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AR PHYSICS: TRANSFORMING PHYSICS DIAGRAMMATIC REPRESENTATIONS ON PAPER INTO INTERACTIVE SIMULATIONS

by

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B.S Sichuan University, 2008

A thesis submitted in partial fulfillment of the requirements
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ABSTRACT

A problem representation is a cognitive structure created by the solver in correspondence to the problem. Sketching representative diagrams in the domain of physics encourages a problem solving strategy that starts from 'envisionment' by which one internally simulates the physical events and predicts outcomes. Research studies also show that sketching representative diagrams improves learner's performance in solving physics problems. The pedagogic benefits of sketching representations on paper make this traditional learning strategy remain pivotal and worthwhile to be preserved and integrated into the current digital learning landscape.

In this paper, I describe *AR Physics*, an Augmented Reality based application that intends to facilitate one's learning of physics concepts about objects' linear motion. It affords the verified physics learning strategy of sketching representative diagrams on paper, and explores the capability of Augmented Reality in enhancing visual conceptions. The application converts the diagrams drawn on paper into virtual representations displayed on a tablet screen. As such learners can create physics simulation based on the diagrams and test their "envisionment" for the diagrams. Users' interaction with *AR Physics* consists of three steps: 1) sketching a diagram on paper; 2) capturing the sketch with a tablet camera to generate a virtual duplication of the diagram on the tablet screen, and 3) placing a physics object and configuring relevant parameters through the application interface to construct a physics simulation.

A user study about the efficiency and usability of *AR Physics* was performed with 12 college students. The students interacted with the application, and completed three tasks relevant to the learning material. They were given eight questions afterwards to examine their post-learning outcome. The same questions were also given prior to the use of the application in order to compare

with the post results. System Usability Scale (SUS) was adopted to assess the application's usability and interviews were conducted to collect subjects' opinions about Augmented Reality in general. The results of the study demonstrate that the application can effectively facilitate subjects' understanding the target physics concepts. The overall satisfaction with the application's usability was disclosed by the SUS score. Finally subjects expressed that they gained a clearer idea about Augmented Reality through the use of the application.

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CHAPTER ONE: INTRODUCTION

The subject of physics is an important area of education over the years, but it involves many complex concepts that pose challenges for students in learning. Among the various ways of assisting physics learning, constructing representations of concepts and problems is a well-accepted and popular approach; the reason and benefits of doing so have been studied extensively. A problem representation is a cognitive structure created by the solver in correspondence to the problem and its construction is based on the solver's domain related knowledge (Chi, Feltovich, & Glaser, 1981). Studies find that sketching representative diagrams leads to better performance of students in solving physics problems (Anzai, 1991; De Kleer, 1977; Larkin, 1981; Van Heuvelen, 1991), as such the pedagogic value of representation systems are confirmed in the domain of physics. More specific research points out that compared with text, diagrammatic representations can better promote learners' self-explanations which will lead to learners' deepened comprehension of the learning materials (Ainsworth & Th Loizou, 2003). Although the development of information technology is reshaping today's learning activities by offering a great number of computer-based learning tools and environments, the benefits of sketching representations on paper make this traditional learning strategy remain pivotal and worthwhile to be preserved and integrated into the current digital learning landscape.

Augmented Reality refers to the technology that is capable of overlaying the physical world with digital information in a real-time manner. Its capabilities in augmenting visual perception and associating positions in the physical world make the exploration of AR's pedagogical potential for educational purposes appealing to researchers. In the earlier stage of AR's development, the size, weight, and costs of AR devices impeded the technology to be extensively adopted (R. Azuma et al., 2001; Lee, 2012), but this is rapidly changing given the emergence and popularity of handheld

devices. With smart phones and tablets, AR is increasingly ushered into mobile platforms where more useful and pragmatic applications which can assist the daily practices of learners promise to flourish.

The benefits of constructing representations in physics learning and the power of AR urge the design and development of *AR Physics*, an Augmented Reality based learning application which aims to teach students the physics concepts about an object's linear motion. Its primary design features are 1) affording a traditional physics learning strategy: creating representative diagrams on paper; 2) augmenting the diagrams with lightweight visualizations on a tablet computer and 3) simulating an object's linear motions based on the hand-drawn diagrams. In short, *AR Physics* enables diagrammatic representations on paper to be virtually presented and further interactions that promote learning to be developed on the augmented diagrams.

CHAPTER TWO: LITERATURE REVIEW

Diagrammatic Representation Systems in Physics Learning

A problem representation is a cognitive structure created by the solver in correspondence to the problem and its construction is based on the solver's domain related knowledge (Chi, Feltovich, & Glaser, 1981b). A variety of forms can be taken to communicate the problem, such as text, diagram, mathematical equations, pictures etc., and an appropriate usage of one or more representation systems can facilitate problem solving and understanding (Meltzer, 2005). From a cognitive perspective, sketching representations is a process of externalizing human's thinking which indicates an important cognitive tool to facilitate their information processing (Tversky, 1999). It has also been found that diagrammatic representations contribute to prompting learners' self-explanations and leading to their thorough understanding of the learning materials (Ainsworth & Th Loizou, 2003)

In pedagogy, the usage of representation has been thoroughly researched in particular to assist the learning of physics. De Kleer (1977) built up a simulation program *NEWTON* to demonstrate how to apply representations to address problems in mechanics. He argued that the use of representations implied an experience called 'envisionment', in which one internally simulates the physical phenomenon so as to predict the outcomes. The subsequent work of Larkin (1981) attributed one's skill in solving physics problems to his ability of envisioning. He also found that students could be trained to use the representations to achieve better performance in problem solving. Van (1991) advocated a problem solving process that started from constructing a diagram representation. According to him, the diagram displays the physical process described in the problem statement, based on which students can reason about the process qualitatively,

construct mathematical representations and finally solve the problems quantitatively. This process, in comparison with the primitive formula-centered strategy (a strategy devoid of qualitative analysis), has been proved more efficient in helping students solve physics problems in his study. Van's research contributes to the theoretical and empirical foundation for the usage of representative diagrams in pedagogy. His conclusion resonates in the work of Anzai (1991), who identified that one of the major differences between physics experts and novices on physics problem solving was their ability to draw representational diagrams and make inferences from the diagrams. In his research, the functions of physics diagrams included 1) helping learners generate the relationships between abstract identities and 2) helping learners represent specific problems from which new inferences can be made.

The previous research has given sufficient support to the construction of a diagram while solving physics problems and this learning strategy has potential to be enhanced by contemporary technologies. For example, using a digital pen and a tablet computer can enable learners to draw in a digital platform. A digital pen is an input device that can recognize a user's handwriting and converts the handwriting information to digital data for computers to utilize. In the project *PhysicsBook* (Cheema & LaViola, 2012), a digital pen is used for users to sketch diagrams on a tablet and then the program can animate the diagrams and present the change of associated variables during the animation. A digital pen enables users to draw naturally in freehand, offering tremendous potential for transferring the benefits of conventional sketch-based learning to digital media, but its insufficiency emerges when it comes to drawing diagrams accurately. For example, it is difficult to sketch a straight line or a 30 degree angle merely with a digital pen because drawing accurate diagrams usually requires supplemental tools like rulers, but such accessories that are able to work with digital pens are currently lacking. As such, other approaches to incorporating

representative diagrams in digital learning need to be explored; drawing with traditional pen and paper and then utilizing Augmented Reality to augment the physical drawings is one of them.

The Power of Augmented Reality

Augmented Reality (AR) is a technology that is capable of overlaying the physical world with additional digital information in a real-time manner. Although it has been in existence for almost three decades, it is in the last few years that the technology becomes affordable enough for the general population to access.

From a technical point of view, an AR system should possess three characteristics: 1) it is a combination of real and virtual elements; 2) it supports the real-time interactivity and 3) the combination of real and virtual objects takes a 3D form to be presented (R. T. Azuma, 1997). There are two primary techniques for implementing the augmentation, use of a marker or to utilize the Global Positioning System (GPS). A marker is an image that is uniquely registered in an AR system. By doing so, the system will exclusively detect the marker in the physical world and display the virtual contents according to the marker's relevant position to the device camera. A typical marker is a QR code but as the technology advances, more artistic images can be used. In a GPS supported system, the marker is unnecessary and the information is displayed based on the device's geological position. By overlaying the physical environment with virtual information, a location-based immersive experience can be created.

In recent decades, AR's potential benefits in pedagogy have received growing attention from researchers. Trials of applying AR for educational purposes constantly emerge and those applications can be categorized into 5 directions: 1) AR books that allow for 3D characters springing from pages, 2) AR games, 3) AR applications that convey information about real world

constructions or places, 4) AR-based modeling tool that translates 2D sketches to 3D models, and 5) Skills training tools that provide contextual learning experiences (Yuen, Yaoyuneyong, & Johnson, 2011). In general AR is deemed to be able to generate immersive reality-based educational experiences in different disciplines. For example, when being applied to the subject of physics, AR is able to make the invisible attributes and features of an object become visible, and this advantage is utilized in an AR-based magnetic field visualization system (Matsutomo, Miyauchi, Noguchi, & Yamashita, 2012) in which a simulated magnetic field is generated by having a web camera capture a mock magnet. In assisting the learning of classical mechanics, AR exceeds the book-based traditional learning methods in school because it is able to visually present the dynamic variations of an object's velocity and acceleration in time, and thus is regarded as more interesting and effective in improving the learning of the target concepts (Duarte, Cardoso, & Lamounier Jr, 2005). In another study where an AR simulation was used to teach concepts of mechanics, learners were equipped with a Head-Mounted Display (HMD) and used a wireless input pen to choose various shapes and joints from a Personal Input Panel (PIP). The chosen objects were displayed in 3D through the HMD for learners to manipulate and build up their own experiments. The subsequent educational use cases validated the potential and versatility of the simulation to be integrated effectively into physics lessons (Kaufmann & Meyer, 2008).

In contrast to AR's potential for promoting learning in artificial instructional settings is the limited usage of AR for augmenting people's natural learning activities. It is challenging to incorporate AR with traditional learning methods (Lee, 2012) and the cost, size, and weight of the requisite devices such as the Head-Mounted Display (HMD) and other peripheral devices impede the extensive use of AR in daily life (R. Azuma et al., 2001). Fortunately, the emergence of wireless mobile devices such as smart phones and tablet PCs offers an approach to simplifying the

hardware setups. Having the computing, display, and input functions integrated and the GPS tracking capability imbedded, mobile platforms are gradually becoming the breeding ground for AR applications.

Learning from Computer Simulations

Computer simulation is a program that runs on a computer or a network of computers to reproduce behaviors of a system. In the interaction with computer simulation, users usually undergo a process consisting of primitive analysis which is concerned with the identification of variables in the system, generation of initial hypothesis, and testing the hypothesis until it is finally being accepted or rejected by users (Van Joolingen & De Jong, 1991). The main action of a user while operating a simulation is to modify the value of input variables, observe the change of output variables so as to infer the rules and characteristics of the system underlying the simulation (De Jong & Van Joolingen, 1998).

Computer simulation pervades science education for many reasons. They are widely used to create safe and accessible exploratory learning environments (Alessi & Trollip, 1991). Without simulations, scientific experiments that require specialized equipment would not be available for the general population. They scaffold the authentic inquiry-based learning practices which include question generation, hypothesis construction and project execution (De Jong, 2006). They provide ways for instructors to assess learners' performance and give feedback (Hickey, Kindfield, Horwitz, & Christie, 2003). They dramatically boost students' retention rate by allowing for practice and also by providing a mechanism for teaching others (Boehle, 2005).

In parallel with the affirmation on the pedagogic value of computer simulation is the increasing number of simulation software that does not only teach additional contents but does so

with an improved graphic quality. For example, *PhET* is a library of online educational simulations created for teachers and students that demonstrates concepts in physics, chemistry, biology, earth science, and mathematics. Research on *PhET* has generated a significant amount of findings about the learners achieving improved learning results from *PhET* than from the traditional learning methods including laboratory experiments, lecture presentations, etc. (Wieman, Adams, & Perkins, 2008). *Algodoo* is a commercial learning application which teaches physics concepts by empowering users to create simulations with simple drawing tools such as circles, ropes and chains. These applications incorporate simulation into playful and visually appealing design, achieving tremendous progress in terms of combining education and fun.

In the following section, an application, *AR Physics,* which utilizes AR to incorporate drawing representative diagrams and present a simulation experience in the learning process, will be presented and analyzed

CHAPTER THREE: AR PHYSICS

General Introduction

AR Physics is an Augmented Reality (AR) based application that converts a conventional and verified physics learning process, in which students draw a representative diagram on paper, into an interactive learning experience where students will be provided with dynamic feedback on their freehand drawings displayed on the screen of a digital device.

Sketching diagrams encourages a problem solving strategy that starts from "envisionment" by which one internally simulates the physical events and predicts outcomes (De Kleer, 1977). *AR Physics* preserves this process. Moreover it creates a simulation of the physical events for the learner to test his/her prediction until the concepts underlying the simulation become a part of the learner's mental information. Table 1 illustrates the learning methods supported in *AR Physics*:

Table 1: Learning method supported in *AR Physics*

Learning Method	**Support in AR Physics**
Envision	Sketch diagrams
Test	Simulation

For example, in the matter of a physics problem about an object's linear motion on an inclined plane, a representative program can be sketched as Figure 1. In the diagram, the physical process stated in the problem - an object moving on an inclined plane is depicted in which the relevant position between the moving object and the inclined plane is qualitatively demonstrated. Based on the diagram, the forces added to the object can be analyzed and annotated (Figure 2) from which its motion on the plane can be further inferred. The outcome predicted by the learner will be testified in *AR Physics* because it will augment the static diagram to have a virtual object

moving on it so as to display a simulation of the stated problem. In the simulation, the learner will see how the object moves by respecting the physics laws of motion and adjust his/her comprehension about the linear motion based on the simulation.

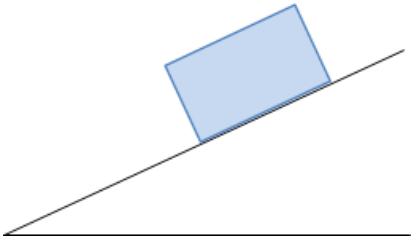


Figure 1: An example of a physical diagram sketched on paper

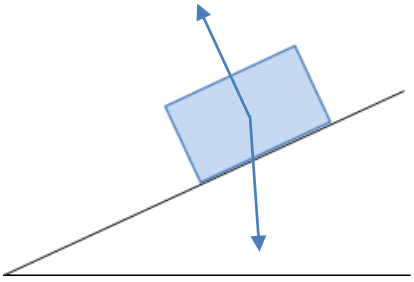
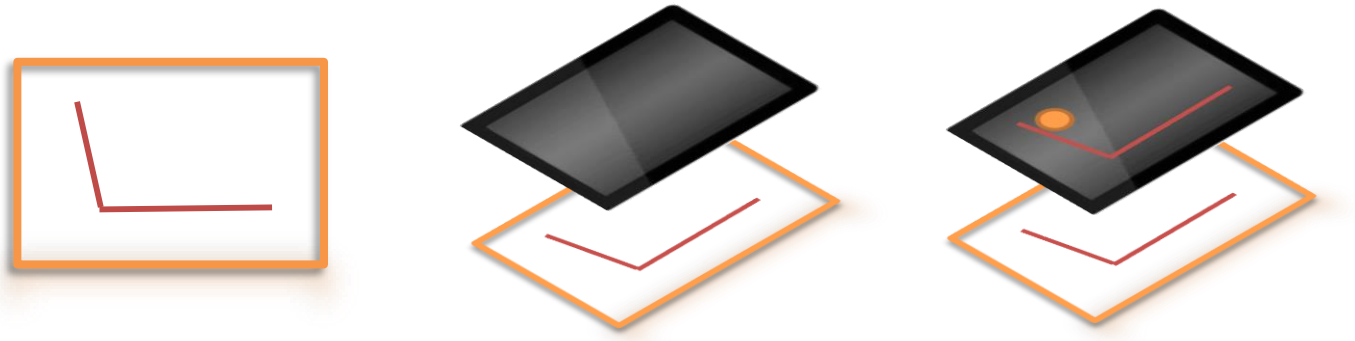


Figure 2: Force analysis on an object's motion on an inclined plane

To produce the interactive experience based on the diagram, *AR Physics* encourages learners to sketch the "track" portion on paper (the inclined plane in Figure 1) and then hold a tablet to capture the paper with its see-through camera. The track will be recognized by the application and presented digitally on the tablet screen in 3D. Students will then be allowed to include additional objects into the diagram (e.g., the object on the top of the incline in Figure 1) to create a dynamic physics simulation during which they can observe how the objects and associated quantities vary. A simplified workflow of the application can be illustrated as below:



1. Sketch a diagram on paper
2. Capture the diagram with a tablet camera
3. Construct a simulation based on the diagram

Figure 3: A workflow of the application

Focal Domain

The focal domain of the application is an object's linear motion as it is the most basic of all object motions and the relevant theories and concepts such as free fall motion, velocity, acceleration, etc. are taught as core content in physics.

There are two types of linear motions based on Newton's first law of motion: the linear motion with constant velocity or zero acceleration and the linear motion with variable velocity or non-zero acceleration. An object moving on a horizontal plane, without encountering any external forces, will move with a constant velocity. The displacement S of this object is related to its speed v and moving time t as Equation 1 shows. An object moving on a horizontal plane, when encountering external forces will get an acceleration and its velocity will be changed as a result. Equation 2 displays the change of the object's speed V in relation to its acceleration a, moving time t and initial velocity V_0. Equation 3 displays the displacement S of this object when it moves with an acceleration. Equation 2 and 3 also apply to the motion of an object on an inclined planed because under this condition, the object is moving with a non-zero acceleration. Free fall means

an object is moving vertically with an acceleration of gravity, which is a constant '*g*'. The numeric value of g is 9.8m/s/s. Its displacement in relation with moving time can be displayed with Equation 4. In *AR Physics*, the four equations support the implementation of a physics simulation system. The following figure displays this information in equation form.

$$S = v \cdot t \quad (1)$$

$$V = V_0 + a \cdot t \quad (2)$$

$$S = V_0 \cdot t + {}^1\!/_2 \cdot a \cdot t^2 \quad (3)$$

$$S = {}^1\!/_2 \cdot g \cdot t^2 \quad (4)$$

Features and implementation

AR Physics delivers a combined experience of drawing diagrams on paper, constructing, manipulating and observing a physics simulation based on the diagrams. The interaction with the application consists of three steps: 1) users sketch a diagram on paper; 2) users capture the sketch with a tablet camera to generate a virtual duplication of the diagram on the tablet screen, and 3) they place a physics object and configure relevant parameters through the application interface to construct a physics simulation.

Supporting frame

A supporting frame (Figure 4) was built to hold the tablet and accommodate the sketch board. The reason for doing so is because it was noticed that a tablet when being held by users was not stable enough to capture the diagrams with consistency. With the frame, the tablet is placed on top of, and a certain distance apart from, the sketch board lying underneath so users can keep a consistent relevant position with each other and provide a stable operating environment to users.

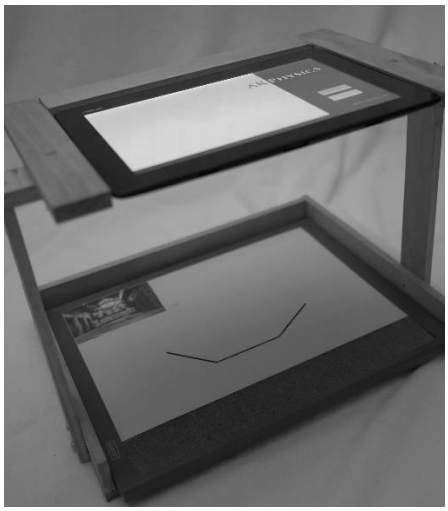


Figure 4: Supporting frame of the tablet

Sketch and Recognize Track

The track is the portion to be sketched on paper. It will be recognized by the program and become a part of the physics simulation. Two issues need to be addressed to implement the basic track recognition: 1) generation of a virtual 3D world that will overlay the physical sketch board so the digital track generated in step two can be superimposed onto the sketch board. This is also the core element in AR that serves to combine virtual and real; 2) generation of a digital representation of the track drawn on the sketch board. For the first issue, I adopted the marker-based system, which is a predominant technique in AR to overlay the virtual information onto the physical world. In *AR Physics*, a 3" by *2*" marker is printed and tucked into the top left corner of the sketch board. The marker contains the "visual cues" for the device camera to seek. Upon successfully locating the marker, the camera will inform the system so the system can calculate the tablet camera viewpoint relative to the physical marker and calibrate the camera of the virtual 3D world until it shares the same viewpoint as the tablet camera. In other words, what is presented to the users in the virtual world will be the same with what they see through the tablet camera.

To generate a virtual representation of the track, I used the technique of line detection in computer vision. Line detection enables user to distinguish the silhouette of a drawn track from the sketch board based on the difference in their colors (the track is colored and the sketch board is white). Once the system 'knows' the shape and position of the track, it will generate its virtual duplication on the tablet screen. In order to achieve a sharp contrast and optimize the precision of the track recognition, a marker pen with thick black ink is adopted as the users' sketching tool.

What needs to be mentioned is that in the current landscape of AR applications, incorporating the recognition of user generated objects into the system is rarely implemented. Most applications locate the marker and display preset virtual objects or information overlaying the real world. However, due to the limitation of the device quality and current technical abilities, the recognition results present a certain degree of deficiency in *AR Physics*. For example in an environment with dim light or shadow, the recognition of the track might be incomplete. I considered this defect in design and enabled a 'recapture' function in the application. The recapture function allows users to capture the track multiple times until a 'good-enough' representation of the track is generated on the screen. Figure 5 shows a drawn track being recognized and displayed on the screen (The black line represents the track drawn with a marker and the pink line represents the recognized track).

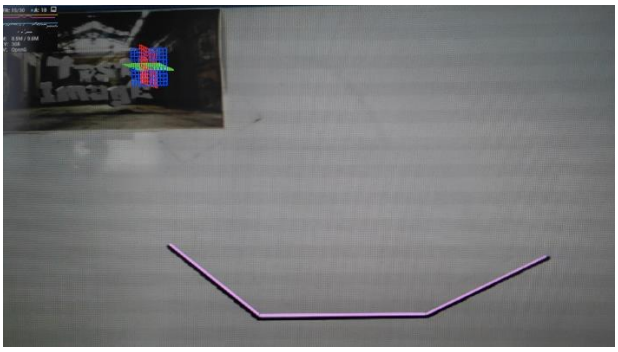


Figure 5: A recognized track based on a drawn track

Moving Object and Variables

A complete physics diagram is comprised of a track, which is sketched on paper, and an object that will move on the track. After getting a digital track from a user's sketch, the program will allow users to drag and drop a ball, which plays the role of a moving object, on the screen. The ball can be placed on or apart from the track to form various relationships in position with it such as in Figure 6.

Additionally, relevant variables are provided to diversify the simulation. According to Newton's laws, an object's linear motion is related to its speed, moving time and displacement. Therefore, in this simulation system I narrowed down the configurable input variables to the mass and initial speed of the object while keeping the current speed of the ball and its moving time as the output variables. The design of the variables is intended to highlight the core contents of the target learning domain, and urge learners to reflect on the relationship between the relevant variables.

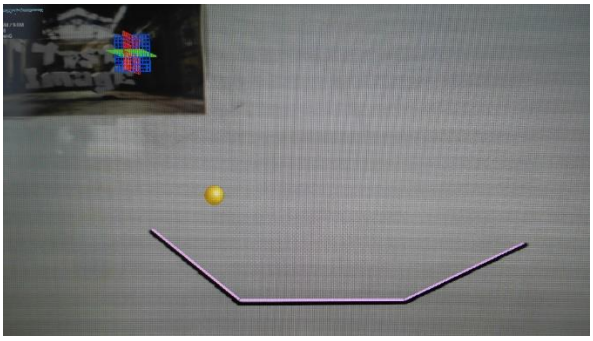


Figure 6: A ball placed above the track

Simulation

With the track captured and variables set, learners complete the construction of a simple physics simulation scene. By activating the simulation, leaners can observe the movement of the object on the track along with the change of variables (current speed and time) during the simulation. In order to assist the observation process, I provided reset and pause functions. The reset function brings back the input variables to the original value and the ball to its starting position so the learner can repeat the simulation when needed; the pause function pauses the ball's movement for users to catch the momentary value of the variables, for example when the ball reaches a horizontal plane in a free falling simulation. Table 2 summarizes the User Interface (UI) functions provided in AR Physics and Figure 7 shows an example simulation.

Table 2: UI functions provided in *AR Physics*

Capture/Recapture	Recognize the diagram drawn on the white board and generate a virtual diagram
Start	Start the simulation
Reset	End the running simulation and reset the ball's position, mass and initial speed to default value
Pause / Continue	Pause / continue the simulation

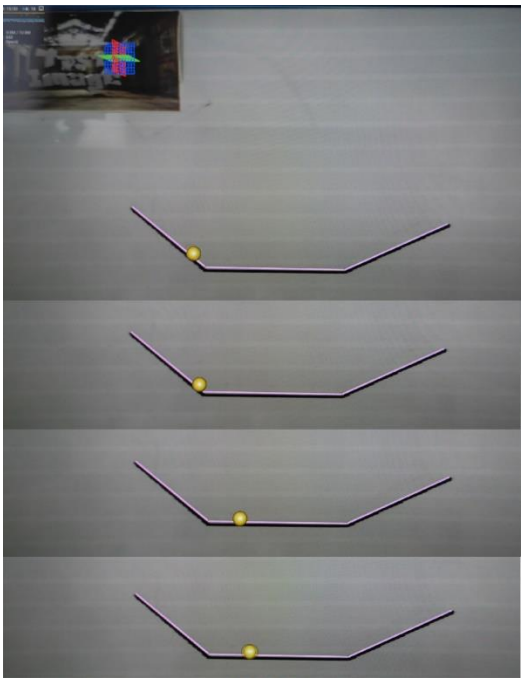


Figure 7: A simulation of the ball moving on the track

CHAPTER FOUR: METHODOLOGY

Research Questions

Research about learning processes has indicated the positive effects of sketching representative diagrams in the domain of physics. Although this sketch-based learning strategy has been applied in many educational tools, its integration with the technology of AR is relatively unexplored. As such, the efficacy of *AR Physics* need to be examined. Meanwhile its usability and potential impact on users' concepts about Augmented Reality will be explored. A user study with the following specific research questions was performed:

1- How does the application influence users' ideas about Augmented Reality and its potential application in education?

2- What are the usability and functionality issues existing in the application, and what feasible solutions can be found to address them?

3- Does *AR Physics* achieve its purpose of improving users' understanding of the target physical concepts?

The answers to these questions will provide insights into how AR can be utilized as an effective educational tool and potentially confirm the value of the *AR Physics* application as a useful design for the learning of linear motion in physics. This research will also expose the critical design issues and allow for an examination of its potential along with the advancement of Augmented Reality in the future.

Experiment Design

A human subjects experiment on *AR Physics* was conducted to investigate the educational potential and evaluate the usability of the application. To generate the results that are expected to provide answers to the research questions outlined in the previous section, both quantitative and qualitative methods were used in the experiment. The quantitative results assess the usability of the application and its efficiency in improving user's comprehension on the target physical concepts. The qualitative results reveal participants' change of concept about Augmented Reality and their subjective experience while using the application.

Hardware Settings

In the experiment, I used an Android based tablet with the following specifications:

- 1 GHz ARM CPU
- 1 GB Internal Memory
- 130 Megapixel camera
- 10.1 inch touch screen

The tablet is powerful enough to run *AR Physics* at an average of 25 frames per second.

Subjects

12 senior college students (4 female, 8 male) ranging in age from 21 to 30 (avg = 24.1) were invited to participate in the study. Students participated in the study as part of a Web Design workshop course. 3% of the course grade was given to the participants as an incentive. Among the 12 participants, 9 studied physics in high school and 4 studied in college. None of them participated the physics activities out of school.

Tasks

In the experiment, all the participants were required to interact with the application to complete three tasks in sequence: Free fall, Motion on Inclined Plane and Motion on Horizontal Plane. Below are the scripts for the three tasks.

Task One: Free Fall

a. Draw a simple horizontal line on the sketch board.
b. Capture the line with the tablet camera to have the line presented on the screen
c. Place a ball above and a certain distance apart from the line.
d. Hit the start button on the interface and observe the ball falling off until it reached the horizontal plane.
e. Change the value of the input variable: mass and then restart the simulation.
f. Move the ball to a lower position and then restart the simulation.

Task one displays the free falling motion of an object. Meanwhile it conveys the impacts of two variables: the mass and the height of the object on this motion.

Task Two: Motion on Inclined Plane

a. Draw an inclined linear line on the sketch board.
b. Capture the line with the tablet camera to have the line presented on the screen
c. Place a ball at a certain position on the incline.
d. Hit the start button on the interface and observe the ball sliding down until it reaches the end of the inclined line.

e. Reset the simulation and change the value of the input variable: mass and then restart the simulation.
f. Reset the simulation and move the ball to a different starting position on the inclined line and then restart the simulation.
g. Change the diagram to modify the angle of the inclined on the sketch board. Repeat steps b, c and d.

Task two displays an object's motion on an idealized, frictionless inclined plane. Meanwhile it conveys the impacts of three variables on this motion: the mass and starting position of the ball, and the angle of the incline.

A derivative task of task two:

a. Have an auxiliary horizontal line at the bottom of the inclined line.
b. Have the ball fall off from the same position instead of rolling down the incline.

The derivative task is designed to help participants understand that a descending object's speed is closely associated with its original potential energy, decided by its height at the start, but is irrelevant to how it descends (free falling or rolling down an incline).

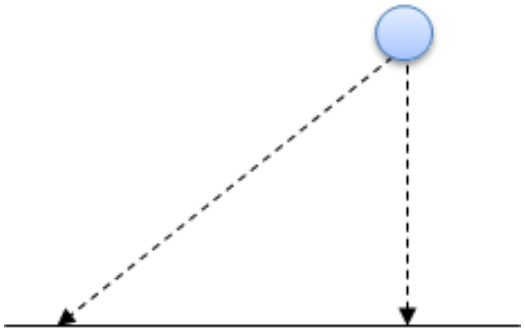


Figure 8: Derivative task of Task Two

Task Three: Motion on Horizontal and Inclined Planes

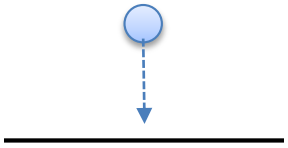
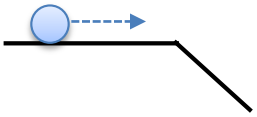
a. Draw a horizontal line on the sketch board.
b. Capture the line with the tablet camera to have the line presented on the screen.
c. Place a ball on the line.
d. Give a value to the input variable: initial horizontal speed.
e. Hit the start button on the interface and observe the ball moving on the horizontal line.
f. Add an inclined line to the end of the horizontal.
g. Reset the simulation and change the value of the input variable: initial horizontal speed and then restart the simulation.

Task three displays an object's motion on an idealized, frictionless horizontal plane. Meanwhile, it displays the influence of the initial speed of the ball, especially when it encounters a decline.

During the three tasks, participants were advised to pay attention to the change of variables displayed on the screen, and use the pause function when necessary. In addition, they were encouraged to speak aloud what they observed in the simulations.

Table 3 lists out the representative diagrams, the variables that can be changed, and the learning goals for each tasks.

Table 3: Possible Diagrams for each task

	Task 1	**Task 2**	**Task 3**
Diagram	*Horizontal for Free fall* 	*Inclined plane* 	*Horizontal and Inclined plane* 
Variables	Ball's mass; Ball's starting position	Ball's mass Ball's starting position Incline's angle	Ball's initial speed
Learning goals	According to Equation 1, 1) a free falling object's mass has no impact on its speed; 2) its falling height has impact on its speed.	According to Equation 2, 1) An object's mass has no impact on its linear motion status; 2) An object's moving distance, time and speed interrelate	According to Equation 3, 1) An object's current moving speed relates to its initial speed

Measurement

Preliminary and post questionnaires were used in the experiment. The preliminary questionnaire includes questions to collect participants' demographics, physics learning background (interests, experience, academic performance, etc.), and eight multiple choice learning questions (See Appendix A). The learning questions evaluated participant's physics knowledge about free fall and linear motion on horizontal and inclined planes.

The post questionnaire includes two parts. The first part is the System Usability Scale (SUS), which is a simple but reliable tool measuring the usability of various products and services, including hardware, software, mobile devices, websites and applications (Brooke, 1996). The scale consists of 10 item questions with 5 responses options from Strongly Agree to Strongly Disagree. SUS has been widely used and one of its noted benefits is its validity even on a small sample size. The second part of the post survey has the same physics learning questions on the preliminary test

to measure a participant's improvements in physics understanding after interacting with the application (See Appendix A).

Preliminary and post interviews were also conducted with each participant to assess their perceptions of Augmented Reality, their opinion about its application to learning, as well as any challenges they encountered when using the application (See Appendix B). Participant's answers to the survey questions were audio taped.

Procedure

The investigator greeted the participants and gave them the consent form to read upon their arrival. Once the participants agreed to continue, the investigator gave them a copy of the preliminary questionnaire to complete. Next, the participants were interviewed and their responses were recorded. At the beginning of the experiment, the investigator gave the participant a brief introduction about the application, and provided them the drawing tools including a dark ink marker, an eraser, and a ruler. The participants were told that the use of ruler was optional while drawing. Then the investigator led the participant through the three tasks in sequence. After all the tasks were completed, the participants were given a post questionnaire to complete, followed by the post interview. The whole procedure lasted about 40 minutes and at the end, the investigator debriefed the participant on the purpose of the study and thanked them for their participation.

CHAPTER FIVE: FINDINGS

Participants' Perception of AR

Participants' perceptions about Augmented Reality were explored through this study. In the preliminary interview, 10 participants gave a positive response to the question of whether they heard of AR before and were able to give at least one example or an experience they had with AR in their life. The rest of the participants expressed either a vague idea of AR or uncertainty about the difference between Augmented Reality and Virtual Reality. Among the AR examples cited by the participants, *Nintendo 3DS* was mentioned the most frequently (four times). It comes with a set of cards that when viewed by players from the device camera, cause 2D characters to appear in 3D. Further, *Google Glass*, the most well-known AR apparatus which can be worn by users as glasses and augment the world viewed through the lens was also referred to multiple times. The participants' answers do not only disclose the most successful commercial AR products so far but suggest that Augmented Realty has been widely recognized by youths.

Participants were also asked about their opinions about applying AR to help people learn. 11 participants expressed their confidence about the technology's pedagogic value. According to their responses, AR's ability to incorporate learning into daily life and real world experience was one of its major advantages. As one participant stated:

"*The more you are able to encompass technology into everyday life, the better off you are. I mean, you can search up any information you want on Google right now and you can have it like that (snapping his finger). Imagine you could have searches right on your eyes…Imagine you could have contacts or something…* "

Two participants noted that AR was able to transform flat representations into three dimensions and provide learners with multiple perspectives for viewing. They felt that architecture and geometry were the disciplines that could benefit the most from this feature. In general, participants' responses indicate their acceptance of AR and expectation for it to facilitate learning, suggesting that AR has become a widely acknowledged and trusted technology when being applied to learning, which in turn resonates in other studies which also encourage the further utilization of AR for educational purposes.

In the post survey, participants were asked whether the interaction with *AR Physics* led to any changes to their perceptions of AR. 11 participants thought the application represented a prototypical AR product, helped confirm their previous view of what AR is, and some even reported that *AR Physics* supplements their ideas of Augmented Reality. One participant stated:

"*I do think I get a better idea (of what AR is). I haven't used one that does anything like this before. Everything else was kind of like…it just overlays something on the world around you. It is not really something that you are interacting with that much in the real world. It is always something overlaid and you just tap your screen and then it is done. This one really shows me that it can see what you are doing in the real world and incorporate that into the application.*"

This response highlights the difference between *AR Physics* and other applications. Most of the current marker-based AR applications on the market present the experience by loading preset images or animations overlaying an object in reality. In *AR Physics* the experience is improved in that it is augmenting an object generated by users. Learners draw a line, an angle, or a more complex diagram, and these different drawings will be recognized and turned into an interactive

simulation in real time. From a technical point of view, this feature is achieved by the use of Augmented Reality in combination with computer vision.

Usability

The System Usability Scale (SUS) was used to evaluate the application's usability in the post survey. To rate the SUS scores, participant's original scores for the 10 questions ranging from 1 to 5 were converted into 10 new numbers each ranging from 0 to 4. Adding up the converted responses for each participant and multiplying the total by 2.5 generates a new number ranging from 0 to 100. This number is the interpretable score given by each participant to the application. According to previous research using the SUS scale (Sauro, 2011), a score above 68 would be considered above average. The average score of the 12 participants based on the conversion method in this study was 75.83, which means the 12 participants rated the usability of *AR Physics* as Above Average.

In spite of the overall promising result, the post survey reveals some areas that warrant further consideration and refinement of the application. When we asked the participants what was the most challenging issue they had when using the application, five out of 12 participants indicated the diagram detection and recognition. The quality of line detection based on AR is susceptible to disturbances in the external environment, such as dim light and shadows. The camera fidelity of the device is another factor that may cause inconsistency in detection. I provided the function of recapture in the application to alleviate the problem. The recapture function allows users to capture their drawn tracks multiple times until they attain a satisfactory one. However to achieve a more accurate result in track recognition requires a more sophisticated algorithm that demands more computing power and higher camera resolution, both of which are not available on

the tablets currently on the market. In addition to the diagram detection, the tactile responses while interacting with the interface were also mentioned in the post interview several times. For example, three participants reported difficulties in dragging and positioning the ball to the interface; two participants suggested using bigger buttons and icons so it would be easier to "click" them. The feedback received was in accordance with generally agreed principles for UI design on tablet devices such as the need for a larger touch area. The responses provided some insights on how to improve interface issues and to achieve a better user experience overall.

In addition to the problems pointed out by the participants, I also noticed some additional issues during the experiment that impeded participants' ability to engage with the target physics concepts.

1) First, the simulation of an object's motion is not realistic enough. This issue becomes apparent in the free falling task. In the real world, an object will fall with an acceleration of 9.8 m/s/s. To simulate the process, I need to assign a suitable acceleration value to the ball in the system. However, the value I assigned is not big enough which misled the participants to believe the ball is falling with a constant speed in the simulation (acceleration is zero). Although I predicted this issue and had the numerical value of the current speed displayed on the screen, participants tended to ignore these numbers and focused on the more eye-catching image of the ball falling. The solutions to this issue includes 1) tweak the value of the gravity acceleration in the system to make the simulation as realistic as possible; 2) provide a more iconic and conspicuous indicator of the speed such as an arrow that will elongate along with the increasing speed of the ball so the users will be attracted to notice the change of the speed.

2) Secondly, lack of tools to assist the completion of diagrams and the construction of simulations. When sketching diagrams, participants needed to draw a horizontal line on which the ball can move at a constant speed (no vertical acceleration). However it was found in the experiment that they had problems with drawing a perfectly horizontal line (A ruler was provided to them but it did not solve the issue). Several times participants sketched a straight but slightly declining line. Subsequently they had the misconception that when the ball moves on a "horizontal" line, its speed changes. To solve this issue, an assisting tool such as a pre-drawn line which is perfectly horizontal needs to be provided so the users can draw a line parallel to it. When constructing a simulation, participants had a problem with positioning the ball because in some tasks placing the ball on the same spot is required (the inconsistent starting positions of the ball will bring new variations to the simulation), but it is hard to achieve without tools. As a result the participant may be given a misleading conclusion by the simulation. For example, in the task comparing the speed of the ball when it slides down an inclined line and free falls from the same height, participants reached an incorrect conclusion that when reaching the same horizontal level, the speed of the ball is different in this two situations. This violates the physical principles. However, this difference in speed is caused by a human error in that the participant did not have the ball start from the same position. One possible solution is to provide tools to assist the process of building a simulation scene. In the case of this positioning issue, to print the coordinates of the ball on a screen for users to refer to would help.

Learning Improvements

Comparison between pre and post questionnaire

Participants' knowledge about physics was examined with eight learning questions before and after using the *AR Physics* application. Answers were scored and I ran the paired t-Test on the average score of all the participants on the learning questions in the preliminary survey and the post survey. It was found there was a significant difference for the scores, $t\ (11) = 3.22$, $p < .05$, indicating that participants' average score in the post survey is significantly greater than their average score in the preliminary. In other words, the participants' performance on the physics questions improved after completing the three tasks in *AR Physics*. When analyzing the scores of the questions corresponding to each of the three activities, we found that for the free fall questions, the participants received an average score of 1.5 in the post survey, significantly greater than the average score of 1 in the pre-survey ($p < 0.05$). For the questions pertaining to motion on inclined plane, the participants' average score is 3.75 in the post survey and 3.17 in the pre-survey, demonstrating a significant difference ($p < 0.05$) between the two scores according to the t-test. These results successfully demonstrated the educational effect of the application in the domain an object's linear motion.

Correlation Analysis

I collected the data about participants' physics learning experience, interests in physics, their self-evaluation on how good they are at physics, as well as their feelings of difficulty with physics in the preliminary survey. A Pearson's Test was run to find any correlation among those factors. However, no significant correlation was found with this limited sample size.

Qualitative feedback

I interviewed the participants after the experiment about whether they feel the use of Augmented Reality helps them learn in this application and in general, and received extremely positive feedback on this question. 11 participants agreed that the Augmented Reality is helpful for them to understand physics and solve the learning questions. They cited different reasons for this. For example, two mentioned that the virtual representations helped explain the questions clearly and three emphasized that seeing "something" happen in real time made physics easier to understand compared to having these ideas explained verbally.

In terms of preserving the traditional freehand drawing of diagrams rather than using the computer generated diagrams in the application, all participants expressed their enjoyment of this experience when we asked them how they like the way of learning by freehand drawing in the post interview. Two participants said they were visual artists and drawing itself is an interesting activity for them. Some credited drawing for making things less theoretical and one compared drawing by hands with by computer. He said:

"*Since you are drawing, you can actually feel you are doing it. You can do it with something drawn by computer, but that will take away the sense of doing. Having something you are actually drawing makes it (learning) more interesting and understandable.*"

The responses from participants give support to the incorporation of drawing diagrams by hand in a variety of aspects, and affirmed the value of this traditional learning strategy.

CHAPTER SIX: CONCLUSION

Augmented Reality as an emerging technology has received growing attention in recent years. Its abilities to augment peoples' vision of the physical world and to create association with geographic location have made it applicable for educational purposes in a variety of disciplines. This paper describes an AR-based application built up on a handheld tablet device. The application intends to teach some physics concepts about an object's linear motion. In addition to the use of Augmented Reality, the application incorporates the freehand drawing of representative diagrams into the learning process because in the field of physics, it has been verified that drawing representative diagrams of physical concepts can help learners achieve better understanding. Augmented Reality is able to bring the statics diagram on paper into the virtual world so people can modify it, use it in an interactive physics simulation, and get feedback from what they drew.

A user study was conducted on the prototype of *AR Physics* with 12 participants. The purpose of the study is to examine: 1) how the application influences users' ideas about Augmented Reality and its potential application in education; 2) what are the usability and functionality issues existing in the application, and what feasible solutions can be found to address them; 3) and whether *AR Physics* achieves its purpose of improving users' understanding of the target physical concepts.

The qualitative result from the interview with the participants shows that Augmented Reality is widely accepted by youth and it is regarded as beneficial for learning. The usability assessments reveals that participants feel satisfied with the usability of the application in general, though some deficiencies exist. More importantly, the application was shown effective in improving participants' physics knowledge with participants reaching a significantly higher

average score on the learning questions in the post survey than in the preliminary survey. A number of issues that impaired the efficacy of the application were found. The primary ones include the fact that the recognition of the tracks drawn by participants is susceptible to the external environment; the simulation of an object's motion is not realistic, and the application is lacking tools to assist users to complete diagrams and simulation. Corresponding solutions should be implemented in future work. For the deficiency of track recognition, a device with more computing power and camera resolution is needed. The simulation of an object's physical motion needs delicate tweaks to values used in the physics system. Finally, some tools need to be provided on the interface to help users to complete diagrams and physics simulation.

In conclusion, *AR Physics* supports a verified learning strategy in physics: envisioning the physics phenomenon by sketching diagrams. Furthermore it supplements the strategy by enabling the 'envisionment' to be testified in a physics simulation with the help of AR. When being applied to the domain of linear motion, it has shown a great potential, but its value in a broader knowledge domain deserves further exploration. The hope is that this prototype and the research work will not only contribute to overall study of AR based learning applications, but also encourage more research about how to take the advantage of AR to enhance traditional learning strategies.

APPENDIX A: PRELIMINARY AND POST SURVEY QUESTIONS

Preliminary survey questions Part I

These are a few questions about your background and knowledge of physics. Either check the correct response or fill in an answer.

1. Age?

2. Gender?

3. Level of Education?

4. Major in college?

5. Did you take a physics course in high school?

6. Have you taken a physics course at the college level?

7. Have you participated in any physics related study activities such as a science-oriented summer camp?

8. How much do you like physics?

9. How good are you at physics?

10. How difficult do you feel physics is?

Post Survey Questions Part I

For the following questions, select how strongly you agree with the statement with 1 meaning "Strongly Disagree" and 5 meaning "Strongly Agree. Please answer the questions based on your immediate response.

1. I think that I would like to use this application frequently
2. I found the application unnecessarily complex
3. I thought the application was easy to use
4. I think that I would need the support of a technical person to be able to use this application
5. I found the various functions in this application were well integrated
6. I thought there was too much inconsistency in this application
7. I would imagine that most people would learn to use this application very quickly
8. I found the application very cumbersome to use
9. I felt very confident using the application
10. I needed to learn a lot of things before I could get going with this application

Preliminary and Post Survey Questions Part II

For the following questions, select the correct answer based on your knowledge.

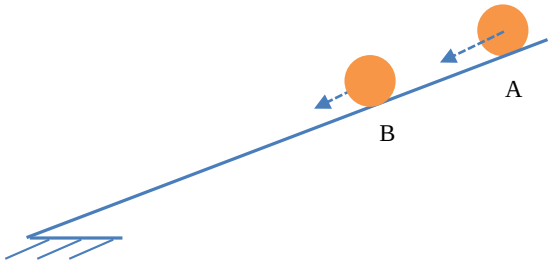
1. Given a metal ball dropping onto an inelastic floor from a height of 1 meter, how will its vertical speed change without considering the air friction?
   - ☐ It will become higher
   - ☐ It will become lower
   - ☐ It will stay unchanged
   - ☐ It depends on the mass and size of the ball

2. Considering two metal balls separately drop onto an inelastic floor from a height of 1 meter and a height of 2 meters, which of the statements below is correct?
   - ☐ The ball dropping from the height of 2 meters will reach floor within shorter time
   - ☐ The ball dropping from the height of 1 meter will reach floor within shorter time
   - ☐ These two balls will reach floor within the same duration of the time
   - ☐ The ball with bigger mass will reach floor within shorter time

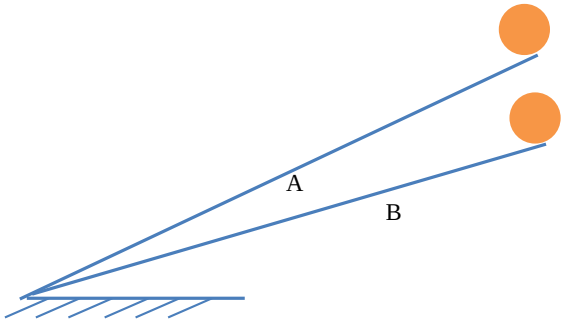
3. Given a frictionless inclined plane, how do you think the speed of an object would change if it is rolling down the plane?
   - ☐ It will become higher
   - ☐ It will become lower
   - ☐ It will stay unchanged
   - ☐ It depends on the mass and size of the object

4. Given two metal balls with different mass rolling down a frictionless inclined plane from the same position, which object do you think will reach down the end of the incline first?
   - ☐ The one with bigger mass
   - ☐ The one with smaller mass
   - ☐ The two objects will reach at the same time
   - ☐ Not sure

5. Given a metal ball rolling down a frictionless inclined plane respectively from position A and position B, starting from which position will give the ball a higher speed when it reaches down the end of the incline?
   - ☐ Position A
   - ☐ Position B
   - ☐ The speed will be the same
   - ☐ Not sure



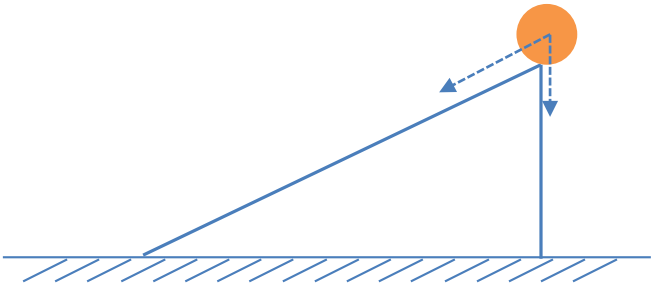
6. Given a metal ball rolling down two frictionless inelastic inclined planes as below, which plane will give the ball a higher speed when it reaches down the end?
   - ☐ Plane A
   - ☐ Plane B
   - ☐ The speed will be the same
   - ☐ None of the above



7. Given a metal ball rolling on a frictionless horizontal plane at certain speed, which of the following statements is (are) correct when it reaches the end of the horizontal?
   - ☐ The ball will continue to roll down the inclined plane
   - ☐ The ball will fly out of the plane
   - ☐ The ball will stop rolling
   - ☐ Depending on the speed of the ball, the ball will either roll down the inclined plane or fly out



8. Given a metal ball moving under 2 conditions 1) it rolls down a frictionless inclined plane to an inelastic floor, 2) it falls down from the same height to the same floor, what is the relationship between the speed of the ball when reaching the floor under these 2 conditions?
   - ☐ Under condition 1, the ball's speed is higher
   - ☐ Under condition 2, the ball's speed is higher
   - ☐ The speed will be the same under the two conditions
   - ☐ None of the above



APPENDIX B: PRELIMINARY AND POST INTERVIEW QUESTIONS

Preliminary Interview Questions

1. Have you ever heard of Augmented Reality technologies?

2. Do you think Augmented Reality can be applied to help people learn?

Post Interview Questions

1. Since you've used an Augmented Reality application in this study, do you have a clearer idea of what it is?

2. Do you think in this application the Augmented Reality helps you learn?

3. Do you enjoy the way of learning by freehand drawing?

4. What do you feel is the most troubling issue that prevents you from learning efficiently in this application?

5. Do you think you would be interested in this kind of learning approach if the tablet and frame can be replaced by some AR apparatus like Google Glass?

APPENDIX C: STATISTICAL TEST

	Post Total	*Pre Total*
Mean	6.166666667	5.083333333
Variance	2.333333333	2.992424242
Observations	12	12
Pearson Correlation	0.751151234	
Hypothesized Mean Difference	0	
df	11	
t Stat	3.222650285	
P(T<=t) one-tail	0.004060346	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.008120692	
t Critical two-tail	2.20098516	

APPENDIX D: LEARNING QUESTIONS RAW DATA

Preliminary Questionnaire Learning Questions Data

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Par01	0	1	1	1	1	1	1	0
Par02	0	0	1	0	1	1	0	0
Par03	1	0	1	0	1	1	1	0
Par04	1	1	1	1	1	0	1	1
Par05	0	0	0	1	0	0	1	0
Par06	0	1	1	1	1	1	1	0
Par07	1	0	0	0	1	1	1	0
Par08	1	1	1	0	1	1	1	0
Par09	0	1	1	0	1	1	1	1
Par10	0	1	0	1	0	1	1	0
Par11	0	0	1	0	1	1	1	0
Par12	1	1	1	1	1	1	1	1

Post Questionnaire Learning Questions Data

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Par01	1	1	1	0	1	1	1	1
Par02	1	0	0	0	0	0	1	1
Par03	1	0	1	1	1	1	1	0
Par04	1	1	1	1	1	1	1	1
Par05	1	0	1	0	0	0	1	1
Par06	1	1	1	0	1	1	1	1
Par07	1	1	1	0	1	1	1	0

Par08	1	1	1	0	1	1	1	1
Par09	1	0	1	0	1	1	1	1
Par10	1	1	1	1	1	1	1	0
Par11	0	0	1	0	1	1	0	0
Par12	1	1	1	1	1	1	1	1

System Usability Scale (SUS) Data

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Par01	2	4	3	4	4	3	3	4	4	3
Par02	3	2	4	2	3	2	3	2	4	2
Par03	4	2	2	1	4	2	2	2	2	0
Par04	2	4	4	4	4	4	3	4	4	4
Par05	3	3	3	3	3	4	4	4	3	3
Par06	3	3	3	3	4	3	4	3	3	4
Par07	3	4	4	4	3	4	4	4	4	1
Par08	1	4	3	4	3	2	4	4	4	4
Par09	2	3	3	4	3	1	2	2	3	3
Par10	2	3	3	4	3	4	4	4	4	4
Par11	2	2	2	1	3	2	1	3	2	4
Par12	2	3	2	4	2	2	3	2	3	4

APPENDIX E: IRB APPROVAL

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Yao Zhou**

Date: **March 27, 2014**

Dear Researcher:

On 03/27/2014, the IRB approved the following human participant research until 3/26/2015 inclusive:

Type of Review:	Submission Response for UCF Initial Review Submission Form
Project Title:	Learning Assessment in AR Physics
Investigator:	Yao Zhou
IRB Number:	SBE-14-10148
Funding Agency:	
Grant Title:	
Research ID:	N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 3/26/2015, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a dated copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Kanille Chap

IRB Coordinator

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