based fiducial marker detection and graphic rendering at an interactive speed. Since then, the term 'Mobile Augmented Reality' (mobile AR) came into the picture.

Our research contributes to human studies of AR application where investigation was carried out to discover the implication of AR application on human behavior. More specifically, the subject of study is to find out how AR would enhance outcomes of collaborative study and in which aspects can it affect the collaborative study. By providing

empirical evidence, it was our hope to show to the educational and AR communities that technology of AR has a great potential in education domain.

1.2.2 Past Works on Collaborative AR

Researches on collaborative AR started mid-nineties (Zhou, Duh, & Billinghurst, 2008) and it was shown that AR can support both remote and co-located collaboration (Billinghurst, Weghorst, & Furness, 1996), (Szalavári, Schmalstieg, Fuhrmann, & Gervautz, 1996). Remote AR collaboration such as AR conference (Kato & Billinghurst, 1999) aims to create telepresence with the overlay of virtual imagery so that it enables multiple persons to collaborative on cyberspace seamlessly. On the other hand, AR for co-located collaboration can be used to create a virtual 3D shared CSCW workspace (Billinghurst & Kato, 2002). Recent researches (Reitmayr & Schmalstieg, 2001), (Wagner, Pintaric, Ledermann, & Schmalstieg, 2005), (Henrysson, Billinghurst, & Ollila, 2005) have started to investigate the effect of mobile AR supported shared virtual 3D space towards face-to-face collaboration. A pilot study (Henrysson, Billinghurst, & Ollila, 2005) conducted found that users preferred AR gaming more than non-AR face-to-face game. This indicates that AR could bring richer user experience to enhance user's interest in collaboration.

Works on collaborative AR has been focused on head-mounted display (HMD), desktop and handheld-based environment. Construct3D (Kaufmann, Schmalstieg, & Wagner, 2004) is designed as a 3D geometric construction tool that can be used for a wide range of educational purposes (e.g. geometrical education, physics, etc). Students wearing HMD can engage into face-to-face interactions in real-time 3D virtual space (Fig 6). Similarly, AR Tetris (Wichert, 2002) allows users to collaborate remotely with fiducial markers in a master/trainee scenario (Fig 7).

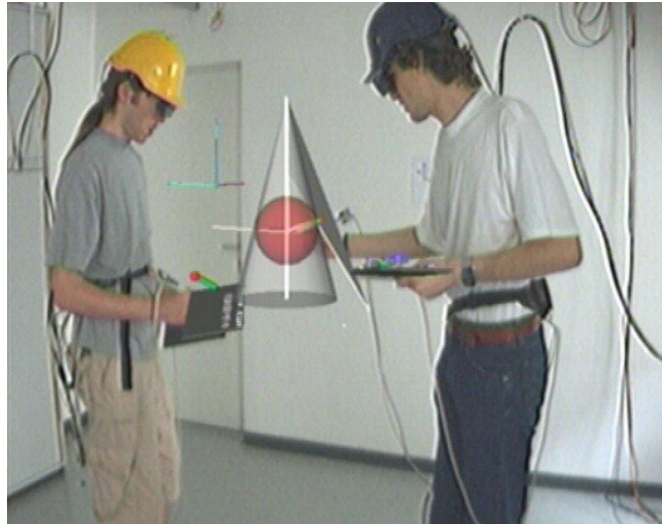


Figure 6 Construct3D

(Kaufmann, Schmalstieg, & Wagner, Construct3D: A Virtual Reality Application for Mathematics and Geometry Education, 2004)

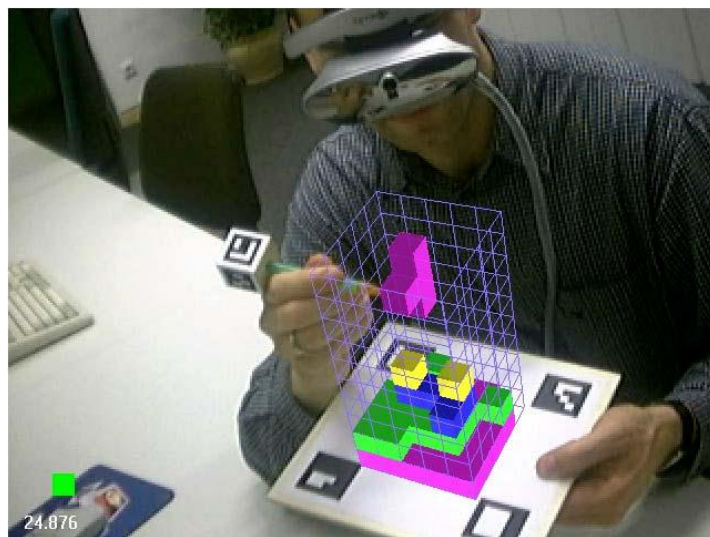


Figure 7 AR Tetris

(Wichert, 2002)

These collaborative systems are designed to be applied in a range of educational contexts. However, they are all investment-intensive setups. Hence, it is impractical for them to be widely deployed outside the research laboratory in the near future. On the other hand, ARQuake (Thomas, Close, Donoghue, Squires, Bondi, & Piekarski, 2002) is a mobile AR in-door/outdoor application that uses hybrid of GPS information and vision based

technique. It is enabled by a backpack configuration (Fig 8, 9) so that its cost and performance (30 frames per second) are more balanced comparing to previous two systems. In contrast, AR tennis (Henrysson, Billinghurst, & Ollila, 2005), (Fig 10) is designed for mobility because the expensive AR computation and game simulation are both processed internally in mobile phones and no additional external hardware is required. Although fully functional, its pitfalls are its' low resolution in augmented video frame and slow frame transition rate (i.e., 3 to 4 frames per second). In view of abovementioned pros and cons from various different AR systems, in this project, we have applied a different approach as described in the system chapter (i.e. chapter 3) later.



Figure 8 Backpack Configuration (back view)

(Thomas, Close, Donoghue, Squires, Bondi, & Piekarski, 2002)



Figure 9 Backpack Configuration (front view)

(Thomas, Close, Donoghue, Squires, Bondi, & Piekarski, 2002)



Figure 10 AR Tennis Game

(Henrysson, Billingham, & Ollila, 2005)

1.3 Computer supported collaborative learning

1.3.1 Overview

Collaborative learning has been researched for many years. The goal was to investigate what kind of circumstances can learning process made more effective. A number of variables were selected for study such as group heterogeneity, individual prerequisites and so on (Dillenbourg, Baker, Blaye, & O'Malley, 1996). Past researchers had made effort to propose theories explaining the mechanism driving effective collaborative learning.

Technological development was advancing rapidly during the last decades. Researches on CSCL began in late eighty of 20th century and it soon became the main research stream in the field of learning technology (Dillenbourg & Fischer, 2007). For almost two decades, individualization is the major principles that dominating the computer-based instruction until Dickson and Vereen (1983) empirically discovered that share a computer between two students can be more effective than a single student using computer alone in term of learning outcome. This 'unexpected' effect rises from the additional element of social interaction. Based on the early research on collaborative learning, researchers started to question how computer system should be designed in a way that best facilitate collaborative learning. As a result, CSCL emerged as the new research field that attracted researchers from both education and technological communities. Nowadays, it has been evolved into a multidisciplinary research fields consisting of learning, anthropology, psychology, communication, sociology, cognitive science, media and informatics (Jones, Dirckinck-Holmfeld, & Lindtröm, 2005).

1.3.2 Collaborative Learning

Collaborative learning process is central to this research project as the topic being discussed in this dissertation concerns on how the technology could mediate normal face-to-face collaborative learning and enhance its effectiveness. The study concerned the outcome observed from the mediated collaborative learning process. As a result, it was worthwhile to review the theories and approaches governing collaborative learning based in the past researches as well as their research methods. With the understanding on how collaboration can be made more effective, technologies can be applied in the way that better facilitate the learning process. This section started with the explanation on the nature of differences between collaborative and cooperative task and its implications in order to distinguish the type of collaboration we have concerned. Secondly, the research path of collaborative learning has also been briefly introduced here. It involves major approaches proposed and research methods as efforts to explain the underlying mechanism of cognitive development over collaborative learning process. Moreover, some investigations on conditions of fostering effective collaborative learning have also been presented.

First of all, collaborative learning is conceptually different from cooperative learning. The difference lies on the nature of the task division. Cooperation means the parallel distribution of works and each individual works independently on certain part of problem (Dillenbourg, Baker, Blaye, & O'Malley, 1996). Technically, individual does not need to communicate during the process. Moreover, collaboration that we were studying refers to "... mutual engagement of participants in a coordinated effort to solve the problem together." (Roschelle & Teasley, 1991). As a result, coordinated effort (i.e. collaborative mental effort) is expected from each participant in collaborative problem solving. In this

research work, we concerned on collaborative learning in which each participant make effort to construct shared knowledge (Dillenbourg & Fischer, 2007).

As a short overview, early research works on collaborative learning aimed to develop theories explaining how individual functions in the group. Such investigations reflect the dominant research trend over 1970 to early 1980 in the area of cognitive psychology and artificial intelligent. At that time, social interaction was merely viewed as the background but not the core focus of research on individual cognitive development. In other words, this essentially means individuals can be treated as single cognitive systems and collaborative process is considered as the information exchanges between multiple cognitive systems. In recent years, researchers have started to focus on the group itself. More specifically, they started to pay more attentions onto investigations of social interaction as processors for cognitive development (Dillenbourg, Baker, Blaye, & O'Malley, 1996).

Three approaches have been surveyed to explain the underlying mechanism of collaborative learning. Socio-constructivist approach (Doise & Mugny, 1984) (a.k.a Socio-cognitive approach) concerns the role of inter-action towards individual cognitive development. This development is the result of “a spiral of causality” in which individual development and social interaction are considered as the mutual causal factor of each other. This mediating process is called “socio-cognitive conflict”. It arises from difference among individual based on their different centrations. Differences are believed to generate impetus for resolving conflicts. A “decentred” solution could be finally derived by transcending various centrations. Apart from that, socio-culture approach is also a major approach. It was proposed by Vygotsky (Vygotsky, L. S, 1962), (Vygotsky, L. S, 1978). Distinguishes itself from socio-constructivist approach, this approach focuses on “causal

relationship between social interaction and individual cognitive change” (Dillenbourg, Baker, Blaye, & O'Malley, 1996). In Vygotsky's point of view, individual development occurred inter-psychologically (between/among multiple individuals) first and then intrapsychologically (oneself). Social speech is linked to individual's inner speech through interpsychological process and the phenomenon is termed internalization. Moreover, third approach is called “shared cognition approach”. It focuses more on the social aspect of collaboration while two previous approaches concerns inter-individual domain. Group is considered as a single cognitive system to be analyzed. As an example, explanations are not viewed as something one person delivered to another person but jointly created by both partners for the purpose of understanding each other (Baker, 1991) and this leads to the cognitive improvement (Webb, 1991).

These approaches also differ in their research methods. Socio-cognitive observes the outcome from collaboration while the process of collaboration is not the major concern. Different control groups are assigned to perform collaborative task and the outcome from each case is collected and studied. On the other hand, two other approaches, namely socio-culture and shared cognition, tend to analyze the social interaction during the collaboration because of their focus on mediation effect of social interaction (Dillenbourg, Baker, Blaye, & O'Malley, 1996). At this time, it is worthwhile to point out that Dillenbourg (1996) did not prioritize any one of the viewpoints so it is open to researchers that what approaches they can choose to adopt.

On the other hand, apart from the theoretical explanation telling us about how collaborative could mediate the learning process, it is necessary to point out that not all collaborations are generating positive effect unconditionally. Collaborative activities itself

are neither effective nor non-effective. It is only concluded that collaboration is effective under certain specific conditions and the aim of most research activities on collaborative learning is to investigate those conditions so that we could formulate guidelines for designing an optimal collaborative working environment that foster better learning outcomes. Over years, researchers have been studying these conditions experimentally with various variables that may influence the effect of collaborative learning. Variables that have been concerned include group's composition, feature of task, context of collaboration and medium available for communication.

Group composition consists of number of group member, individual's prerequisite as well as gender difference. For instance, empirical evidences show that pairing of individuals achieves optimal outcome rather than formation of larger groups because individual starts to be competitive in a larger group while being most cooperative in a one to one collaboration (Trowbridge, 1987). Individual prerequisites refer to the personal cognitive level that could influence collaborative process. Relevant studies have investigated the kind of skills learners should acquire to benefit from collaborative learning process. In general, it is expected that learners have the ability to decentre from one's own perspective and have the sufficient communication skill to "sustain discussion of alternative hypothesis" (Dillenbourg, Baker, Blaye, & O'Malley, 1996).

Task features means the nature of certain tasks could influence results because some tasks are "distributed in nature" whereas other tasks do not. This is because the mental processes involve in those tasks are hard to be verbalized and communicated to the partners. Researchers have shown that these independent variables affect learning outcomes in a complex manner.

As a conclusion, collaborative learning is neither effective nor ineffective by nature collaboration. Researchers studied the conditions where collaborative learning could function effectively. They had also tried to explain several causal mechanisms that theoretically explain the mediating process. In consideration of the time constraints and author's background knowledge, this study only focused on the outcomes of collaboration process mediated by AR simulation. Thus, socio-cognitive approach was adopted as the background theoretical framework and research methods were used accordingly. Group composition was decided to be two people in a group for an optimal performance to prevent individual from being competitive in a larger group. Learning task is discussion-based in natural so that communications need to be promoted during the process.

1.3.3 Computer technology & simulation in collaborative learning

Computer and multimedia technology has exhibited several advantages in mediating collaborative learning process. In a computer-supported environment, experimenters can design the collaborative process such that some aspects of the collaboration could be explicitly controlled to support the type of interaction that is expected to promote learning (Dillenbourg, Baker, Blaye, & O'Malley, 1996). Researchers have shown that rather than external representations (Roschelle & Teasley, 1991), it is the intrinsic effort that individual made to understand his/her partner that drives the interaction activity and in turn leads to cognitive change. So the questions remain to answer are for example how to involve student in a scenario in which he/her can be motivated to be engaged in collaborative learning? Which technology could we use to facilitate their interest? What kind of learning tasks are supported by the technology can effectively engage students?

Computer simulation means using computer program to simulate models based on certain pre-defined rules. For example, computer could simulate the scenario in physical world governed by the laws of physics. Experiment (Jimoyiannis & Komis, 2001) had shown that computer simulations helped students significantly in research based physics problems and eventually led them to obtain greater learning achievement than traditional instruction. Jimotiannis and Komis (2001) stated that “computer simulation provide a bridge between students’ prior knowledge and the learning of new physical concept and help them developing scientific understanding through an active reformulation of their misconception”. And according to their work, there were several learning advantages that technology of computer simulation possesses:

1. Students can apply their hypothesis and test it with immediate feedback from computer simulation
2. Computer simulation provide student with the interface such that student can isolate and manipulate parameters to construct knowledge of the relationships between physical concept, variable and phenomena
3. Usage of various representations like pictures, animations, graphs , vectors and numerical data as the tools to enhance students’ understanding of the concept, relations and processes
4. Present physical phenomena that are difficult to present in a classroom because they may be complex, money consuming, dangerous, technically impractical and so on

It is certain that multimedia technology in computer simulation could enhance learning by enabling interaction and visual reference but it is not sufficient under some

circumstances. On the one hand, multimedia technology enables learners to receive instruction beyond textual information and enable multisensory education through audio, video, image, animation and so on and these generated “highly memorable and illustrative concept” (Crosby & Iding, 1997). The potential and advantage of multimedia based education has been demonstrated by numerous existing instructional applications. On the other hand, its limitation has also been revealed. Panayiotopoulos and S. Vosinakis (2000) have noted that classic multimedia technology is good for applications that require simple visual reference. It is insufficient for advanced topics such as geometry, geography, chemistry, biology and physics. In order to support user interaction, software application requires much richer visual information presentation so that 3D representations are needed. Secondly, classic multimedia technology could merely provide learner with a third person’s view of the problem where user is not actively involved as part of the simulation system because the interaction mode is restricted to 2D only (mouse and keyboard). A passive role could easily deter users from getting involved into the simulation and achieving the learning target (Panayiotopoulos & S. Vosinakis, 2000). This leads to the engaging of the technology of virtual reality (VR) in educational applications.

In summary, employment of computer simulation was empirically verified as an effective approach for delivering representation of the phenomena of physics that students are learning because it offered learners a multimedia environment to construct knowledge and receiving feedbacks. However, classic 2D multimedia applications could not satisfy the required level of visual representation. Since then the technology of virtual reality came into the picture of educational applications.

1.3.4 Mixed Reality and Education

Technology of VR possessed the characteristic of immersion, direct user engagement, richer visual feedback and interactivity (Roussou, Gillingham, & Moher, 1998) (Zeltzer, 1992) (Witmer & Singer, 1998). The technology is able to engage its users as part of the active system. Learners are able to navigate the 3D world and interact with the virtual objects. This offers learning experience that classic multimedia technology is not possible to achieve. Moreover, object presented in 3D environment were presented much more accurate than in 2D representation so that user could observe the world from different view point (Panayiotopoulos & S. Vosinakis, 2000). This kind of immersion could foster highly memorable concept and learning interest at the same time.

As we all known, collaboration is an important aspect in CSCL. It refers to exchanging of ideas among collaborators. Achieving effective social interaction is an important objective for collaborative educational applications. It is not hard to see that, immersive VR technology can hardly promote natural social interaction because users are not able to see each other in reality. In the case where users are co-located, it is a powerful educational scenario for them to collaborate in virtual space using natural means of communication. On the other hand, AR not only shared most key characteristic of VR such as richer visual representation, engagement and interactivity, but also allow user to interact naturally (e.g. Face-to-face). Another argument on psychological issue about immersive VR was “In immersive VR, their view is locked but AR allows them to keep control and see the real world around them” (Kaufmann, 2003). This told us that some learners preferred to stay connected to real world while performing learning task. Based on the review, it was interesting to observe how AR can effectively functioning as the mean to socially foster

better collaborative learning process especially comparing to the similar collaboration on classic 2D multimedia technology given the powerfulness on characteristic of VR in offering richer learning experience and the natural way of social interaction.

1.3.5 Communications on Collaborative Process

Based on the discussion, it is also important to select mean of communication during the collaborative process. Recent developments in technology enabled remote collaboration through text messaging, audio communication, audio-video synchronized communication and so on. How should we design our AR support environment is a critical issue. The process of communication could be either face-to-face based or communicate over network (e.g. text messaging, audio, video). Generally, it depends on the types of collaborative task.

High bandwidth communication (e.g. face-to-face, video audio based communication) was good for generating more interaction such that learners could collaborate closely. On the other hand, low bandwidth communication (e.g. text messaging, e-mail, forum discussion) in some way exerted pressure onto participating individual so that he/she was forced to think more carefully for each interaction. Generally, high bandwidth communication such as face-to-face communication was more efficient for tasks involving discussion in nature (Dillenbourg, Baker, Blaye, & O'Malley, 1996). The collaborative task (introduced in chapter two) in our experiment requires extensive discussion and collaborative research. Full bandwidth of communication is necessary to fulfill the need of idea exchanging from both parties. This led to the decision of using face-to-face communication to engage participants into discussion during the collaborative learning process because the research question in the study is discussion-based. Furthermore, PC based collaborative environment limits the way learners could perform collaborative

learning and their thinking. In order to give them more physical space in performing their task (e.g. they could take note on paper and wrote down their research thinking), the client software was ported to mobile phones so that they were given the freedom to use the AR service any time during the process.

Chapter 2 Research Questions & Methods

2.1 Research Question & Objectives

From literature reviews in chapter one, it was known that collaborative learning was not by itself effective in enhancing learning outcome. It depends on various conditions like group's composition, feature of task, context of collaboration and medium available for communication, etc. It was demonstrated that computer technology could effectively enhance collaborative learning on the topics of physics subject, but classic multimedia technology has its limitation in visual presentation and so on. AR technology shares a few key characteristic of VR technology and also allows natural way of maximum bandwidth communication easily. In consideration of this, it is used as the media to deliver physics simulation. It is the interest of this research to study if AR mediated collaboration is more effective a 2D multimedia technology mediated collaboration. Moreover, they are compared with traditional face-to-face collaboration as well to assess the effectiveness of technology mediated collaborative learning.

In this research, we aimed to answer above questions examining how AR technology could mediate face-to-face collaborative learning by applying AR as an intervention to traditional face-to-face collaborative process. More specifically, the intervention from AR is to augment the reality with virtual physical experiments as a shared workspace for collaborative learning and our objective is to measure the meditative effect of this intervention. As the first step, we chose to apply maximum communication bandwidth (i.e. Face-to-face collaboration) so that participants can communicate in full bandwidth. Through

pre-test, post-test and questionnaire, their learning outcomes and experiences were captured. The objective of the user experiment is to measure the following learning effects:

- a) **Objective learning effectiveness** → the improvement of learner's knowledge on selected topic objectively. This told us how AR could enhance learning outcome from an objective and non-biased perspective.
- b) **Motivational Effect** → to assess each learner's feedback on how they felt they had learnt on the selected topic and if the system could bring them more learning interest. This reports the motivational effect that AR system would bring into the collaborative learning process.
- c) **Usability** → the purpose of usability measurement is to bring some food of thought to the future interaction design on mobile AR system. With the feedback about the usability issues, it could be served as reference for future mobile AR application interface design.

In this study, mobile phones (HTC Nexus one) supported by server is used as the media to deliver AR experience and assist face-to-face collaborative learning. One consideration is that in order to give learner more physical space to collaborate. In addition, implementing client software on mobile platform gives more freedom for learner to choose when to use the system and how much time they want to spend on using the system. Moreover, it also serves as a demonstration of the concept of semi-ubiquitous architecture introduced later in chapter three.

2.2 Research Methods

2.2.1 Research Overview

As mentioned, the social-cognitive approach has been adopted as theoretical framework and its research method assesses the outcome of AR mediated collaborative learning without going deep into the analysis of mediation process. Thus our research findings were collected from the pre, post-experiment test (J.Pratt, 2002) and questionnaire. The user study has been conducted with sixty undergraduate students from Communications & New Media Programme, faculty of arts and social science, National University of Singapore. There were 16 males and 44 females (aged 21 to 27, $M=21.98$, $SD=1.36$) in the participants' population. The topic on 'elastic collision' was selected for the studies as this topic appeared in the physics textbooks of junior colleges from Singapore. The criterion of selecting participant was that he/she must have taken physics as a subject in his/her secondary school education but have not taken it in his/her junior college or polytechnic education. This was to ensure they have the fundamental knowledge in conducting collaborative learning and on the other hand do not possess pre-knowledge on the selected topic. Pairs of students (Fig 11) were randomly selected to do one of the three types of collaborative tasks: paper based, 2D technology supported and AR supported collaborative learning.



Figure 11 Collaborative learning between pair of students

2.2.2 Three Conditions of Collaborative Learning

a) Paper based collaborative learning

Paper-based collaboration (see Figure 12) refers to the scenarios that students were given the discussion question with pens and papers and they have to engage in learning with the help of collaboratively drawing and writing diagrams and information that they have find out in order to deduce solutions (i.e. they engaged in a traditional collaborative learning process).



Figure 12 Students engaging in paper based collaborative learning

b) 2D technology supported collaborative learning

For 2D technology supported groups, pairs of students were allowed to use 2D application on mobile phones as the additional assistance in the collaborative learning process. Two students must use the system simultaneously in the collaborative session. As a result, they watched the simulation at the same time (see figure 13).



Figure 13 Students engaging in 2D-supported collaborative learning

c) AR supported collaborative learning

Whole experiment setup of AR supported groups was identical to 2D technology based collaborative learning except they were allowed to use collaborative AR application on mobile systems (in instead of 2D tools on mobile phone) this time. The group was also given a paper marker as they need to face the phone camera towards the pattern on that marker (entire pattern must be captured by camera in order to be recognized) in order to start the virtual 3D simulation (Fig 14).



Figure 14 students engaging in AR technology supported collaborative learning

2.2.3 Experiment Procedures

Sixty students (pair of students assigned as one group, 30 groups in total) were randomly assigned to 3 conditions. That was, 10 groups of paper based, 10 groups of 2D technology supported and 10 groups of AR supported collaborative tasks.

For each group, experiment procedures are summarized as follow

- a) Two students were required to read a set of instructional material for 15 minutes (see instructional material at appendix A)
 - b) They were required to take a pre-test to assess their knowledge on elastic collision (pre-test question at appendix B)
 - c) Given a discussion task on elastic collision (discussion question at Appendix C), they were required to collaborate with each other. Depends on the conditions, each group was allowed to access different assistance tools as abovementioned.
- For the 2D technology and AR supported group, they were free to choose to use

the system assigned to them at any time during the discussion process. The discussion process lasted until they reached a solution and both agree on it.

- d) After submitted the discussion summary, they were required to complete a post-test to assess their knowledge on elastic collision. (post-test question at appendix)
- e) Finally, they were asked to complete a questionnaire for us to capture their learning experience. (questionnaire at appendix E)

2.2.4 Discussion Question, AR supported & 2D technology supported system

In the discussion task, pairs of students were given the scenario briefly as: there are two cubes A and B, A is moving and the B is stationary. Assuming elastic collision, different kind of subsequence motion can happen under different pre-condition. The pre-condition were: mass and velocity of A, mass of B (since B is always stationary). Objective of collaborative learning task was for students to deduce which kind of pre-conditions leads to which kind of subsequence motions and to explain the reasons of their prediction (Please refer to discussion question in Appendix C for detail). For 2D multimedia technology supported and AR supported group, students were able to input required mass and velocity into the system, run and observe the simulation together.

Instructional material provided fundamental knowledge students needed to conduct research on the topic of elastic collision. For head-on collision, total momentum and energy of the system are conserved. Elastic collision is a type of head-on collision in which total kinetic energy is conserved within the system so that no internal energy is converted to

heat. This means there must not be friction and impact energy loss (the energy lost from friction and impact are transformed to heat). It is certain that such collision is impossible to be reproduced in real world at a junior college physics class. However, computer program could easily simulate the scenario so that students only need to turn off the effect of friction and impact energy loss without much effort from the user interface provided. Different from 2D multimedia technology, AR went further to bring simulation into real world. Figures below (Fig. 15, 16) shown the picture taken from the 2D flash simulation system and AR system during the simulation of elastic collision. Both systems simulated the scenarios presented in discussion task. Numerical values of several physics attributes were displayed on the top side to help student with their research tasks.

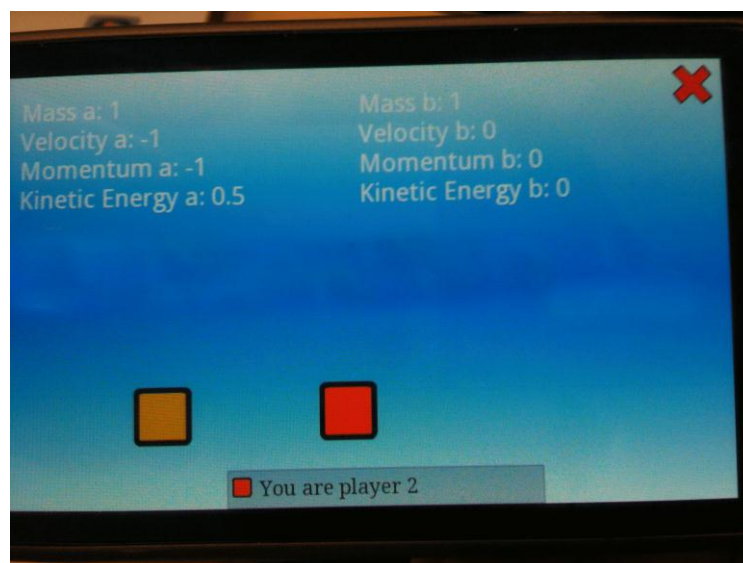


Figure 15 2D flash simulation of elastic collision

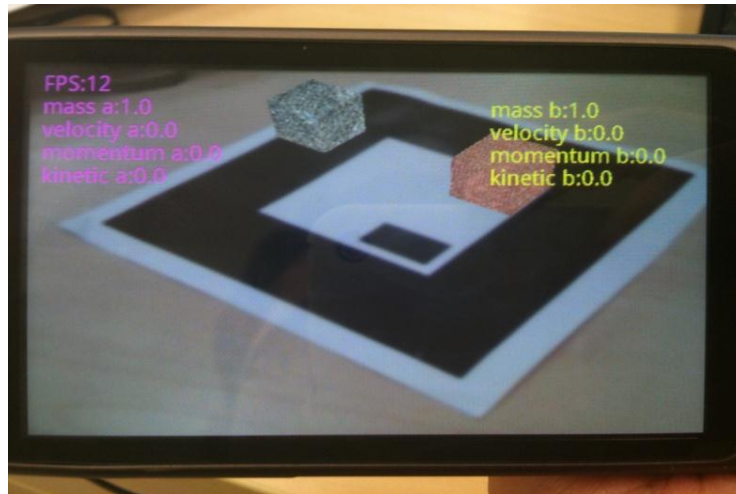


Figure 16 AR simulation of elastic collision

2.2.5 Measurements

As briefly introduced in 2.1, three aspects of the mediating effect was measured from AR system, namely objective learning effectiveness, motivational effect and usability. Objective learning effectiveness refers to the objective knowledge gain throughout the collaborative learning process. It was measured by the change of scores in a pre-test post-test design (Lai, Lai, Chen, Ho, & Ho, 2007), (Pretest -posttest Desgins, 2009). There were easier and harder questions in pre-test and post-test so that the points of each question varies depending on its difficulty level. In pre-test questions, answers to question 1 and 4 could be directly found from the instructional material, thus they each worth 2 points. Question 2 and 3 involved some analysis and thinking process so that each worth 3 points. Similarly, it was same for post-test (the point for each question is marked in red next to the question in appendix). With the questions assessing participants' knowledge in different level, changes in pre-and post-test scores could give us a fair measurement on objective learning outcome (i.e. knowledge acquired during the process). On the other hand, it had

also been pointed out that measuring test scores as the mean to assess objective effectiveness is not adequate in reflecting the overall quality of learning especially for the learning experience (Neumann & Finaly-Neumann, 1989). In view of this, it was suggested (Hiltz, Coppola, Rotter, Turoff, & Benbunan-Fich, 2000) the inclusion of measurements on subjective learning effectiveness (i.e. motivational effect as mentioned), which refers to how learners perceive the knowledge that they have acquired during the learning process (Hui, Hu, Clark, Tam, & Milton, 2008), could assess learning quality more thoroughly. Subjective learning effectiveness was designed to be captured by a questionnaire after post-test. The measurement scale was adapted from (Alavi, 1994) and modified for the context of this research. It included perceived skill development, self-reported learning, learning interest and group evaluation. All items were assessed using five-point Likert-type scale. Table 1 below had shown the intended measurement for each question from the questionnaire.

Table 1 Intended Measurements from Questionnaire

Question	Measurement
1	Perceived Skill Development
2	Self-reported Learning
3	Learning Interest
4	Group Evaluation
5	Usability

Apart from that, as a recent booming area, there were very few case studies on usability issues in existing mobile AR collaborative systems and a standardization of usability measurement did not exist yet. Therefore, it was worthwhile for us to assess the usability as

an effort to measure the overall user experience and the possible rooms for improvements. Some previous usability studies (Kaufmann & Dünser, 2007) on collaborative AR system (non-mobile) gave us some food of thought on the contents of measurement. For example, attributes like learnability, satisfaction, interface, pleasant to use, error frequency and knowledge suitability was used mainly to assess the overall experience of using AR educational application. In addition, besides concerning user's technical and educational affordance which had been covered in the abovementioned attributes, it was pointed out (Kirschner & Kreijns, 2006) that social affordance (see Fig 17) for collaboration was also necessary to be assessed. In view of this, measurement of discussion suitability and ease of discussion were also added.

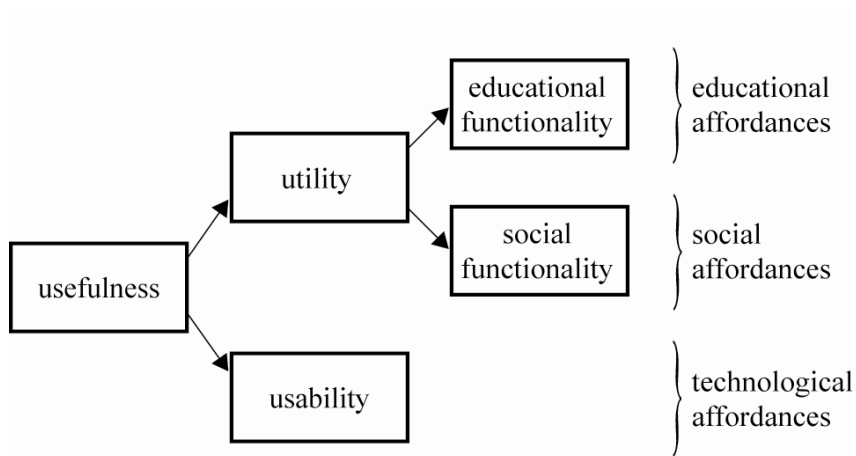


Figure 17 Three Affordances for User Experience

(Kirschner & Kreijns, 2006)

Each question in question 5 of the questionnaire was designed to assess a different aspect of user experience as listed in table 2.

Table 2 Assessment of Usability for Learning Experience

Questions	Assessment
5(1)	Ease of learning
5(2)	Ease of use
5(3)	Error frequency
5(4)	Interface/menu
5(5)	Knowledge suitability
5(6)	Discussion suitability
5(7)	Ease of discussion
5(8)	Pleasant to use
5(9)	Overall satisfaction

Last but not least, Question 6 and 7 were open-ended question to gather users' overall feedback on the experience in using AR system. They were designed to gather information primarily from users' perspective about how could possibly better improve the system in order to foster better collaborative learning in the future.

Chapter 3 AR & 2D Software system

3.1 Overview of AR System

The prototype “AR physics” was introduced in Chapter 2. In this chapter, attention would be drawn insight into the technologies that enables “AR physics” as well as our design consideration.

The AR system is essentially a combination of software and hardware system. Typical AR system consist of camera, computer, display devices such as HMD, LCD, operating software and so on depending on the context of the AR application. Apart from that, software system makes up the major part of AR system. Wagner & Schmalstieg (2003) summarized the whole computational procedure of vision-based AR into five sequential steps. They are “frame capture from camera”, “tracking”, “application”, “rendering” and “display”.

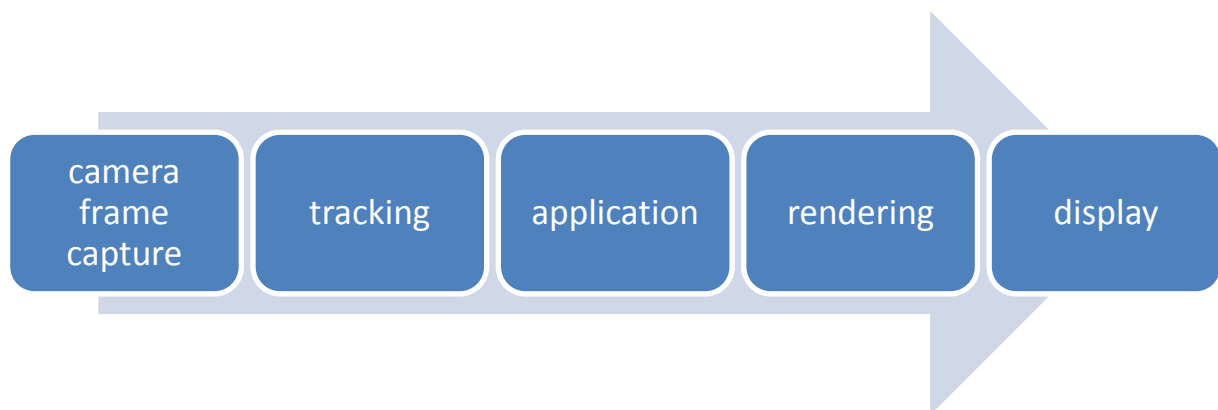


Figure 18 AR system flow

As shown in Figure 18, the entire procedure of AR application starts from image acquisition in which camera captured an image, apply the necessary image processing technique and pass the result to tracker program. The role of tracker is to identify the information presented in the image (e.g. a fiducial marker, a natural feature) and estimate

the camera pose according to the information detected. After the features' location and relative pose with camera has been estimated, the virtual imagery is updated (for a new simulation cycle) and been rendered on top of the real scene. Depending on the device, display technology varies. For example, for PC-based AR applications, programmer can choose to use popular rendering application programmer interface (API) such as OpenGL or DirectX to render the virtual image. In a smart phone or PDA, a lightweight version of OpenGL (i.e. OpenGL ES) API is usually available for graphic rendering.

Since our AR system belongs to the category of vision-based tracking, a brief introduction to vision-base tracking is given here. Vision-based tracking procedure (Fig 19) is essentially a series of computer vision processing on each and every video frame captured by camera. Image thresholding processing facilitates the detection of rectangular region by segmenting the regions of interest from which we can extract the potion where markers appear in the frame. Sub-sequentially, based on the extracted region, pose and position of the paper marker with respect to the camera can be estimated mathematically (i.e. the parameter of the line equations can be estimated from line fitting, plane equation can be deduced from line equations, then the normal on the plane can be calculated) and translated to a transformation matrix. Finally, graphical library (e.g. OpenGL) could use the transformation matrix to transform and render the virtual imagery in top of the real imagery.

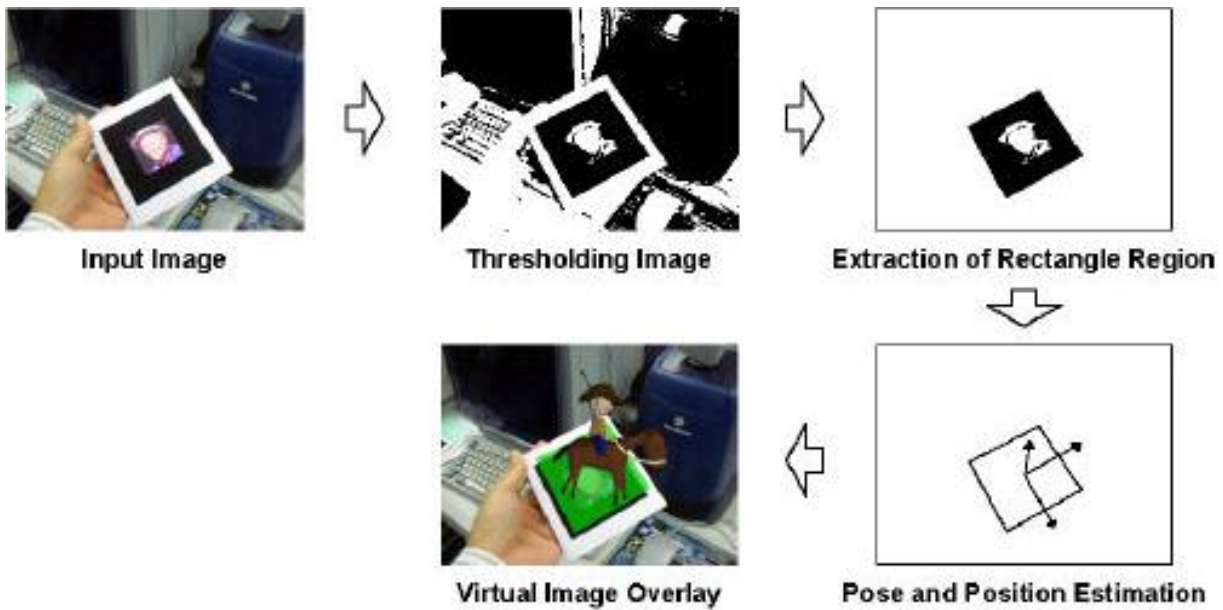


Figure 19 Vision-based AR Tracking Process

(Kato H. , Billinghamurst, Poupyrev, Imamoto, & Tachibana, 2000)

3.2 Server-based mobile augmented reality

In this section, description of our AR software systems was given. Generally speaking, our AR application is a server-based semi-mobile AR solution according to the design consideration in making 'AR physic' a more handily tool for collaborator so that they can choose to use it anytime comparing to a PC based solution. We chose to rely on the power of a server to assist mobile client handling computationally intensive tasks like tracking and application simulation. Although after ARToolkit been ported to iPhone OS and gives good performance (up to 15 fps), the performance in android platform is not catching up closely for some reasons. AndAR (AndAR - Android Augmented Reality, 2010) is an effort from human interface technology laboratory, New Zealand (HIT Lab NZ) to port the ARToolkit to android platform. Our testing found that its performance is about 5-6 fps in Google Nexus one (android 2.3) phone. As a conclusion, workload of AR processing at mobile client is relatively computational expensive with respect to the processing power the

Nexus one phone possess. One possible solution to improve its performance is to offload certain expensive tasks to server. Four different kinds of possible client-server architectures have been proposed previously (Wagner & Schmalstieg, 2003) (in Fig 20) and they are essentially different combination of task allocation between mobile client and the server.

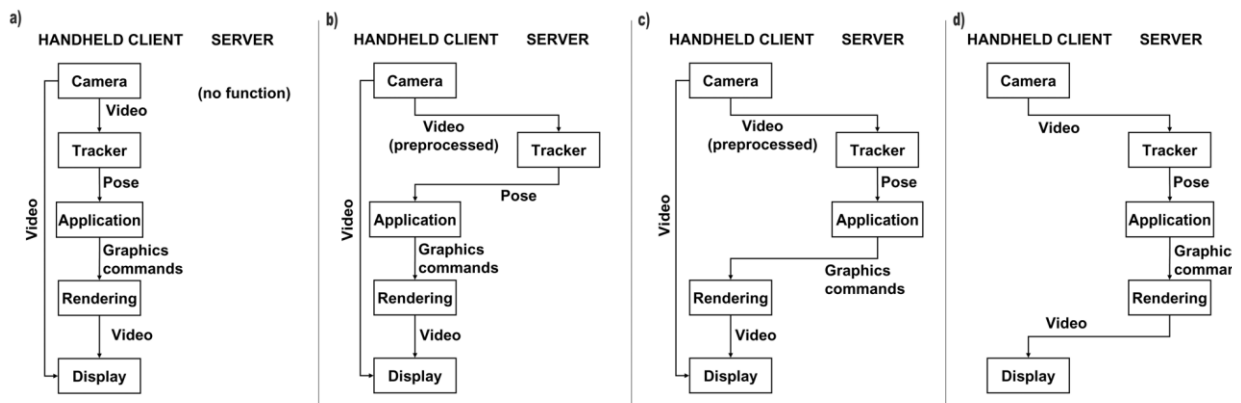


Figure 20 Client-Server Interaction Type

(Wagner & Schmalstieg, 2003)

As Wagner & Schmalstieg have stated, case (a) and case (b) are extreme solutions. Case (a) is the ideal case in term of mobility and flexibility. It is most desirable if the mobile device has sufficient computation power to handle the AR processing in high speed. ARToolkit in iPhone have shown its power. However, Android SDK's nature (i.e. SDK is Java wrapped, native code unable to access camera directly) and possibly some other reasons that have not been discovered make android phone underperforming in handling real time AR tasks. On the other hand, case (4) can also be useful in certain scenario (e.g. augmented video broadcasting). But its "video-in/video out" communication structure requires extreme high bandwidth and the kind of high-speed mobile network is not available yet. These two structures have not been widely used yet but certainly barriers can be conquered in future and they can become useful. Case (b) and (c) are in-between solutions. Two structures have

both be designed to offload tracking capability to server. The difference is: case (b) keep the task of application processing in mobile client and case (c) handover this task to server as well. The information replied from server to mobile client is also different based on the structure. For case (b), tracker on server estimates the information about the camera pose and sends it back to mobile client. For case (c), since the application processing is on server, mobile client only need to hear the instruction on graphic rendering. Comparatively, case (c) is better when amendment for application is needed frequently. Wagner & Schmalstieg chose case (b) as they intended to retain the application processing exclusively on mobile client.

3.3 Semi-Ubiquitous Structure

While Wagner & Schmalstieg had chosen case (b) as their design structure, software prototype (Gu, Li, Chang, & Duh, 2011) in this research work favored the third design in order to give the server both capabilities in handling the AR computation and application simulation (e.g. physics simulation) to better facilitate collaboration (actual design architecture in Fig 22). At server side, NyARToolkit (NyARToolkit, ARToolkit Class Library for Java/C#/Andriod) was chosen as the AR processing unit. The procedure starts from mobile clients acquiring, compressing video frames and sending those frames to a dedicated server for further processing. Raw video frame is in YUV420 format, as the chrominance component is not needed for AR processing, U,V layers are dropped before transferring in order to reduce the size of data over the air. The dedicated server receiving Y component (i.e. gray video frames) would decode (i.e. convert each frame to RGB888 format that works for ARToolkit) them for fiducial marker detection, simulate visual environment states (with physic engine) and reply rendering commands to each mobile client that has initiated the AR

service. Upon receiving commands from the server, mobile devices render augmented frames accordingly. The commands are sent continuously from the server, consists of the model-view matrices of two virtual cubes. As a result, it demonstrated the feasibility of developing a server-based collaborative mobile AR application. In fact, by design, we have intended to offer AR collaboration as a networked service (i.e. AR service) targeting to serve mobile clients. Service is provided by a dedicated server that is attached to a Wi-Fi access point (as in Fig 21), which broadcasts service within a relatively small physical area such as in the area of classroom, office, multi-person workspace, etc. It allows mobile devices that are within the network proximity to receive AR service through their Wi-Fi network connection with the server. The concept was motivated by scenarios in which AR services can be offered ubiquitously from neighborhood stores, restaurants and classrooms, functioning as a novel way of delivering advertisement and education. Such design not only supports AR processing in low-powered mobile phones but also facilitates easiness of content upgrading at the server side to support more advanced features (e.g. implementation of more intensive application simulation) without the concern of the heterogeneity of computational capacity among different mobile phones. In the context of education, classroom environment is one of the ideal places to broadcast AR service because it allows students to perform collaborative learning easily.

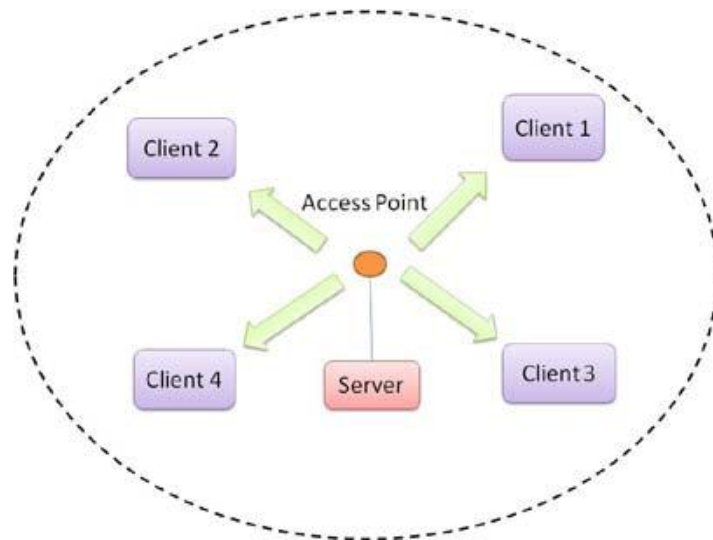


Figure 21 Architecture of AR Service

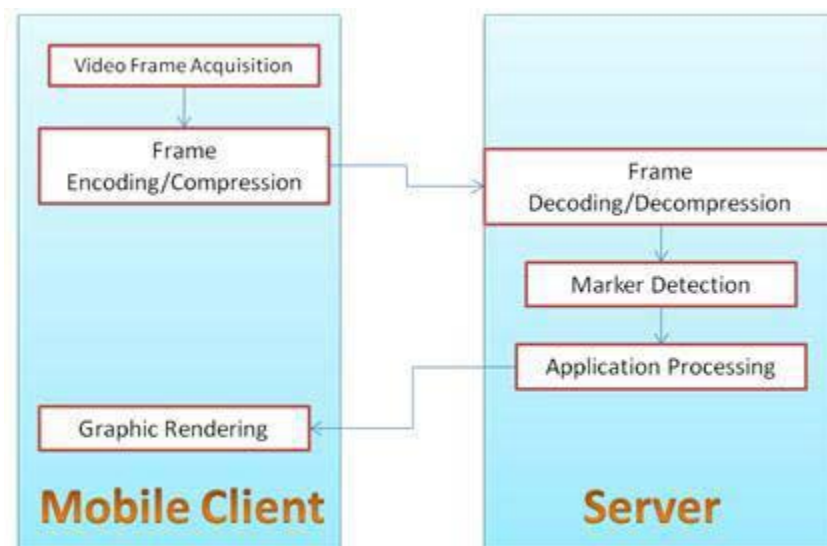


Figure 22 Server-Client Architecture for AR Physics

3.4 Physics Engine

A physics engine has been implemented at server to offer the physical capability to 3D objects in the virtual world. The physics engine constitute a important part of application processing since it is configured to detect rigid body collision and simulate the physical motion in real time. Collision detection is a processing to check the virtual objects in 3d

world to ensure that that “one object does not cut through another and response to the case if it happened” (Tutorial on Collision Detection). As a result, physics engine simulate the real world physics in the 3D virtual world according to the law of physic. Essentially, it constructed a 3d version of computer simulation in physics. Comparing to 2D simulation, real time collision detection in 3d is more expensive in term of computational power required. The technique has been widely applied as an essentially part of 3D gaming. In our design, since the physics engine is situated on server, computational power is assume to be adequate so it cease the worry of limitation of computing power on mobile device. Thus, it could be safely assumed that the processing of physics engine is in real time speed. The rate of physics simulation is then coupled to the rate of frame arrival at server in order to make the game simulation speed adaptive to the variable frame arrival rate at the server side. This is to avoid any inconsistence of game simulation speed that mobile client user can possibly experience in the event of heavy network congestion.

3.5 Server-Client Communication

This section discussed the concept of communication protocols that had been designed and used for client server communication in the implementation of AR physics. Protocol design is critical to communication between a server and users. The software prototype developed in carrying out this project enabled the server to communicate with multiple users simultaneously to perform AR multicasting tasks. In order to support the desired task in the system design, a set of protocols had been designed supporting the communication between the server and users. The following is a brief illustration of the application protocols in our system:

- **Registration & De-registration:**

When mobile clients connect to the server for the first time, their identities are added into database. And when mobile clients terminate the service, their identities are de-registered at the server. Their states change from 'initial' to 'registered' after successfully registered with server (Fig 23).

- **Frame Transfer:**

As AR computation is designed to be processed at the server side. Each mobile client needs to transfer its acquired video frame to the server in real time. In order to reduce the amount of data in the network, captured video frames are compressed into light weight YUV420 format at the mobile client side; whereas on the server side, incoming frames will be decoded into a RGB888 format. (Noted that U, V layers are dropped before sending as they are not needed for tracking process)

- **AR Processing:**

"AR-Sumo" employs NyARToolkit [10] as the tool to detect fiducial marker. This library returns a 4x4 transformation matrix (model view matrix) facilitating OpenGL to draw 3D virtual imagery onto the fiducial marker if it is found. Transformation matrices of the rest of the virtual objects are then the product of multiplication between transformation matrix and the rigid body transformation matrices (e.g. translation and rotation) that derived from the physical simulation.

- **User Input:**

Before the start of the simulation, both users are required to discuss and enter into mobile client the information of mass and velocity to the object that assigned to him/her.

Once he/she finished entering information and pressed the 'OK' button, mobile client generates a command sent to server to report that information. Server then changes the state of the mobile client from 'registered' to 'ready' (Fig 23). As soon as both mobile clients are ready, server starts the physics simulation.

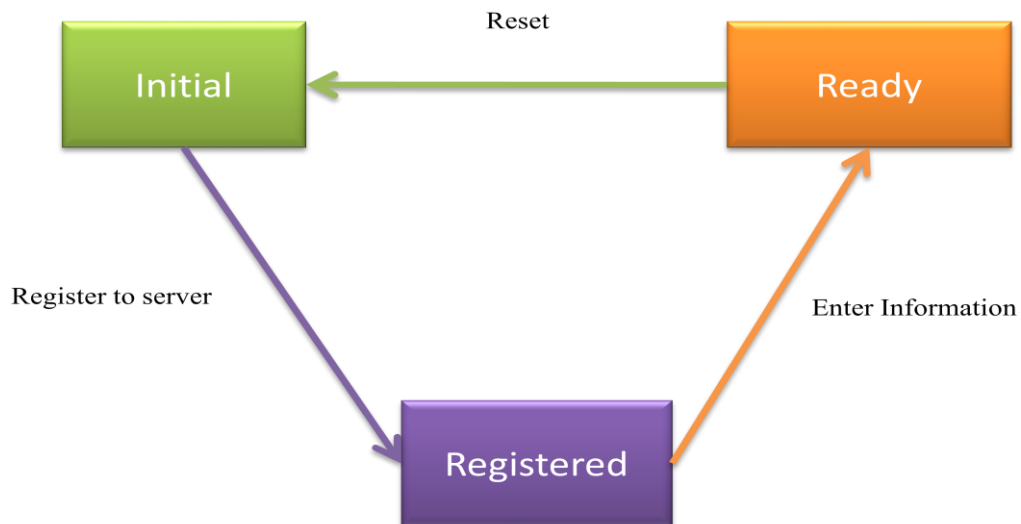


Figure 23 State Diagram of Mobile Client

3.6 2D simulation of Physics

As previously introduced in chapter two, a 2D multimedia tool “flash-based collaborative learning system” on Google Nexus one had also been built to order to provide a 2D multimedia supported collaborative environment. To make it as similar architecture to “AR physic”, a server was also included in our design (in Fig 24) and mobile phones collaborate with each other with the support of the centralized server. The role of server is to retain authorized control on 2D simulation. 2D simulation starts as soon as the software program on the server receives the information that both users have entered in mobile client. Similarly for AR system, both users need to enter the required pre-conditions (i.e.

mass and velocity) into the system and simulation starts as soon as server receive information from both clients.

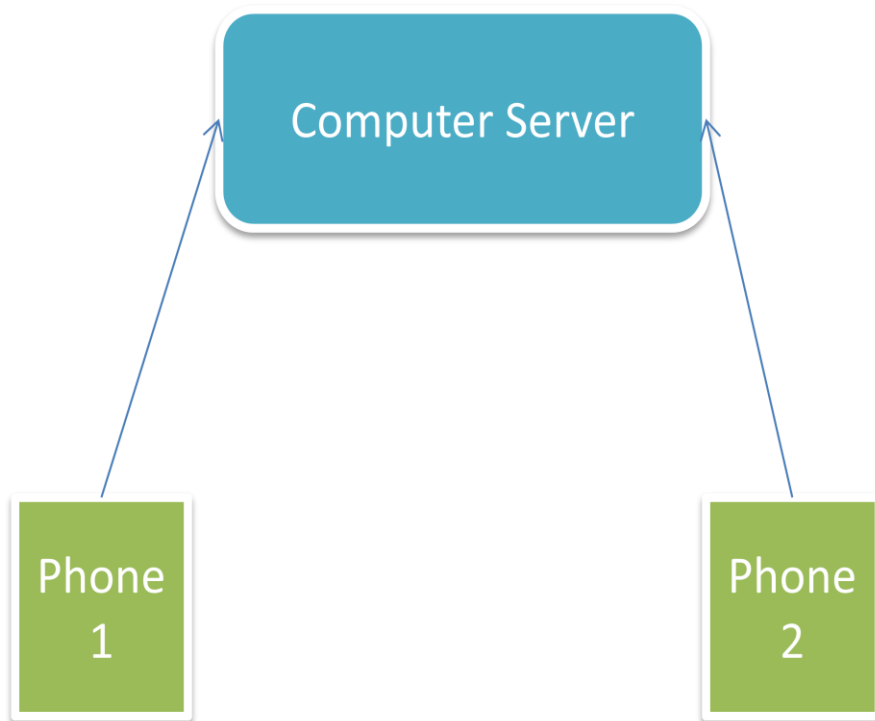


Figure 24 Architecture of 2D based learning system

Chapter 4. Results and Discussion

4.1 Overview

The experiment objectives, tools and procedures had been introduced earlier at chapter two in great detail. This chapter reported the result obtained from data analysis and also discussed how the experimental results empirically answered our research questions raised in chapter two.

4.2 Objective Learning Outcomes

As one of the important measurements, objective learning effectiveness was assessed from a pre-test and post-test setup. Score of pre-test showed a homogenous distributed knowledge level among participants and no significant difference found across three groups. On the other hand, the pre-test to post-test gain revealed significant differences among three conditions (refer to table 3), $F(2,57)= 12.651, p<0.001$. More specifically, the gain from AR-based condition was in general significantly higher than those from other two conditions (i.e. AR>2D>paper, '>' indicating 'significantly higher scoring'). Ignoring the individuals' learning ability, results concluded that the knowledge gain was the largest for AR supported groups. In addition, 2D supported groups reflected much higher knowledge gain as compare to paper based groups. (See table 3). These results empirically answered our research questions leading to the conclusion: mobile AR could better mediate/support face-to-face collaborative learning in terms of greater objective knowledge gain. Moreover, the result on the differences of knowledge gains between 2D supported groups and paper based group reflected the fact from literature in which multisensory information could foster "highly memorable and illustrative concept" as we have mentioned in literature review from chapter one. On the other hand, it also revealed the fact that 'AR

physic' did not overload participants with higher technical affordance than 2D supported group (since participants learnt better with support of AR technology). In other word, they did not over-spend their mental effort on handle the technical usability issue raised from the new technology and could focus on their actual tasks. This issue were empirically tested and would be formally reported in the usability discussion section in this chapter.

Table 3 pre-test and post-test scores

Dependent variable	Paper(SD)	2D(SD)	AR(SD)
Pre-test	4.95(1.761)	4.25(1.916)	4.40(1.698)
Post-test	5.40(1.501)	6.05(2.012)	7.35(1.424)
Post-test to pre-test Gain	0.45(1.468)	1.80(1.576)	2.95(1.669)

4.3 Subjective Learning Quality

As mentioned and explained in Chapter 2, the subjective learning quality was also assessed. The scale reliability was shown in table 4 (generally high). Data shown in Table 5 is measurements of subjective learning quality as an effort to assess the overall learning experience. For perceived skill development, there was a significant difference across three conditions, ($F(2, 57)=12.009$ $p<0.001$). More specifically, the differences between the paper-based condition and the other two conditions were significant. However, no significant difference between the AR-based and the 2D-based conditions was found (i.e. AR=2D>paper, '=' indicates 'not significantly different'). Moreover, there were also significant differences in self-reported learning ($F(2, 57)=18.775$, $p<0.001$) and learning interest ($F(2, 57)=36.343$, $p<0.001$) across all three conditions (AR>2D>paper). Last but not least, significant difference was found in the group learning evaluation across three conditions ($F(2, 57) = 14.324$, $p<0.001$), but impacts from the AR-supported and the 2D-supported simulations were

relatively close (AR=2D>paper). In the following subsection, each measurement was discussed.

4.3.1 Perceived skill development

The measurements assessed the skill increments from learners' perspective. Since 2D and AR supported group did not reflect significant differences from the measurement, it means both 2D and AR technology possess similar mediating effect on personal skill development. In fact, it would be impractical to expect a substantial skill development throughout a one-hour experiment and it was advisable as part of the future work of conducting a long term study (e.g. 3 to 6 months) in order to completely capture the characteristics on the effect of how AR technology could foster better skill development than 2D technology. On the other hand, with the help of these technologies, we could see a trend of stronger skill development with compare to paper based traditional collaborative learning (significant different) (i.e. AR=2D>paper). It again provided the empirical evidence to demonstrate the value of e-learning than traditional learning (this point was mentioned in chapter one as it had been verified empirically from the literatures). This matches the expectation as selected physic topic is ideal to be presented in a computer simulated environment (e.g. AR, 2D) according to Jimotiannis and Komis (2001): (please refer to chapter two).

1. Students could change the mass and velocity of the object and get immediate feedback
2. Student can change manipulate one parameter while keep another constant
3. Visualization of phenomena from AR/2D technology enhanced their memory
4. Elastic collision is impossible to be presented in a classroom environment.

4.3.2 Self-report learning

The assessment focused on subjective knowledge gain while the previous concentrated on subjective skill gain. They were essentially the feedbacks from users on how well they believed they had acquired the concept from the selected topics during the process. For instance, they were asked the question like “do you better understand the phenomena of elastic collision.” Differ than objective knowledge gain, this measurement was subjective from learner’s point of view and it indicated how users thought they had learnt rather than how actually they had learnt. Students in AR supported group felt that they had gained more knowledge than the students in 2D supported group. Furthermore, students in 2D supported group felt that they have learnt better than student in paper-based group. (i.e. AR>2D>paper) Through this observation, it was concluded that AR technology could foster best subjective learning experience comparing to the rest of two. These results also agreed with the objective learning outcome measurement. Thus the conclusion could be arrived safely: students were both objectively and subjectively acquiring more knowledge in the collaborative learning mediated by AR technology.

Table 4 Scale Reliability for Subjective Learning Quality

Perceived learning development	Self-reported learning	Learning interest	Group learning evaluation
0.845	0.906	0.813	0.790

Table 5 Subjective Learning Quality Assessment

Dependent variable	Paper(SD)	2D(SD)	AR(SD)
Perceived skill development	3.34(0.518)	3.98(0.557)	4.01(0.372)
Self-reported learning	3.23(0.593)	3.70(0.430)	4.13(0.330)

Learning interest	2.64(0.613)	3.05(0.614)	4.02(0.278)
Group learning evaluation	3.33(0.518)	3.86(0.412)	4.05(0.379)

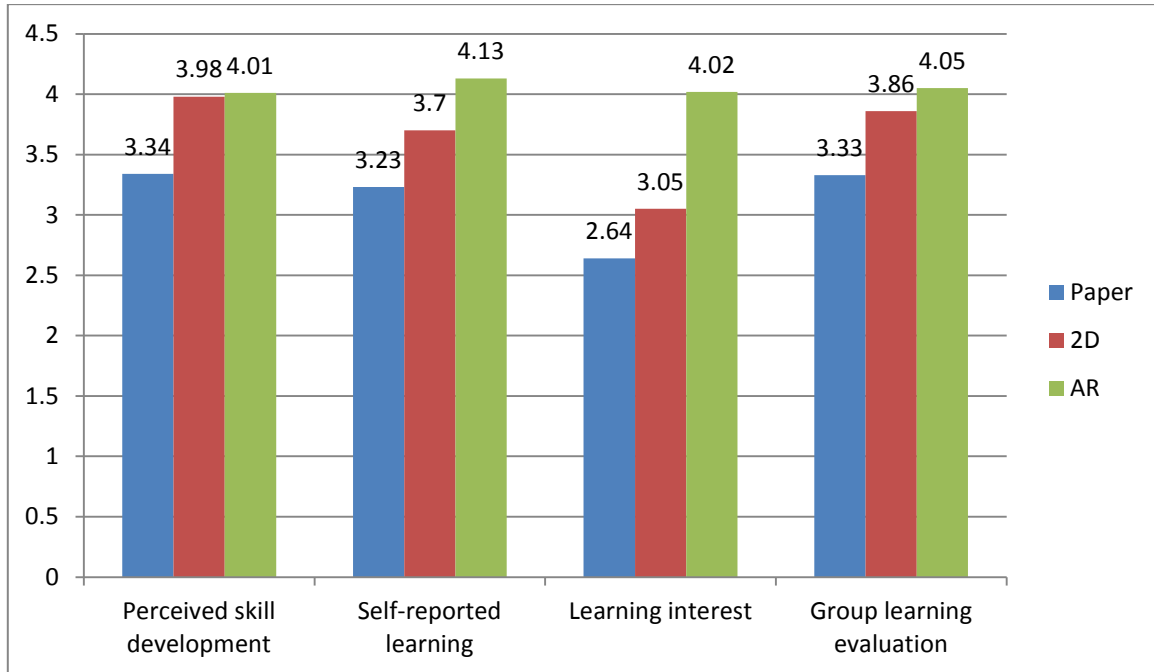


Figure 25 Measurement of subjective learning quality

4.3.3 Learning interest

As titled, this measurement indicated if students had grown more interest on the selected topic they had collaboratively explored. Results indicated a significant growing interest from paper-based, 2D supported to AR supported collaborative learning (i.e. AR>2D>paper). These results from measurements in fact agreed with our earlier assumption in which young students were more open to new technologies which they had not experienced. However, whether this interest was able to sustain for long period still remind as an open question. Further studies may be necessary for us to monitor if this interest could last for long term.

4.3.4 Group learning evaluation

Group learning evaluation refers to participants' opinion on the collaboration process such as how they evaluated the effect of collaborative learning after gone through the collaborative learning process. The difference between AR supported groups and 2D supported groups was not as significant as the difference between either of the two groups and paper-based group (i.e. AR=2D>paper). Thus, we could conclude that both 2D and AR technology could promote better collaboration. Similarly, continuous study was suggested to investigate the long term effect.

4.3 Usability Measurement

For usability assessment, a total of nine usability feedbacks had been captured from questionnaire. They were sorted according to their average scores and represented in figure 25. (Noted: full score for each usability measurement is 5)

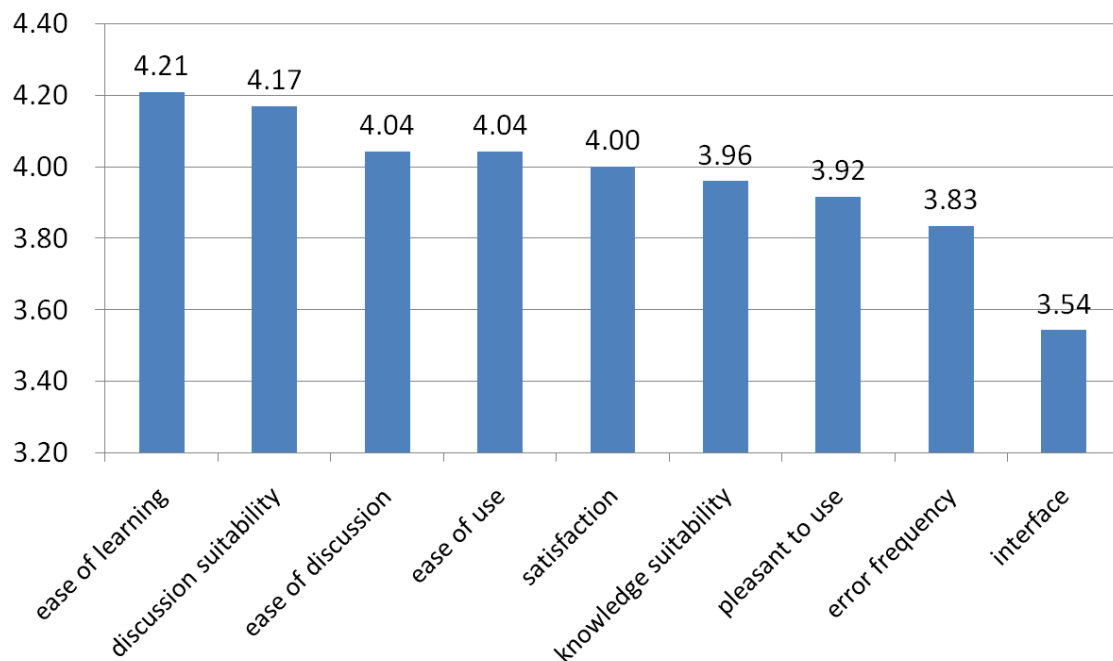


Figure 26 Usability Measurement

The score had reveals the fact that ‘AR physic’ was easy to use and suitable for the topic discussed. Overall usability score was high and users generally felt pleasant while using the AR system. One issue attracted our attention was the score obtained for ‘interface’ appeared to be lower across all items. We did not evaluate the issue further since it is out of the scope of this research work. Nevertheless, it is worthwhile to conduct relevant research or study it as part of the future work in the future.

4.4 Users’ feedback

Question 6 &7 in the questionnaire was designed to gather additional feedback from users’ perspective (only from AR supported groups). Question 6 asked about “What features of augmented reality (AR) technology contribute to the collaborative learning of your group?” General feedbacks from user are summarised in Table 6.

Table 6 General Comments of Question 6 in Questionnaire

No.	Category	Citations from Questionnaire
1	AR & 3D Visualization	It was easy to visualize hence easy to be understood.
		Better visualization of the problem
		The ability to view abstract concepts in a concrete manner
		seeing the graphics move
		The ability to visualize the motion and change of velocity
		The 3D depicts of the scenarios give a better image and understanding on the outcome
		The ability of visualizing the objects and the process which the collision happened
		It helped to apply the theory in the sense that it made the theory a reality.
		The ability to test and learning interest are invaluable to learn such subjects. It is much better to learn a subject like

		this through observation with AR.
		3D technology and software design
2	Computer Simulation	It is able to simulate reality without having to actually do the real thing. It aided us when we were doing the question especially when we don't know the logic well.
		The ability to observe in a controlled environment
		Ability to try out the scenarios on the spot when we have conflicting views or were unsure
		We could always try different times to reach a conclusion.
		We can see the simulation in accordance to the figures that we programmed in the system
		We can manipulate the mass and velocity.
		The chance of using mobile devices to conduct experiment
		The immediate motion that was clear provided effective learning for my group
3	Collaboration	Collaborative learning and being able to control the experiment and test out

From the above comments, it was pretty clear here most participants credit their knowledge development to AR technology where 3D visualization illustrating the knowledge of elastic collision clearer than normal computer simulation. In addition, some of the participants value the knowledge development on the collaborative process.

Last but not least, Question 7 asked about the feeling that users have after experience AR after learning process. Similarly, general feedback was summarized in table 7.

Table 7 General Comments of Question 7 in Questionnaire

No	Category	Citations from Questionnaire
1	Novel & Interesting experience	Interesting, keen to try
		Interesting to observe something new
		Fun, interesting and want to try if there are more other questions

		Quite interesting and it's a new experience
		New. Overall, a great learning experience.
6	User friendly	It is rather easy to operate and quite easy to visualize.
		It was user friendly and easy to use.
		I'm comfortable using AR. It seems useful and easy to pick up.
		Quite easy to use.

As a summary, all participants provided positive feedbacks. Overall, they believed AR gave them a great learning experience. In addition, software prototype "AR physic" developed for this research was easy to use.

Chapter Five. Conclusion and Future Work

5.1 Overview of the research project

As a relatively young technology (over forty years), AR had already exhibited its strength over many fields, from CSCW to entertainment, education, etc. Researches on AR had evolved from pure technological research activity towards more integrative and multidisciplinary investigations. Not only computer scientists, mathematicians and engineers, but also researchers from social science, psychology were also able to contribute their expertise to AR community. Conferences and workshop about mixed reality are increasingly attracting more attentions.

Before system implementation and experimental design, the hypothesis has been proposed in which AR could be a better media than either traditional paper based or 2D supported technology. Where did this confidence come from and what make the researchers in this work believe so and willing to contribute time into this topic? They were those past works on AR in which had been reviewed from literature and also the personal experience with AR project in research laboratory of NUS-KEIO centre. At the time of this research project, there were a number of research projects worldwide on collaborative AR but often came with investment intensive hardware setup. Review from literatures gave convincing facts that mobile AR had a future in both entertainment and educational technology. So instead of working on HMD, backpack configuration or even simply PC based platform, smart phones was chosen for AR delivering tool. Though there were huge limitations like computational capability and interaction method, with the rapid advance in mobile technology and state-of-arts computing power, it was believe that problems were

temporary and would not persist in long term. Also as had mentioned in chapter three, with server's support, it was practical for AR application to be delivered as 'AR service' and been broadcast just like radio broadcasting.

5.2 Difficulties

Difficulties were everywhere along the way. AR was rather a new area to author a year ago. So did the android application development. To build a system prototype effort had been made into the studying of AR Library like ARToolkit, NyARToolkit as well as development toolkit of android 2.2/2.3.

Moreover, self-contained AR (NyARToolkit Android) on android phones shown unsatisfactory performance. Idea of server-supported architecture was proposed at that time to avoid falling into intensive work on performance issue since it was not the main concern and major area of achievement for the project. Thanks to the help from researcher assistants of NUS-KEIO centre, National University of Singapore, author learnt the overall procedure of AR processing that was able to use the AR Library on server successfully.

Last but not least, author was from engineering background in his undergraduate studies and had no prior knowledge in experimental design and behavioural data analysis, not to mention being able to use the statistical tools like SPSS. For this reason, he has read numerous resources online to build up his foundation. On the other hand, his partner Li Nai of this project had offered me great help based on her expertise in communication.

5.3 Future works

Due to the time constraint on the length of the project time, the project was concluded after analysis of users' performance data. In long term, the project definitely

worthies further investigation. First possible future work was to look into the mediating process and study how AR mediates the learning process as this dissertation had concentrated on learning outcomes solely. Thus, it could be interesting to analyze the underlying mechanism in which AR could better mediate collaborative learning process. Secondly, it was also interesting to measure the long term effect on learning effectiveness by observing participants continuously. It was believed that measurement like skill development increment could be more obvious in long period as a one hour experiment was not the ideal approach to assess this. Moreover, the questionnaire assessing usability needs certain level of revision as advised by expert, it will be better to use multiple tests to assess different aspects of usability.

Technically, it was a good idea to further improve the performance of AR application on android platform. For server based architecture, data between server and client further could be reduced by thresholding capture images before they were sent to server. One pixel of the gray image costs 8 bits. A good thresholding could decrease it down to 2 bits and at the mean time retained the necessary detail for marker detection. On the other hand, server-based architecture caused delays in receiving information about the virtual scene. So there was some inconsistency in real/virtual scene registration. One possible solution was that we could choose to render camera image (real world image) at a delayed time to increase the virtual / real world consistency.

Last but not least, gaining some degree of mobility by porting the client software into the mobile phone in the experiment also carries problems. It is well known that all mobile devices have small display and limited input methods. This makes phone-human

interaction difficult comparing to PC environment. It is always a long term objective to make the interaction more intuitive and user friendly.

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Appendix

Appendix section consists of list of testing material, questionnaire, pre and post test question. Reader of this dissertation could refer to those as reference. In addition, list of publication associated with this research works. The publications mainly concentrate on learning technology and AR conference.

Appendix A. Instructional Material

Dynamics

1) What is Dynamics?

Dynamics: deals with the underlying causes of motion

Dynamics is the study of how force and mass affect the motion of bodies.

2) Principle of Dynamics

Newton's Second Law of Motion:

The rate of change of **momentum** of a body is proportional to the **net force** that acts on it, and the momentum change takes place in the direction of the force.

- The linear momentum (p) or simply momentum of a body is the product of its mass and its velocity.

$$p=mv$$

- It is a vector quantity. It has the same direction as the velocity.
- SI base units: $\text{kg} \cdot \text{m/s}$

3) Conservation of momentum

Principle of conservation of momentum:

The total momentum of an isolated system remains constant (or is conserved).

- An **isolated system** is one that is not acted on by any net external force or torque. There is also no transfer of mass into or out of the system.
→ Mass and energy of an isolated system remain constant.
- A force is considered **external** if it is exerted by a body outside the system.
Forces exerted on each other by bodies within the system are internal forces.

4) Collisions

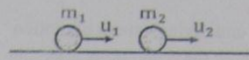
- A collision is a process in which two or more bodies interact and a large impulsive force exerts on them for a relatively short time.
- Hence, we can ignore the small change in the total of momentum of the bodies caused by any external force.
- So for collision problems, we can use the law of conservation of momentum in the form:
"The total momentum of a system of interacting bodies just before collision is equal to that just after collision."

5) Head-on Collision

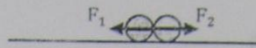
- **What is meant by a head-on collision?**
 - Line of impact passes through the c. g. of both bodies. The velocities of the colliding bodies are collinear (or directed along the same straight line) both before and after impact.
 - Called collision in one-dimension
- **Conservation of momentum in head-on collision problems:**

Consider the head-on collision of 2 bodies of masses m_1 and m_2 moving with velocities u_1 and u_2 before collision, and velocities v_1 and v_2 after collision.

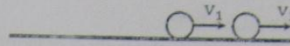
Before collision:



During collision:
Impulsive forces (F_1 & F_2)
act on both bodies



After collision:



Take vectors to the right as positive.

By the principle of conservation of momentum,

Total momentum before collision = Total momentum after collision

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2 \quad \dots\dots (1)$$

We can also rearrange eqn. (1) into:

$$m_1 (u_1 - v_1) = m_2 (v_2 - u_2)$$

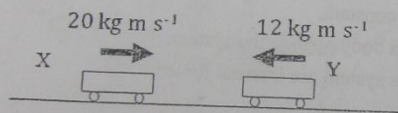
which can be read as:

Loss in momentum of body 1 = Loss in momentum of body 2

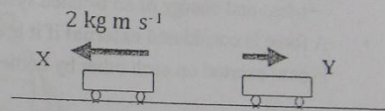
Example (17)

Two trolleys X and Y as shown are about to collide. After collision, they travel in opposite directions and the momentum of X is 2 kg m s^{-1} . What is the magnitude of the momentum of trolley Y? (N88/1/4)

Before collision:



After collision:



Solution:

Take right as positive.

By conservation of momentum,

Total momentum before collision = Total momentum after collision

$$20 + (-12) = (-2) + p$$

$$\Rightarrow p = 10 \text{ kg m s}^{-1}$$

6.3 Type of collisions

(a) Elastic collisions

- Total kinetic energy of the colliding bodies is conserved.
- E.g. collisions between atomic, nuclear and fundamental particles, ideal gas molecules

(b) Inelastic collisions

- Kinetic energy of the colliding bodies is not conserved.
- The kinetic energy is converted to
 - (i) internal energy of the bodies (which is dissipated as heat),
 - (ii) elastic potential energy of deformation and

(iii) other form of energies.

- E.g. The Earth colliding with a meteorite; A ball bouncing on the ground, because in reality balls do not bounce perfectly.

(c) Perfectly or completely inelastic collisions

- The colliding bodies stick together after impact and move with a common velocity.
- Kinetic energy of the colliding bodies is not conserved. The loss of kinetic energy is large but not complete.
- E.g. bullet embedded in a target

(d) Explosions

- Kinetic energy is increased. (super elastic)
- This could occur if potential energy were released by the impact.
- E.g. collision of one trolley with another releases a compressed spring.

In ALL collisions,

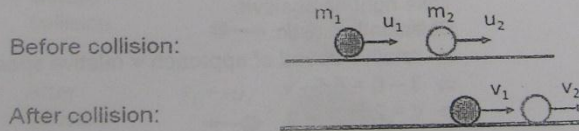
- ✓ Total momentum is conserved.
- ✓ Total energy (kinetic energy plus other forms of energies) is conserved.

Quiz

In the following collisions, what are conserved?

	Elastic	Inelastic	Completely inelastic
total momentum	✓	✓	✓
total kinetic energy	✓		
total energy	✓	✓	✓

7) Head-on, Elastic Collision



For any collision, total momentum is conserved:

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2 \quad \dots\dots (1)$$

For elastic collision \Rightarrow KE is conserved:

$$\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \quad \dots\dots (2)$$

Rearrange (2) :

$$m_1(u_1^2 - v_1^2) = m_2(v_2^2 - u_2^2)$$

$$m_1(u_1 + v_1)(u_1 - v_1) = m_2(v_2 + u_2)(v_2 - u_2) \quad \dots\dots (3)$$

Rearrange (1) :

$$m_1(u_1 - v_1) = m_2(v_2 - u_2) \quad \dots\dots (4)$$

$$(3) + (4): \quad (u_1 + v_1) = (v_2 + u_2) \quad \dots\dots (5)$$

$$u_1 - u_2 = v_2 - v_1 \quad \dots\dots (6)$$

Conclusion: For head-on, elastic collision,

$$\text{relative speed of approach} = \text{relative speed of separation}$$

In summary,

For all collision problems, apply conservation of momentum equation (1):

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

For perfectly elastic collision problems, we apply both equations (1) and (6):

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

$$u_1 - u_2 = v_2 - v_1$$

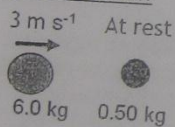
Both equations are vector equations. Hence choose a direction as positive and account for negative velocity where necessary.

Example (18)

A bowling ball of mass 6.0 kg moving with velocity 3.0 m s⁻¹ has a head-on elastic collision with a pin of mass 0.50 kg. The pin moves off with a velocity of 5.5 m s⁻¹. Calculate the velocity of the bowling ball after the collision.

Solution:

Before collision:



Take right as positive.

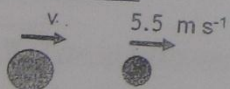
Collision is elastic

⇒ relative speed of approach = relative speed of separation

$$\Rightarrow 3 - 0 = 5.5 - v$$

$$\Rightarrow v = 2.5 \text{ m s}^{-1}$$

After collision:



Bowling ball moves to the right at 2.5 m s⁻¹

Appendix B. Pre-test

Face-to-face Collaborative Learning of Physics

Pre-test Questions

Q1. In which of the following systems are both momentum and kinetic energy conserved? (2 points)

- A. An elastic collision B. A partially elastic collision
C. A totally inelastic collision D. None of the above

Q2. What factor do you think is important in predicting the subsequent motion of the objects after collision? (You may tick more than one option.) (3 points)

- A. Velocity B. Friction C. Mass D. Force E. Weight F. Size G. Others

Q3. Two particles of equal mass undergo an elastic collision. Particle #1 has a speed of 10.0 m/s towards east, and particle #2 is at rest. After the collision, what are the velocities of each particle? (3 points)

- A. 12.0 m/s B. 5.0 m/s C. 10. m/s D. zero E. None of the above

Q4. A valid unit for momentum is which of the following? (2 points)

- A. $\text{kg}\cdot\text{m}/\text{s}^2$ B. kg/m^2 C. $\text{kg}\cdot\text{m}/\text{s}$ D. $\text{N}\cdot\text{m}$

Appendix C. Discussion Question

Discussion Task

Based on your reading material, please discuss the following question as follows in a group:

(1) Under the context that the object B is stationary and the object A moves towards B, how many kinds of subsequent motions can happen after the elastic collision? And how does the relationship between the masses of two objects influence the subsequent motions of the two objects after the elastic collision?

(2) How do you explain the change of motions of the two objects after elastic collision?



Once you reach an agreement, you can submit a group discussion summary.

Appendix D. Post-test

Face-to-face Collaborative Learning of Physics

Post-test Questions

Q1. In the elastic collision, what is conserved? (You may tick more than one option.) (1 point)

A. Total momentum B. Total kinetic energy C. Total energy

Q2. What factor do you think is important in predicting the subsequent motion of the objects after collision? (You may tick more than one option.) (4 points)

A. Speed B. Velocity C. Force D. Mass E. Weight F. Size G. Others

Q3. A rubber ball with a speed of 5.0 m/s collides head-on elastically with an identical ball at rest. What is the speed of the initially stationary ball after the collision? (3 points)

A. 1.0 m/s B. 5.0 m/s C. 2.5 m/s D. zero E. None of the above

Q4. Which object has the greatest momentum? (2 points)

A. a 0.001 kg bumblebee travelling at 2m/s

B. a 0.1 kg baseball travelling at 20m/s

C. a 5 kg bowling ball travelling at 3m/s

D. a 10 kg sled at rest

Appendix E. Questionnaire for User Experiment

Face-to-face Collaborative Learning of Physics

Questionnaire

In the part, you will be asked to answer some questions based on your discussion session, which include perception of learning experience and group evaluation.

There is no right or wrong answer to all questions. The expected duration of your participation is about 15 minutes. Complete anonymity of your responses can be guaranteed.

Thank you very much for your help and have a wonderful day ahead!

Section I

In this section, we would like to know how you feel about your learning experience during the discussion session.

QA1. Please assess your level of agreement with each item based on the discussion session. Please circle one number for each statement to show your response. → Perceived learning development

Statements	Strongly agree	Somewhat agree	Neutral	Somewhat disagree	Strongly disagree
(1) I learnt to assess the likelihood of an outcome.	5	4	3	2	1
(2) I learnt to integrate concrete phenomena with abstract concepts	5	4	3	2	1
(3) I learnt to verify what I had learnt	5	4	3	2	1
(4) I learnt to justify explanations	5	4	3	2	1
(5) I learnt to think critically	5	4	3	2	1

QA2. Please assess your level of agreement with each item based on the discussion session. Please circle one number for each statement to show your response. → Self report learning

Statements	Strongly agree	Somewhat agree	Neutral	Somewhat disagree	Strongly disagree
(1) I better understood the phenomena of elastic collision	5	4	3	2	1
(2) I had increased understanding of	5	4	3	2	1

basic concepts of elastic collision					
(3) I had increased understanding of applying the principle of conservation of momentum to solve elastic collision problems	5	4	3	2	1

QA3. Please assess your level of agreement with each item based on the discussion session. Please circle one number for each statement to show your response. → Learning interest

Statements	Strongly agree	Somewhat agree	Neutral	Somewhat disagree	Strongly disagree
(1) I am now more interested in the topic of elastic collision	5	4	3	2	1
(2) The discussion was fun.	5	4	3	2	1
(3) When we discussed the question, I got involved.	5	4	3	2	1

QA4. Please assess your level of agreement with each evaluation of your learning experience based on the discussion session. Please circle one number for each statement to show your response.

→ Group learning evaluation

Statements	Strongly agree	Somewhat agree	Neutral	Somewhat disagree	Strongly disagree
(1) Group work was a good learning experience	5	4	3	2	1
(2) Group work contributed to my learning.	5	4	3	2	1
(3) Group work made learning fun for me.	5	4	3	2	1

QA5. (For participants who use AR systems in the experiment) Please assess your level of agreement with each item based on the discussion session. Please circle one number for each statement to show your response. → Usability

Statements	Strongly agree	Somewhat agree	Neutral	Somewhat disagree	Strongly disagree
(1) The system was easy to learn for me as an early user.	5	4	3	2	1

(2)The system was easy to use in the process of discussion.	5	4	3	2	1
(3)The error frequency of the system was low.	5	4	3	2	1
(4) The interface of the system was good.	5	4	3	2	1
(5) The system was suitable for learning science knowledge.	5	4	3	2	1
(6)The system was suitable for this discussion task.	5	4	3	2	1
(7)The system made it easy to communicate with my partner.	5	4	3	2	1
(8)The system was pleasant to use.	5	4	3	2	1
(9)I was satisfied with using the system.	5	4	3	2	1

QA6. (For participants who use AR systems in the experiment) What features of augmented reality (AR) technology contribute to the collaborative learning of your group?

QA7. (For participants who use AR systems in the experiment) What feelings do have when using AR?

Section II

QB1. Gender

Male	1
Female	2

QB2. Age: _____

QB3. Year of undergraduate study:

First year	1
Second year	2
Third year	3
Fourth year	4

Appendix F. Academic publications

- [1] **Gu, Y.X.**, Li, N., Chang, L. Duh, H.B.L. (2011). Employ Augmented Reality System for Face-to-face Collaborative Learning. Submitted to 1st Workshop on Mobile Augmented Reality @ MobileHCI 2011, Stockholm, Sweden.
- [2] Li, N., **Gu, Y.X.**, Chang, L., Duh, H.B.L. (2011). Influences of AR-supported Simulation on Learning Effectiveness in Face-to-face Collaborative Learning for Physics. To appear in the *Proceedings of the 11th IEEE International Conference on Advanced Learning Technologies*, Athens, Georgia, USA
- [3] Li, N., **Gu, Y.X.**, Chang, L., Duh, H.B.L. (2011). Sociality of Mobile Collaborative AR: Augmenting a Dual-problem Space for Social Interaction in Collaborative Social Learning. To appear in the *Proceedings of the 11th IEEE International Conference on Advanced Learning Technologies*, Athens, Georgia, USA
- [4] **Gu, Y. X.**, Li, N., Duh, H.B.L. ,Chang, L. (2011). A Mobile AR System for Face-to-face Collaborative Learning for Physics. Paper presented at the 4th Korea-Japan Workshop on Mixed Reality, Osaka, Japan
- [5] **Gu, Y.X.**, Li, N., Chang, L. Duh, H.B.L. (2011). A Collaborative Augmented Reality Networked Platform for Edutainment. In T. Huang, L. Alem. *Mobile Collaborative Augmented Reality System: Recent Trends*. Springer

Employ Augmented Reality System for Face-to-face Collaborative Learning

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Abstract

Augmented Reality (AR) is a developing medium that offers more opportunities for students to engage in collaboration. We presented several mobile AR systems in an effort to strengthen the efficacy of collaboration. Empirical evidences for one of the systems were also provided to illustrate how it was used to enhance the effectiveness of face-to-face collaborative learning. The findings demonstrated the educational values of AR technology in face-to-face collaborative learning.

Keywords

CSCL, augmented reality, collaborative learning

Introduction

The rapid advances of information and communication technologies have the potential to create evolutionary change in the way people acquire new knowledge. Computer-supported collaborative learning (CSCL) has been received considerable attention these years. Augmented Reality (AR), although still a relatively nascent technology, has revealed great possibilities for supporting face-to-face collaborative learning as it introduces enriched personal experiences to collaborators while engaging them through face-to-face interaction [3]. In this paper, we presented several mobile AR systems that are designed to enhance face-

to-face collaboration. In order to fully understand the efficacy of AR technology in facilitating collaborative learning, we examined objective measures of learning achievement and subjective evaluations of learning effectiveness in this research.

Mobile AR Collaborative Learning

The development of mobile devices and wireless networking technologies contributes to the expansion of CSCL environments beyond traditional computers. We present three mobile AR systems built on Android 2.2 phone that direct at fostering the efficacy of face-to-face collaborative learning. The systems are designed such that two students can collaboratively use separate phone to work on the task (as in Figure 1). Figure 2 is a picture of AR system 'AR physics' running on HTC Desire, which aims to help collaborators to acquire the knowledge of elastic collision. Figure 3 is the counterpart of 'AR physics' made with 2D technology. Figure 4 and Figure 5 show another two collaborative learning systems on android platform as well. AR Sumo is a 3D version of traditional 2D sumo game augmented on a paper marker to promote the understanding of the concepts of gravity and friction. Similarly, AR pipedream is developed to foster social interaction in strategically collaborative planning.



Figure 1 Mobile AR-supported collaborative learning

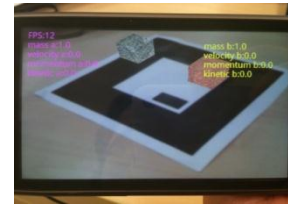


Figure 2 AR Physics

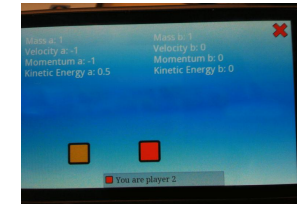


Figure 3 Traditional 2D Physics

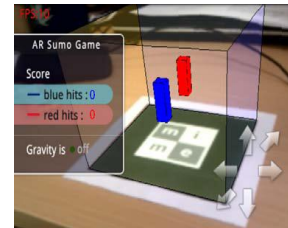


Figure 4 AR Sumo

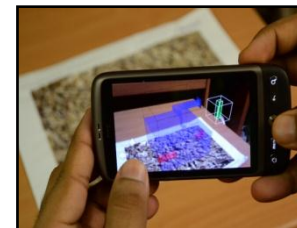


Figure 5 AR Pipedream

Experiment

We conducted a user study with 60 undergraduate students from the National University of Singapore with the system 'AR physics'. The criterion of being a participant was he/she had not learned elastic collision before. There were 16 males and 44 females (aged 21 to 27, $M=21.98$, $SD=1.36$) in the population. All of them had no experience of using AR technology. Pairs of students were randomly assigned to one of the three conditions: paper-based (with the instructional material), 2D-based (with "2D Physics") or AR-based (with "AR Physics"). First, all participants were required to independently read instructional material on elastic collision taken from the notes prepared by a local Junior College. Next, the participants took individual

pre-tests of their knowledge. The participants assigned to the AR-based and the 2D-based conditions were instructed to use the systems right after the independent reading. Then, we asked each pair to discuss two open-ended questions related to elastic collision. They were also required to take an individual post-test after the discussion (with full scores of the two tests each being 10). Finally, the participants filled out a questionnaire used to measure the perceived learning effectiveness. We adapted the scales from Alavi [1] and modified them for this research.

Results

Individual learning achievement

There was no significant difference in the pre-test scores across three conditions. The significant difference in pre-test to post-test gains was found across three conditions ($F(2, 57)=12.651, p<0.001$) and the students in the AR-based condition had significantly higher achievement than those in the other two conditions (See Table 1).

Learning performance	Paper(SD)	2D(SD)	AR(SD)
Pre-test	4.95(1.761)	4.25(1.916)	4.40(1.698)
Post-test	5.40(1.501)	6.05(2.012)	7.35(1.424)
Post-test-pre-test	0.45(1.468)	1.80(1.576)	2.95(1.669)

Table 1 Mean (SD) results for individual learning performance

Perceived learning effectiveness

The reliabilities of the scales, perceived skill development, self-reported learning, learning interest and group learning evaluation, were 0.845, 0.906, 0.813 and 0.790, respectively.

For perceived skill development, there was a significant difference across three conditions, ($F(2, 57)=12.009, p<0.001$). The differences between the paper-based condition and the other two conditions were significant. However, no significant difference between the AR-based and the 2D-based conditions was found. There were significant differences in self-reported learning ($F(2, 57)=18.775, p<0.001$) and learning interest ($F(2, 57)=36.343, p<0.001$) across all three conditions.

We found significant difference in the group learning evaluation across three conditions ($F(2, 57)=14.324, p<0.001$), but impacts of the AR-supported and the 2D-supported simulations were relatively similar (See Table 2).

Dependent variable	Paper(SD)	2D(SD)	AR(SD)
Perceived skill development	3.34(0.518)	3.98(0.557)	4.01(0.372)
Self-reported learning	3.23(0.593)	3.70(0.430)	4.13(0.330)
Learning interest	2.64(0.613)	3.05(0.614)	4.02(0.278)
Group learning evaluation	3.33(0.518)	3.86(0.412)	4.05(0.379)

Table 2 Mean (SD) results for perceived learning effectiveness

Conclusion

This research attempted to employ mobile AR systems in face-to-face collaborative learning and explore the influences of an AR-supported simulation on learning effectiveness in collaborative learning for Physics.

The AR-supported simulation did not only possess shared capacities for strengthening learning effectiveness in face-to-face collaborative physics learning compared with traditional 2D-supported simulation, but also supported further enhancements on individual learning achievement, self-reported learning, and learning interest. In general, students felt that AR technology had delivered enriched collaborative learning experiences and stimulated their interests in Physics study, which benefited their conceptual understanding of scientific concepts.

AR is identified as an effective medium for aiding knowledge acquisition in educational domain [2]. Our work shows the promising role of mobile AR technology in enhancing the effectiveness of face-to-face collaborative learning for Physics. We recommend that future work examine the underlying mechanisms that contribute to the performance improvement in AR-supported collaborative learning environments. Also, more explorations on applying mobile AR technology to collaborative learning can be carried out.

Acknowledgements

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[1] Alavi, M. Computer-mediated collaborative learning: An empirical evaluation. *MIS Quarterly*, 18(2), (1994) 159-174.

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Influences of AR-supported Simulation on Learning Effectiveness in Face-to-face Collaborative Learning for Physics

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Abstract—Augmented Reality (AR), using a mixture of the virtual and physical world, has been recognized as a promising environment for improving the quality of collaboration in educational domains. To identify how an AR-supported simulation affects collaborative learning, this study compared collaborative learning effectiveness between the conditions of AR-supported and traditional face-to-face collaborative learning for Physics. The findings revealed that collaborative use of the AR-supported simulation resulted in higher levels of perceived skill development, self-reported learning and learning interest. The individual learning achievement was also strengthened with the use of AR-supported simulation in collaboration. This study provides empirical evidence for supporting the potential value of AR technology in collaborative learning practices and has implications for research on learning effectiveness evaluation in CSCL.

Keywords-CSCL; augmented reality; collaborative learning; learning effectiveness

I. INTRODUCTION

The development of computing technologies contributes to the expansion of computer-supported collaborative learning (CSCL) activities. Augmented Reality (AR) technology, which allows computer-generated virtual objects to be overlaid onto the physical world, demonstrates great potential for constructing more engaging CSCL environments [6].

AR technology possesses multiple characteristics for promoting the efficacy of face-to-face collaborative learning. In the context of collaborative AR, multiple users can simultaneously access a shared space and manipulate the virtual objects to engage in collaboration. Also, AR technology entails great capacity for implementing interactive visualization. It allows collaborators to experiment with simulations and reflect on abstract concepts and principles in science subjects. Featured with a

combination of attributes of the virtual reality and the real world, AR technology does not only enable delivery of enriched learning experiences, but also makes it possible for collaborators to step back from the scenario and analyze the situation reflectively.

In order to deepen the understanding of the impacts of AR technology on collaborative learning, researchers have started assessing AR applications in educational domains. They found that the integration of AR technology with collaboration reveals great promises for enhancing learning effectiveness [2, 3].

The primary purpose of learning is to strengthen initiative and competence, and the learning outcome is an essential issue for the evaluation of learning effectiveness. The way of conceptualizing learning outcomes is important for the understanding of the learning effectiveness of collaborative learning [7]. It is suggested that both objective learning achievement and perceived learning effectiveness should be addressed to evaluate the effectiveness of collaboration.

In collaborative learning contexts, the quality of group performance is assessed to facilitate the understanding of group functioning. Besides evaluating objective performance at the group level, individual learning achievement is an important indicator to measure the effectiveness of collaborative learning. Perceived learning effectiveness, evaluated by individuals' perceptions towards the learning activity, is a subjective measurement employed in the research of evaluation of collaborative learning effectiveness. Previous work indicated that direct feedback of learning effectiveness from students is useful for obtaining insightful thoughts on the efficacy of collaborative learning [4].

The aim of this research is to explore the influences of an AR-supported simulation on the effectiveness of face-to-face collaborative learning for Physics. We have designed a mobile AR system for implementing elastic collision, which

is a typical phenomenon in the education of dynamics in Physics. The findings will support the worth of AR technology in collaborative learning and enrich the research on learning effectiveness evaluation in CSCL.

II. METHODS

A. Participants

36 undergraduate students from the National University of Singapore participated in the study. The criterion for being a participant was that he/she must have taken Physics as a subject in Secondary School but not taken it in Junior College/Polytechnic. This ensured that the participants had basic knowledge of motion and energy, but did not know about linear momentum and elastic collision. The sample included 16 males and 20 females, whose age ranged from 20 to 25 years old ($M=21.31$, $SD=1.33$).

B. Procedure

All 36 participants were first asked to read a set of notes, which was extracted from notes prepared by the physics department of a local Junior College, on elastic collision for 15 minutes independently. They were divided into 18 two-member groups, and then were randomly assigned to either the non-AR-supported (with instructional material) or the AR-supported (with AR support) condition. Each group was asked to discuss the questions as follows: “Under the context that object B is stationary and object A moves towards object B, how many kinds of subsequent motions can happen after the elastic collision between them? What are the initial conditions required for those subsequent motions to occur?” Since the questions had standard answers, the group performance could be objectively evaluated. For the groups assigned to the AR-supported condition, they were instructed in the way of manipulating the AR system before the discussion. For the groups in the non-AR-supported condition, they were to discuss the questions without the AR system right after the individual reading. In both conditions, once the two students in a group had reached an agreement, they would submit a discussion summary. To assess individual learning achievement, post-test questions based on the knowledge of elastic collision were given. Finally, the participant had to fill in a questionnaire that was used to capture his/her perception on the learning experience in collaboration.

C. Measurements

The collaborative learning effectiveness was assessed by two dimensions: perceived learning effectiveness and learning achievement. The scales for measuring perceived learning effectiveness were adapted from Alavi [5] and modified for this research context, including multi-item individual learning and group learning evaluation scales. Individual learning scales consisted of perceived skill development, self-reported learning and learning interest, while group learning evaluation scales were mainly about the evaluation of collaboration. Each item was assessed using a five-point Likert-type scale. The reliability of perceived skill development, self-reported learning, learning interest and

group learning evaluation were 0.768, 0.730, 0.707 and 0.898 respectively. The score of the group discussion summary was used to evaluate the group performance, while the score of the individual test after the discussion was applied to assess the individual learning achievement.

D. The system

We developed a mobile AR system to simulate elastic collision for assisting face-to-face collaborative learning (See Figure 1, top left). The software prototype has been implemented on an HTC Nexus One phone running Android OS 2.2 with a supporting server program on a PC. The computationally expensive algorithmic computations for marker detection and physics simulation were designed to be carried out on a server, and results were sent back and visualized on the mobile phone.

The system enables both users to visualize two 3D virtual cubes on a marker as well as simulate elastic collision in a virtual shared space with their mobile phones. Each virtual cube is assigned to a user and its mass and initial velocity can be controlled by that user. Users can input the numbers using the interface provided to simulate elastic collision (Figure 1, top right). After both users have finished editing the initial conditions, they can press ok to start the simulation. The whole collision process is visualized with real-time numerical data of mass, velocity, momentum and kinetic energy of the two objects displayed on the left side of the screen. During the whole discussion process, two users are free to choose the appropriate period to use the system and are allowed to run simulations as many times as they may need to derive the answer to the question.



Figure 1. AR-supported collaborative physics learning

III. RESULTS

A. Perceived learning effectiveness

The analysis indicated that the participants with the AR-supported simulation gave significantly higher ratings in perceived skill development than those in the non-AR-supported groups.

For self-reported learning and learning interest, there were also significant differences between the AR-supported groups and the non-AR-supported groups.

Participants made more favorable group learning evaluations than other individual learning scales in both conditions. It was higher for the AR-supported groups than the non-AR-supported groups, but the difference was not significant (See Table I).

TABLE I. MEAN (SD) RESULTS FOR PERCEIVED LEARNING EFFECTIVENESS

Dependent variable	AR mean (SD)	Non-AR mean (SD)	t-value
Perceived skill development	3.87(0.57)	3.40(0.59)	2.38*
Self-reported learning	3.83(0.37)	3.39(0.77)	2.20*
Learning interests	2.98(0.58)	2.36(0.73)	2.82**
Group learning evaluation	4.06(0.76)	3.89(0.41)	0.80

NOTE: **P<0.01, *P<0.05

B. Learning performance

Participants in the AR-supported groups performed better on the discussion task than those in the non-AR-supported groups, but no statistically significant difference was found. Individual post-test results showed that participants in the AR-supported groups got significantly higher scores than those in the non-AR-supported groups (See Table II).

TABLE II. MEAN (SD) RESULTS FOR LEARNING PERFORMANCE

Dependent variable	AR mean (SD)	Non-AR mean (SD)	t-value
Group performance	7.00(1.41)	6.22(1.86)	1.00
Individual achievement	7.03(2.53)	5.00(2.36)	2.50*

NOTE: *P<0.05

IV. DISCUSSION

In this study, we investigated the impact of an AR-supported simulation on the effectiveness of face-to-face collaborative learning for Physics. The results demonstrated the facilitation effects of AR technology on collaborative learning effectiveness.

The collaborators with the AR-supported simulation perceived higher levels of learning skill development, self-reported learning and learning interest after the discussion compared with those without simulation support. The findings revealed that the AR-supported simulation met the requirements for performing effective instruction, and fostering the development of learning initiative and competence [8].

The average rating of the group learning evaluation was the highest among the perceived learning effectiveness scales. The participants reported that collaborative learning led to an active exchange of knowledge, higher learning efficiency, and increased engagement and fun, which were helpful for generating better understanding of concepts and solutions. The use of AR-supported simulation resulted in an increase in group learning evaluation but it was not statistically significant. Since collaborative learning was preferred by students, integrating AR technology with collaborative learning could possibly inspire students' learning interests.

The difference in group learning performance between the AR-supported and the non-AR-supported groups was not

significant, while the use of AR positively affected individual learning achievement. This implied that the AR-supported simulation in collaboration was more likely to serve as a kind of learning resource rather than a collaboration facilitator. Hence, collaborative use of the AR-supported simulation has more obvious effects on individual learning achievement than on group performance.

V. CONCLUSION AND FUTURE WORK

AR interfaces are perceived as the "next generation" pedagogical media to advance learning quality [1]. In this paper, we validated the potential role of AR technology in enhancing collaborative learning effectiveness for Physics. Perceived skill development, self-reported learning and learning interest were strengthened in the AR-supported collaboration. Also, it promoted individual learning achievement.

This study contributes to CSCL research by empirically verifying the positive influences of AR technology on collaborative learning and provides insight into the approach of assessing collaborative learning effectiveness. Future research is needed to explore the mechanism underlying the effectiveness of AR-supported collaborative learning.

ACKNOWLEDGMENT

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Sociality of Mobile Collaborative AR: Augmenting a Dual-problem Space for Social Interaction in Collaborative Social Learning

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Abstract—Mobile collaborative augmented reality (AR) technology demonstrates great potential for augmenting learning experience in collaboration. The convergence of AR, collaboration and handheld devices opens up more opportunities for strengthening the effectiveness of social interaction in collaborative learning. We conceptualize it as a new form of collaborative learning, collaborative AR social learning. Based on the reflections of the sociality characteristics of mobile collaborative AR, we develop a model for better understanding this emerging instructional medium. It has implications for the development of mobile collaborative AR applications for educational purposes in the future.

Keywords—Mobile collaborative AR; collaborative social learning; sociality characteristics

I. INTRODUCTION

In more recent years, the advances in computing technologies have driven the evolution of computer-supported collaborative learning (CSCL) environments. Augmented Reality (AR), a real-time enabling technology whereby virtual graphics overlay the real world, reveals great potentials for enriching learning experiences [6].

The development in mobile devices and wireless network technologies afford more possibilities for people to get involved with unique AR-supported collaborative learning activities. We propose that mobile collaborative AR technology introduces a new type of collaboration to CSCL, collaborative AR social learning. It describes that multiple outdoor collaborators construct shared knowledge through real-time human-to-human and human-to-environment interactions with the support of mobile collaborative AR technology.

With respect to CSCL, the interplay between medium characteristics and learning activities has impacts on learning effectiveness [2]. Recognizing the vital role of social interaction in facilitating knowledge construction in collaboration, the affordances of a CSCL environment for

supporting social interaction have been identified as important indicators to evaluate its success in learning activities. Sociality characteristics are therefore proposed to illustrate “the properties of a CSCL environment that act as social-contextual facilitators relevant for the learner’s social interaction” [8]. As more innovative technologies are introduced to the educational domain, there is a crucial need to analyze the features of the technology for supporting the interactional process in collaborative learning. Mobile collaborative AR technology emerges as a promising medium for fostering collaborative social learning. Hence, it is necessary to gain an understanding of the strengths of mobile collaborative AR in augmenting the interactional process of collaborative learning.

The objectives of this paper are threefold: first, we clarify the potential sociality characteristics of mobile collaborative AR. Second, we propose a model of mobile collaborative AR for better understanding the features of mobile collaborative AR for supporting social interaction in collaborative social learning. Third, on the basis of the model, we examine the sociality characteristics of current applications of mobile collaborative AR and then identify the future directions of the development of mobile collaborative AR in educational domain.

II. SOCIALITY CHARACTERISTICS OF MOBILE COLLABORATIVE AUGMENTED REALITY

Sociality has become one of main issues to address in the research on CSCL these years [8]. Mobile collaborative AR, a convergence of AR, collaboration and handheld devices, provides more opportunities for enhancing social interaction in CSCL.

A. Augmented Reality

The visual elements comprising the content delivered by AR technology are usually emphasized. By taking advantage of various display devices, users are able to obtain a view of

AR-supported content integrating virtual information with the real world. AR technology has become a multimedia solution to innovate learning experiences that allow individuals to interact with virtual information whilst engaging in natural communication in physical world. The referential resources provided by virtual information could support the development of mutual understanding among collaborators by increasing the richness of meaning negotiation [3].

B. Collaboration

The learning entity of collaboration can be a group of co-located people or people distributed in different places. Positive interdependence, which refers to “the perception that one is linked with others in a way so that one cannot succeed unless they do (and vice versa) and/or that their work benefits one and one’s work benefits them” is recognized as the essence of collaboration [4]. In terms of the technology for supporting collaborative learning, positive interdependence has been adopted as a guideline to develop CSCL environments in an effort of promoting the interpersonal linkage among group members and fostering the quality of social interaction in collaborative learning [9]. It is suggested that collaborative use of technology tools potentially serves as a means of strengthening positive interdependence and subsequently enhancing social interaction in collaborative learning.

C. Handheld devices

Without the constraint of fixed setups, mobile technologies create more possibilities for supporting both co-located and remote collaborative learning activities while freely moving around across different places. Handheld devices enable co-located individuals to get involved in knowledge construction by exploring the outside environment and interact with each other through the guidance of virtual information. They can also deliver location-based information to enrich collaborative learning experiences. What is more, multiple users can access a shared space to work on the task together while exchanging information over distance.

III. AN AUGMENTED DUAL-PROBLEM SPACE FOR SOCIAL INTERACTION

The interplay among characteristics of AR, collaboration and handheld devices construct an innovative shared space high in social richness for CSCL, which is defined as collaborative social learning. According to [1], collaborative learning involves two spaces, namely, a content space and a relational space. The content space is built on the problem to be dealt with, and the relational space is established based on the relationship formed among collaborators. Mobile collaborative AR shows great potentials for structuring an augmented dual-problem space to promote social interaction in collaborative learning.

A. Content-oriented characteristics

Mobile collaborative AR technology can enrich the content space for social interaction in collaborative learning through integrating virtual information with specific physical settings.

Location-based interactive information transmitted by handheld devices motivates individuals to mutually explore the knowledge embedded in real environments. Also, mobile collaborative AR enables the addition of more dimensions to location-based information. Based on the specific location, it can deliver relevant information previously disconnected from different sources, which introduces unique learning experiences for collaborators. Indeed, the strengthened learning experience offers a rich supply of contextual resources for shaping the patterns of social interaction in collaborative learning.

B. Relation-oriented characteristics

Mobile collaborative AR technology also has strengths for augmenting the relational space via fostering both geographical and psychological linkages among collaborators in learning activities.

It broadens the means of implementing synchronous collaborative learning by supporting different forms of co-presences. People are able to participate in co-located collaboration in various physical sites. Particularly, with the development of functions of handheld devices and wireless connecting technologies, individuals can obtain interactive experiences in a shared space over distance while interacting with each other. The increased sense of co-presence in turn enhances the construction of mutual understanding in social interaction. Besides supporting one-to-one remote collaborative learning, mobile collaborative AR can also facilitate the collaboration among distributed groups. The connectivity enabled by the technology promotes the relationship establishment among different learning entities across social contexts.

Physical or mediated co-presence does not guarantee the success of collaboration, and psychological proximity is needed to be enhanced as well [6]. Mobile collaborative AR can strengthen positive interdependence among group members in collaborative learning. Individuals have to collaboratively use the handheld devices to view and interact with AR content in learning activities, which is beneficial for fostering coordinated communication.

Based on the reflections of the sociality characteristics of mobile collaborative AR, we propose a model to deepen the understanding of the relationship underlying the effects of mobile collaborative AR on social interaction in collaborative learning. The interplay of features of AR, collaboration and handheld devices leads to the formation of sociality characteristics. All sociality characteristics can be categorized into two primary types, content-oriented and relation-oriented characteristics, and they jointly exert influences on the interactional process of collaborative learning (See Figure 1).

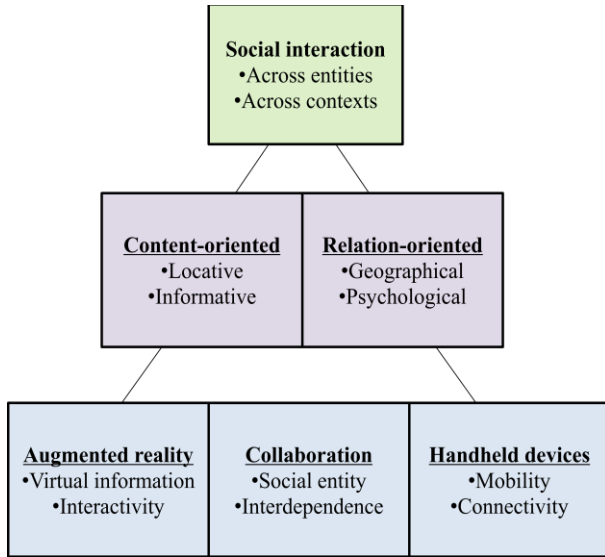


Figure 2. A model of mobile collaborative AR

According to this model, we identify the main sociality characteristics addressed by current applications of mobile collaborative AR in educational domain. A number of applications have been developed to offer location-specific experiences for co-presented collaborative learning outside classrooms [5, 7, 9]. The applications consist of two main scenarios, outdoor investigations (e.g. environment/historical field work) and on-site edutainment activities (e.g. museum visiting). Users can receive location-based virtual information by handheld devices, which are used to aid exploratory learning in certain natural environments. Some applications allow users to interact with virtual information through the input functions of keypads. Most of them aim to support co-located learning activities where a small group of people collaboratively use a handheld device.

The content-oriented characteristics of mobile collaborative AR for delivering location-based information are largely utilized in extant applications, but the input capability is still limited. Advancing interaction techniques should be a concern in the future. In terms of the form of co-presence, more explorations on mediated co-presence supported by mobile collaborative AR can be carried out to build rich contexts for remote collaborative learning. The interdependence issue also needs to be further addressed. More diverse forms of collaborative use of the technologies can be developed instead of merely relying on using a single device. Manipulation of multiple interconnected devices can be explored in an effort to foster the connections among collaborators. Technically, building multiple-users engaged AR-supported collaborative learning environments generally requires centralized information database at the back end. Multiple devices can exchange certain shared information with the exchange of database. Modern mobile devices have well-equipped capability to facilitate this type of data exchange (e.g. WiFi, Bluetooth). Also, peer-to-peer technologies enable mobile devices to communicate with each other without relying on a server to look for other peers.

(i.e., Any social interaction between peers can be initiated without informing a server). So, the technology can not only support large co-located group collaboration, but also make it possible for distributed groups of individuals to engage in remote collaboration. The collaboration among networked groups contributes to the establishment of collaborative AR social learning setting in which people gather knowledge while communicating with each other.

IV. CONCLUSION

Mobile collaborative AR technology has great promises for enhancing social interaction of different learning entities across various contexts in collaborative learning. We identify it as a new type of collaboration in CSCL, collaborative AR social learning. Sociality characteristics are used to clarify the role of mobile collaborative AR technology in augmenting social interaction in learning practices. From the perspective of “dual-problem space” in the research on collaborative learning, we contend that mobile collaborative AR entails the capacity of facilitating the establishment of both content and relational space in collaborative learning. Based on the model presented in this paper, more efforts can be made to implement collaborative AR social learning for strengthening the effectiveness of social interaction in collaborative learning in the future.

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A Mobile AR System for Face-to-face Collaborative Learning for Physics

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ABSTRACT

Augmented Reality (AR) is a developing medium that can be used to create opportunities for students to collaborate via digital technologies. In this study, we present a mobile AR system that facilitates interactions while supporting learning activities. We provide empirical evidence to illustrate how this system is used to develop Physics concepts through face-to-face collaborative interaction. Our findings suggest that AR-enabled simulations can enhance the effectiveness of computer-supported collaborative learning.

Author Keywords

CSCL, augmented reality, collaborative learning

INTRODUCTION & MOTIVATION

The rapid advances of information and communication technologies have the potential to create evolutionary change in the way people acquire new knowledge. Augmented Reality (AR), although still a relatively nascent technology, has revealed interesting possibilities for supporting face-to-face collaborative learning as it introduces enriched personal experiences to collaborators while engaging them through face-to-face interaction [3]. In this research, we used an AR-supported simulation to assist face-to-face collaborative learning of Physics. Our objective was to investigate the influence of AR technologies on the effectiveness of computer-supported collaborative learning. In order to fully understand the efficacy of AR-supported simulations in facilitating this type of learning, we examined objective measures of learning achievement and subjective evaluations of learning effectiveness in this research.

MOBILE AR COLLABORATIVE LEARNING

We built a mobile AR system to simulate elastic collision designed to facilitate learners' knowledge acquisition and interactions. Using Android OS 2.2, we implemented the prototype with supporting software on a PC. The reason for using this design was to offload intensive tasks to a more powerful machine and improve the processing performance in order to deliver a better user experience. During this research, we relied on the power of the desktop to perform marker detection and to run the physics simulation while the mobile client only needed to capture and send the video stream to the desktop and wait

for the response. Figure 1 shows the close view of how the system augments the view of the physical world with a virtual scene to perform the physics simulation. We designed the system so that two users could work collaboratively using separate phones for problem-solving (Figure 2). By designing another simulation supported by 2D graphic technology, we compared the effects of different simulation tools (Figure 3).

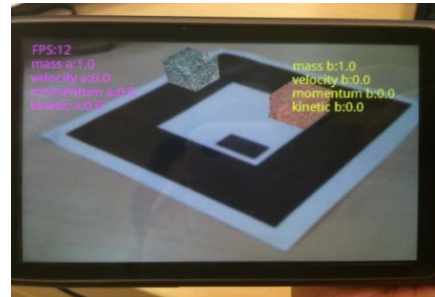


Figure 1 AR-supported simulation of elastic collision



Figure 2 Mobile AR-supported collaborative learning

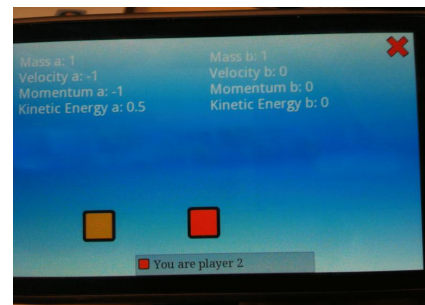


Figure 3 2D-supported simulation of elastic collision

EXPERIMENT

We conducted a user study with 60 undergraduate students from the National University of Singapore. The

criterion of being a participant was he/she had not learned elastic collision before. There were 16 males and 44 females (aged 21 to 27, $M=21.98$, $SD=1.36$) in the population. Pairs of students were randomly assigned to one of three conditions: paper-based (with the support of instructional material), 2D-based (with the support of simulation developed by traditional 2D graphic technology) or AR-based. First, all participants were required to independently read instructional material on elastic collision taken from notes prepared by a local Junior College. Next, the participants took individual pre-tests of their knowledge. Then, we asked each pair to discuss a question related to elastic collision. They were also required to take an individual post-test after the discussion (with full scores of the two tests each being 10). Finally, the participants filled out a questionnaire, which was used to measure their perceived learning effectiveness. We adapted the scales from Alavi [1] and modified them for this research. The reliabilities of the scales, perceived skill development, self-reported learning, learning interest and group learning evaluation, were 0.845, 0.906, 0.813 and 0.790, respectively.

RESULTS

Individual learning achievement

There was no significant difference in the pre-test scores. The significant difference in individual learning gain was found across three conditions ($F(2, 57)= 12.651$, $p<0.001$) and the students in the AR-based condition had significantly higher achievement than those in the other two conditions (See table 1).

Learning achievement	Paper(SD)	2D(SD)	AR(SD)
Pre-test	4.95(1.761)	4.25(1.916)	4.40(1.698)
Post-test	5.40(1.501)	6.05(2.012)	7.35(1.424)
Post-test-Pre-test	0.45(1.468)	1.80(1.576)	2.95(1.669)

Table 1 Mean (SD) results for individual learning achievement

Perceived learning effectiveness

For perceived skill development, there was a significant difference across three conditions, ($F(2, 57)=12.009$, $p<0.001$). The differences between the paper-based condition and the other two conditions were significant. However, no significant difference between the AR-based and the 2D-based conditions was found. There were significant differences in self-reported learning ($F(2, 57)=18.775$, $p<0.001$) and learning interest ($F(2, 57)=36.343$, $p<0.001$) across all three conditions.

We found significant difference in the group learning evaluation across three conditions ($F(2, 57)=14.324$, $p<0.001$), but impacts of the AR-supported and the 2D-supported simulations were relatively similar (See Table 2).

Dependent variable	Paper(SD)	2D(SD)	AR(SD)
Perceived skill development	3.34(0.518)	3.98(0.557)	4.01(0.372)
Self-reported learning	3.23(0.593)	3.70(0.430)	4.13(0.330)
Learning interest	2.64(0.613)	3.05(0.614)	4.02(0.278)
Group learning evaluation	3.33(0.518)	3.86(0.412)	4.05(0.379)

Table 2 Mean (SD) results for perceived learning effectiveness

Discussion and Conclusion

The objective of this research was to explore the influence of an AR-supported simulation on learning effectiveness in face-to-face collaborative learning for Physics.

AR-supported simulation possessed similar capacities for enhancing learning effectiveness in face-to-face collaborative physics learning compared with traditional 2D-supported simulation. It also supported further enhancements on individual learning achievement, self-reported learning, and learning interest. In general, students felt that AR technology had delivered an enriched collaborative learning experience and stimulated their interests in Physics study, which benefited their conceptual understanding.

AR can be used as an effective medium for aiding knowledge acquisition through computer-supported collaborative learning [2]. Our work shows the promising role of AR technology in enhancing the effectiveness of face-to-face collaborative learning for Physics. We recommend that future work examine the underlying mechanisms that contribute to this performance improvement in AR-supported collaborative learning environments.

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A Collaborative Augmented Reality Networked Platform for Edutainment

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Abstract This chapter presents a mobile software prototype for the educational purpose by using the Augmented Reality (AR) and data communication technology. We developed a prototype of mobile game called “AR-Sumo” that aims to offer a shared virtual space for multiple mobile users to interact simultaneously. “AR-Sumo” involves visualization of augmented physical phenomena on a fiducial marker and enables learners to view the physical effects of varying gravities and frictions in a 3D virtualspace. The software implementation is packaged as network service where it is broadcasted from an access point connecting to a designated server. With the established network connection, mobile phones users can receive services semi-ubiquitously within the range of the broadcast. This

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architecture resolves the issue of heterogeneity of computational capacity among different types of mobile phones. As an on-going project, future studies will focus on the usability and designs with an attempt to enhance the efficacy of the application.

1 Introduction

AR is a technology that combines the virtual scene with reality. It is a multidisciplinary area that has been developed for decades, focusing on vision tracking, interaction technique and display technology [19]. Early works on collaborative AR [6] were mostly implemented on desktop computers so it restricted the mobility of AR applications. However, this restriction has been removed in recent years when AR applications can be implemented by portable devices such as certain smart phones (e.g. iPhone), which are equipped with the capacity to process the required computation.

It is a known concept that 3D visualization helps to develop human spatial ability [7]. AR technology is a good medium for establishing a mobile environment. The concept of collaborative AR learning through shared augmented space has been investigated in [2, 8, 17, 19]. Their interface designs allow users to engage in collaboration more intuitively (i.e., in real-time space) but the setups require intensive supports of hardware. Also, the ubiquitous computing system provides extensive mobility or maneuverability. AR tennis [4] is a good example of a portable AR collaboration for entertainment. The objective of this project is to incorporate collaborative AR into mobile learning system. A collaborative game that is designed to be educational would transform the way people learn new knowledge. Our targeted mobile users are students of primary school and we would like to examine how this alternative learning approach would impact the way in which students learn about the physical world.

In this chapter, we describe a proof-of-concept software prototype of “AR-Sumo”. The system demonstrates the feasibility of developing a server-based collaborative mobile AR application. By design, we are interested in offering AR collaboration as a network service (AR service) targeting to serve mobile clients. Service is provided by a dedicated server that is attached to a Wi-Fi access point (Fig 1), which broadcasts service within a small space such as classroom, office, and multi-person workspace, etc. It allows mobile phones that are within the network proximity to receive AR service through their Wi-Fi connection

with the server. The concept is motivated by scenarios in which AR services can be offered ubiquitously from neighbourhood stores, restaurants and classrooms, functioning as a novel way of delivering advertisement and education. Such design not only supports AR processing in low-powered mobile phones but also facilitates easiness of content upgrading at the server side to support more advanced features (e.g. implementation of more intensive application simulation) without the concern of the heterogeneity issue of computational capacity among different mobile phones. For educational purposes, classroom environment is one of the ideal places to broadcast the AR service because it allows students to achieve interactive learning collaboratively.

Section 2 of this chapter covers our reviews on collaborative mobile learning and the theoretical guidelines to the design of “AR-Sumo”. Section 3 gives a detailed discussion of our system implementation in technical aspects. We conclude this chapter with some discussion on our future works in the final section.

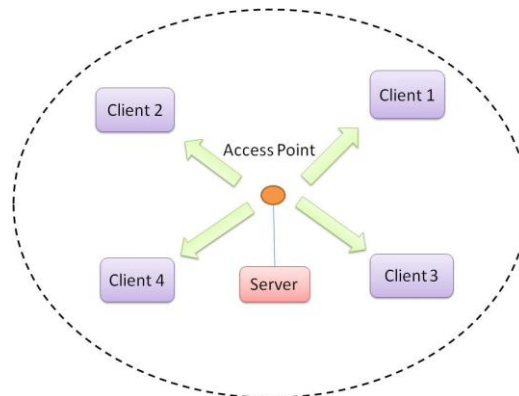


Fig. 1 Concept of Semi-ubiquitous AR Service.

2 Mobile AR & Learning

2.1 Past Collaborative AR Works

Early works on collaborative AR focused on head-mounted display (HMD), desktop and handheld-based environment. Construct3D [6] is designed as a 3D geometric construction tool that can be used for a wide range of educational purposes. Students wearing HMD can

engage in face-to-face interactions in real-time 3D virtual space. Similarly, AR Tetris [18] allows users to collaborate remotely with fiducial markers in a master/trainee scenario. These collaborative systems are designed to be applied in a range of educational contexts. However, the investment-intensive hardware requirement makes them impractical to be widely deployed outside the research laboratory. ARQuake[15] is a mobile AR indoor/outdoor application that uses both GPS information and vision based technique. It is enabled by a backpack configuration in which its cost and performance (30 frames per second) are balanced. In contrast, AR tennis [4] is designed for mobility as in the expensive AR computation and game simulation are both processed internally in mobile phones and no additional external hardware is required. Although fully functional, its pitfalls are its' low resolution in augmented video frame and slow frame transition rate (i.e., 3 to 4 frames per second). To overcome these pitfalls, our "AR-Sumo" prototype is designed as a semi-ubiquitous architecture because of the additional server. The superb data transmission speed from a stable and strong Wi-Fi connection gives the average performance of 10 frames per second. This archived performance outperforms AR tennis significantly. Our "AR-Sumo" has avoided the pitfalls of both AR Tetris and AR Tennis face, and it has achieved a relatively good application performance.

2.2 Overview of Mobile Learning Design

The relevant research on collaborative mobile learning environment design is first reviewed to guide the software prototype development and analysis. Mobile learning enables individuals to access greater educational information via mobile devices without the constraints of time and place. Such practicality contributes to richer learning experiences for individuals. However, the mobile technology may be an impediment to the learning process if the design cannot fit the context. To address the effectiveness issue on the application aspect of mobile learning, researchers have provided insights into the requirements for applications of mobile learning environments by considering multiple factors. Parsons, Ryu and Cranshaw [11] developed a framework for designing mobile learning environments by integrating three factors, namely, learning context, learning objectives and learning experiences.

The collaborative task is an integral part in designing mobile technologies. In the educational context, collaborative learning, referring to two or more individuals learning some new information or knowledge together, is identified as an effective approach for enhancing learning effectiveness [14]. As the advancement of mobile technologies keeps revolutionizing the collaborative learning environment, design issues related with mobile collaborative learning systems have been received considerable attention in an effort to promote learning quality in recent years.

Three principle aspects should be taken into account for evaluating the efficacy of the design. The technological aspect for the design revolves around usability issues such as user interface, hardware, and software systems. Multiple dimensions are incorporated into the usability assessment which includes controllability, learnability, satisfaction, feedback, menu/interface, etc. [5]. Specifically in the education domain, pedagogical and psychological influences should also be considered [7]. The pedagogical aspect pertains to the effectiveness of delivering knowledge to users. And the psychological aspect refers to the engagement and preference of the users. Mobile AR is an emerging technology that enables users to see the real world augmented with virtual objects by utilizing mobile devices. To enhance the usability and effectiveness of mobile AR applications in education setting, researchers have directed at their investigation on the physical configuration and virtual content, and proposed strategies for achieving greater efficacy in the AR environment [7, 13].

An interface with good usability should naturally support human-computer interaction, which allows users to manipulate the virtual objects as intuitively as possible. Additionally, the design and the performance of the objects on the interface that execute the user's manipulations should be user friendly [1]. In terms of designing the content, the main focus is how well it would facilitate learning. The cinematic and the game metaphors are helpful for strengthening learners' engagement in the mobile learning environment [11].

In summary, technical design, pedagogical and psychological aspects are crucial in making a mobile AR-supported educational application provide successful and pleasant experiences for the users. The technical usability and educational effectiveness are the two most important domains to warrant for a careful attention when designing a mobile AR environment with the aim of fostering collaborative learning. Also, it is good to integrate some entertaining elements to keep users' attention and engagement. This would strengthen the effectiveness of the delivery of educational content.

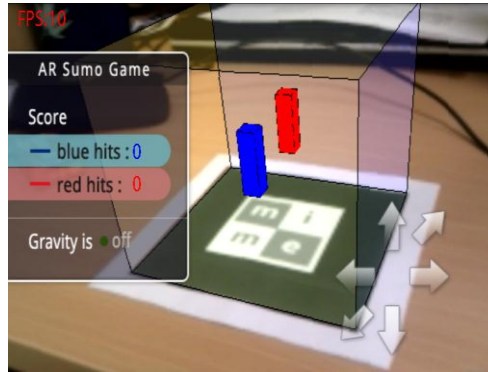


Fig. 2 Game View (AR Sumo).

2.3 Game Design

Mobile AR technology entails potentials in providing an optimal collaborative learning environment. The combination of spatial and tangible interface of the mobile AR application creates opportunities for individuals to directly manipulate virtual objects in the physical environment whilst engage in a face-to-face communication [2]. AR technology can also be applied to construct simulations with a high degree of realism. It is especially useful to facilitate the understanding of science phenomena that are difficult to observe in physical life unless utilizing complex equipments, and in turn fosters knowledge acquisition [12]. Hence, game-based collaborative learning supported by mobile AR technology enables individuals to learn things more coherently as they could visualize the relevant elements, as well as more socially as they have to interact with their peers. They can actively seek and construct knowledge, while the immersion in the game can stimulate a sense of engagement, hence promoting learning experience [3, 13].

Recognized the capacity of mobile AR technology in edutainment, our collaborative “AR-Sumo” game (Fig 2) is designed by the abovementioned principles. As an educational game, “AR-Sumo” allows learning while playing. Motivated by a 2D educational sumo game [9], we have added an additional dimension of visualization and control feature in our “AR-Sumo” game, and also managed to register the entire virtual game world into the reality. “AR-Sumo” allows the registrations of two individuals to play the game. Each

player is able to control a 3D rectangular virtual block (Fig 2). The lesser the collisions with boundaries of the virtual world indicates the better the player performs. The player can choose to use a virtual block controlled by him/her to hit his/her counterpart. The intention of hitting is to sabotage the counterpart to collide into the boundary of the virtual space. If the total number of collisions recorded exceeds a pre-determined value, the player is declared the loser. On the server side, a control console is used to manipulate several virtual world parameters. For instance, a facilitator (e.g. a teacher) can choose to manipulate (tune in, turn on or off) the degree of gravity and friction of the virtual world, which would influence players' experience. Players are made aware that the varying degree of gravitation and friction through their own visualization in the virtual world.

The AR interface should be intuitive for learners to use. In our application, two rectangular blocks with different colors are assigned to two users so that each user can control a block. In order to offer intuitive control interface, a total of six arrow-shaped buttons are located at the bottom right side of the screen (Fig 2) as the indication of applying force to the assigned block in one of the six primitive directions. (i.e. +/- x, +/- y, +/- z). In addition, the player's viewpoint toward the virtual 3D space can be easily changed by moving the phone around.

3 Implementation

3.1 System Architecture

Typical AR applications are sequential combination of video frame acquisition, fiducial marker detection, application/game simulation and graphic rendering. Depending on the computational capabilities of the respective mobile devices, it would be relatively expensive to accommodate the entire sequential combination of tasks. User experience will be reduced accordingly by application performance. The solution is to offload certain task(s) to a server with powerful processing capability.

Four different designs of user-server architectures have been proposed [16]. The first design was a handheld self-contained structure in which the entire AR computation could be processed in a mobile device. The experiments on Google Nexus one phone showed that

this approach yielded poor-quality augmented video (i.e., 5.1 frames per second on average). The second design allowed the task of fiducial marker detection to be offloaded to the server while keeping application simulation and graphic rendering in mobile device. This design is logical. However, having application/game simulation on the same mobile device would cause a huge inconsistency in the application/game state among different mobile devices. Similarly in the third design, the server took over the task of application simulation and became a central processing unit for the AR service.

The last design involved a two-way video transmission and it required a high bandwidth network. While it appeared to be the easiest solution to offload all expensive tasks to server, the disadvantages are palpable. The stability of a Wi-Fi environment could hardly provide a good quality of service (QoS) due to the extremely heavy demand on the network bandwidth for a continuous two-way real-time multimedia content delivery.

While [16] chose to use a combination of the first and second design in implementing their handheld AR system because of the requirement of permanent presence of server. Our software prototype favoured the third design in order to give the server the required capabilities to handle the AR computation and application simulation (e.g. physics simulation). That is, mobile clients would acquire and compress their video frames, and send them to a server for further processing. The dedicated server which receives these video frames would decode them for fiducial marker detection, simulate visual environment states and return rendering commands to each mobile client that has initiated the AR service. Upon receiving commands from the server, mobile users render augmented frames accordingly. The commands are sent continuously from the server, which consists of the model-view matrices of the virtual world's boundary and each virtual object.

3.2 Physics Engine

A physics engine has been implemented on the server to offer the physical capability to 3D objects in the virtual world. In our design, the rate of physics simulation is coupled to the rate of frame arrival at server in order to make the game simulation speed adaptive to the variable frame arrival rate at the server side. The engine enables rigid body collision detection within the virtual world and visualizes the effect of applying force to the virtual objects in a user-controlled 3D environment. In addition, friction and gravitation are the control parameters offered by the engine, and it could be easily tuned in at the server's control console.

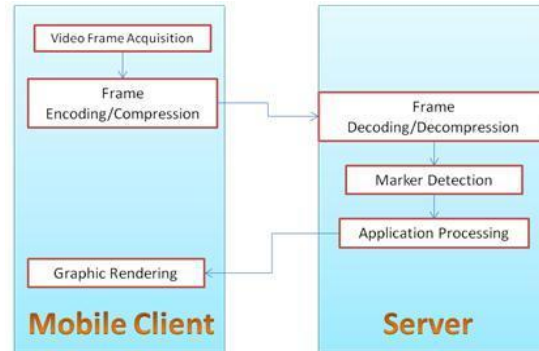


Fig. 3 System Architecture.

3.3 Protocol Design

Protocol design is critical to communication between a server and users. The prototype enabled the server to communicate with multiple users simultaneously to perform certain tasks. In order to support the desired task in our system design, we have designed a set of protocols to support the communication between the server and the users. The following is a brief illustration of application protocols:

- **Registration & De-registration:** When mobile clients connect to the server for the first time, their identities will be added into database. And when mobile clients terminate the service, their identities will be de-registered at the server.
- **Frame Transfer:** As AR computation is designed to be processed at the server side. Each mobile client needs to transfer its acquired video frame to the server in real time. In order to reduce the amount of data in the network, captured video frame will be compressed into a light weight YUV420 format at the mobile client side; whereas on the server side, incoming frames will be decoded into a RGB format.
- **AR Processing:** “AR-Sumo” employs NyARToolkit [10] to detect fiducial marker and it returns 4×4 transformation matrix (model view matrix) facilitating OpenGL to draw 3D virtual world onto the fiducial marker. Transformation matrices of the rest of the virtual objects are then the product of multiplication between model view matrix and the

rigid body transformation matrices (e.g. translation and rotation) that derived from the physical simulation.

- **User Interaction:** Differ from the AR processing as a real-time periodical event. Network messages resulted from player interactions are only exchangeable when a player event is initiated. Messages will be delivered to the server and be simulated from a subsequent simulation cycle.

4 Conclusion & Future Work

Mobile AR plays a significant role in facilitating collaborative learning. This chapter presents “AR-Sumo”, which is a mobile collaborative augmented reality network service for educational and entertainment purposes. An important application of this system is to support existing collaborative learning in school setting. The selected educational elements (e.g. applying force to object from different directions, the effect of different degree of gravitation and friction) in physical world are conveyed to the players throughout their manipulation of virtual objects during the game.

The present work enriches the research on mobile collaborative AR in edutainment domain. First, it creates more opportunities for students to engage in collaborative learning through taking advantages of potentials of AR technology in education. Second, the application is implemented by mobile phones, which allows users to interact with each in natural styles without the constraint of fixed physical setups. Third, the novel semi-ubiquitous AR service architecture is designed to treat AR as network services. This concept can be applied not only in classroom setting but also in many other similar scenarios.

As an on-going project, the development works for the subsequent phase are still in the progress. The current version of software prototype and game design support the collaboration of two players within the broadcast range at an average performance of 10 frames per second on mobile phone. The client software has been deployed to Google Nexus One phone and the server program is situated at a workstation connecting to a router. We would like to support more users to collaborate at the virtual space simultaneously in the near future.

Other future works consists of two main directions: It is necessary to design and conduct a study on user experience of the system. We will evaluate the effectiveness of “AR-Sumo” in terms of knowledge delivery, engagement of users and the usability of the system with an attempt of exploring better evaluation methods of mobile collaborative AR systems. Second direction is to improve its robustness against network congestion. We are now investigating a local dead reckoning algorithm that make use of the information from mobile phone’s inertia sensor and acquired video frame to predict marker position.

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