PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

A CLASSROOM AUGMENTED REALITY GAME TO TEACH ELECTROSTATICS

FRANCISCA T. GIL URETA

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering

Advisor:

MIGUEL NUSSBAUM

Santiago de Chile, December 2010

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To my parents, family and friends who supported me during this work and throughout my whole career.

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RESUMEN

La inclusión de la tecnología en las aulas ha aumentado en los últimos años, con la esperanza de mejorar los resultados educativos. Sin embargo, para mejorar la educación no es suficiente incluir tecnología exclusivamente: es necesario integrar tecnología con prácticas pedagógicas. Con este fin, proponemos un modelo tecnológico-pedagógico para desarrollar juegos educativos de realidad aumentada usando un dispositivo por estudiante. Este trabajo presenta el modelo, denominado Classroom Augmented Reality Games (CARG) y un juego desarrollado para enseñar electrostática, para probar el modelo en un aula real.

Los resultados experimentales de las pruebas pre-post mostraron que los estudiantes que jugaron el juego aprenden tanto como los estudiantes que recibieron una clase tradicional sobre el mismo tema. Por otra parte, para determinados objetivos de aprendizaje, el uso del juego mejora los resultados en la prueba, más que la clase. El éxito del despliegue de la plataforma tecnológica en una clase real y los prometedores resultados educativos, muestran que el modelo presentado es útil para el diseño de juegos educativos en el aula, sin embargo, se deben realizar otras pruebas para entender para las actividades que se adapta mejor.

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Palabras Claves: Colaboración, realidad aumentada, educación.

ABSTRACT

The inclusion of technology in the classroom has increased in the recent years, with the hope of improving educational practices and results. However, the sole inclusion of this technology has not been enough to improve the education: there is a need to integrate the technology with pedagogical practices. With this purpose, we propose a technological-pedagogical model to develop educational augmented reality games using one device per student. This work presents this model, called Classroom Augmented Reality Games (CARG), and a game developed to teach electrostatic to test the model in a real classroom setting.

The experimental results of a pre-post test show that the students who played the game learned while playing as much as the students who received a traditional class on the same subject. Moreover, for specific learning objectives, the use of the game improved more the results in the test than the class. The successful deployment of the technological platform in a real class and the promising educational results, show that the model presented is useful for the design of educational games in the classroom, but further tests have to be done to understand for which activities it is better suited.

Research supported by the Center for Research on Educational Policy and Practice, Grant CIE01- CONICYT, Games for Learning Institute, and Microsoft Research

Keywords: Collaboration, augmented reality, education,

1. INTRODUCTION

1.1 Motivation

1.1.1 Pervasive Games

In the last years computer games have become the main form of entertainment due to their level of attractiveness to game players. Many technological innovations have been made in the videogame industry such as refined graphic cards, powerful microprocessors and high-speed internet connection. These innovations have made possible to create new videogame experiences that have gained countless followers, especially among children and teenagers (Susaeta et al, 2009). However, during this time games have lost an important characteristic: the interactions between humans face to face, and the interaction with the psychical world.

There is a growing tendency in today's videogame industry to bring physical movement and social interactions into games (Magerkurth, Cheok, Mandryk, & Nilsen, 2005). This topic has received the name of *pervasive games,* as they intent to use information and communication technology to overcome the boundaries of traditional games and making the real environment an intrinsic component of the game (Broll, Ohlenburg, Lindt, Herbst, & Braun, 2006).

One of the most popular approaches of pervasive gamming is *location-aware* games, where the entire world, our surroundings, acts as the game board and the players themselves become playing characters (Cheok, et al., 2004; Thomas, Close, Donoghue, Squires, De Bondi, & Piekarski, 2002; Magerkurth, Cheok, Mandryk, & Nilsen, 2005). Pervasive games have shown strong educational potential, especially when used with co-location and location-aware approaches as they encourage learning through highly physical role play and face to face collaboration (Benford, et al., 2005).

The goal of this research is to create a location-aware pervasive augmented reality game, based on the work done by Garcia-Campo et al (2010) on Classroom Multiplayer Presential Games (CMPG) to teach electrostatics. Pervasive Augmented Reality (AR) games are a special type of location-aware pervasive games where the real world is augmented with virtual objects. Our game will create an experience similar to Garcia-Campos' game, but will take the action from the screen into the real world using low cost Tablet PC.

The experience of Garcia-Campo et al (2010) showed that CMPGs can be used successfully in transferring specific learning objectives that have been proved to be difficult for students, such as charge interaction and Coulomb's Law (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001). The main goal of this work is to bring augmented reality games into the classroom using a pervasive game to promote students' face to face interactions, and the interaction with the psychical world.

This chapter briefly reviews the state of Augmented Reality in Games, and then introduces the hypothesis and objectives of this paper in section 1.2 and 1.3. Section 1.4 shows how we address the development and the deployment of the game. Section 1.5 discusses the lessons learned and proposes a research path for future work.

Chapter 2 describes an original model for the creation of immersive collaborative games in the classroom using the technologies discussed in Chapter 1. Section 2.2 proposes how to integrate Augmented Reality Games in the classroom, and section

2.3 details a case of study using the game discussed in Chapter 1. The experimental work is discussed in section 2.4.

1.1.2 Augmented Reality

Augmented Reality is a technology that allows modifying a view of reality by augmenting the elements of the environment. A display acts as a window that shows a computer-augmented view of the real world. In contrast to virtual reality (VR) systems, where the user is completely immersed in the fictitious environment, augmented reality (AR) systems allow the user to remain seeing the real world and give the illusion that the virtual and real objects coexist in the same space (Kaufmann, 2003).

One of the main problems of AR applications is tracking the position and orientations of the real world in order to accurately align the virtual world graphics with objects of the real world view (Rohs, 2007). The most common solution to this problem is to use optical tracking (Rohs, 2007; Wagner & Schmalstieg, 2003), where the camera' view is used to recognize a specific marker or image in the real world, and to calculate its position and orientation. Other applications use GPS (Global Positioning System), but it only works outdoor and has proved to be inaccurate for augmented reality (Thomas, Close, Donoghue, Squires, De Bondi, & Piekarski, 2002).

The first AR systems aiming at unconstrained mobility emerged as wearable variants of desktop computers (Wagner, Pintaric, Ledermann, & Schmalstieg, 2005). These systems packed a notebook in the back of the user, with a group of sensor and peripheral devices to interact with the world. The graphics of the virtual world were shown using an optical see-through head-mounted display (HMD).

This approach was a good proof-of-concept for AR applications but lacked usability and scalability.

Last researches have attempted to create unconstrained and infrastructure independent AR systems, on lightweight wearable devices like mobile phones, smartphones, PDAs and Tablet PCs (Wagner, Pintaric, Ledermann, & Schmalstieg, 2005). Today we can observe a trend towards an increase in the usage of these handheld devices, over traditional personal computers (desktops and laptops). People have integrated these technologies as an everyday companion, and with the advances in hardware, many of these devices have incorporated camera equipment, making them an ideal platform for developing augmented reality (AR) applications (Rohs, 2007). However, despite the fact that hardware used in game consoles and personal computers have improved significantly in the last years, mobile devices' processing and graphics capacity are considerably lower.

An example of handheld AR is The Invisible Train (Wagner, Pintaric, & Schmalstieg, 2004), a multiuser Augmented Reality application for handheld devices. This game runs independently on PDAs eliminating the need of other expensive infrastructure. In the game, players control virtual trains on a real wooden miniature railroad track. The objective of the game is to prevent the virtual trains from colliding. The current state of the game is synchronized between the players via a wireless network. The players participate in the game using the touch screen input, where they can alter the train switches to change the path of the train, or alter the speed of the trains.

Other works, like the prototypes developed by Rohs M. (Rohs, 2007), have focused on giving a stronger influence to physical actions over screen input. The Penalty Kick prototype is a game that consists of a soccer field printed on a cereal box using virtual overlays generated by a camera phone. The display of the phone shows a virtual goal keeper and ball on top of the cereal box, using a coordinated system defined by a marker printed in the box. The player shoots the ball using the keys of the phone, the direction and speed of the kick depends on the distance, orientation, and tilting of the phone.

1.2 Hypothesis

The first hypothesis of this work is that augmented reality games can be used to teach subjects that have shown to be especially difficult to understand. The game helps the students to learn the corresponding subjects by giving them tools to explore a virtual physic world applying the conceptual knowledge learned in class. In particular, our hypothesis will be tested on a reinterpretation of the game developed by Garcia-Campo et al (2010) to teach charge interaction and Coulomb's Law.

The second hypothesis is that face to face interaction and collaboration among students during the activity, which is desirable as an objective by itself (Johnson & Johnson 1999), will have a greater impact in the students' learning than a regular exercise class.

1.3 Objectives

Consistently with the proposed hypothesis, the general objective of this thesis corresponds to develop an augmented reality activity to teach Coulomb's Law. The activity will follow the line of work done by Garcia-Campo et al (2010) contextualizing it in an action/puzzle game (Kirriemuir & McFarlane, 2004).

A more concrete objective is to develop a face to face collaborative augmented reality game to be used with a low cost tablet computer and tested in a classroom.

To validate the second hypothesis quantitatively, we will design a regular exercise class for the same subjects covered by the game, where the difficulty of the exercises will be similar to the difficulty of the game. In addition, the students will answer a questionnaire regarding previous video games experiences, in order to see how these experiences influence their academic results.

1.4 Methodology

1.4.1 Game Design

Designing an educational game implies integrating technological, domain-specific, pedagogical and psychological aspects (Kaufmann, 2003). There is no single technology or pedagogical model that fits all educational needs. For our game we developed a model that combines Pervasive Augmented Reality and face-to-face Computer Supported Collaborative Learning (CSCL) (Zurita & Nussbaum, 2004). The learning goals were inherited from the work done by Garcia-Campo et al (2010), originally obtained from the expected learning outcomes for 12th graders on the subject of Coulomb's Law, proposed by the Chilean Ministry of Education (MINEDUC, 1998). The pedagogical aspects of the game are discussed in sections 2.2 and 2.3 while this section presents the technical aspects of the development of the game.

The game developed by Garcia-Campo et al (2010) is a multi-mice CMPG, where students act as human beings in the distant future where people have managed to establish their first colony on a planet outside our solar system. The students play as *collectors* of a strange material, called tiberium, which representes the only power source for the colony. These crystals are electrically charged, so *collectors* have a TAD, a special device that can get charged in order to interact with the crystals. To win the game, students have to move the crystals into special portals where the tiberium is recollected. Image 1.1 shows the settings of this game, where crystals portals and collectors can be seen.

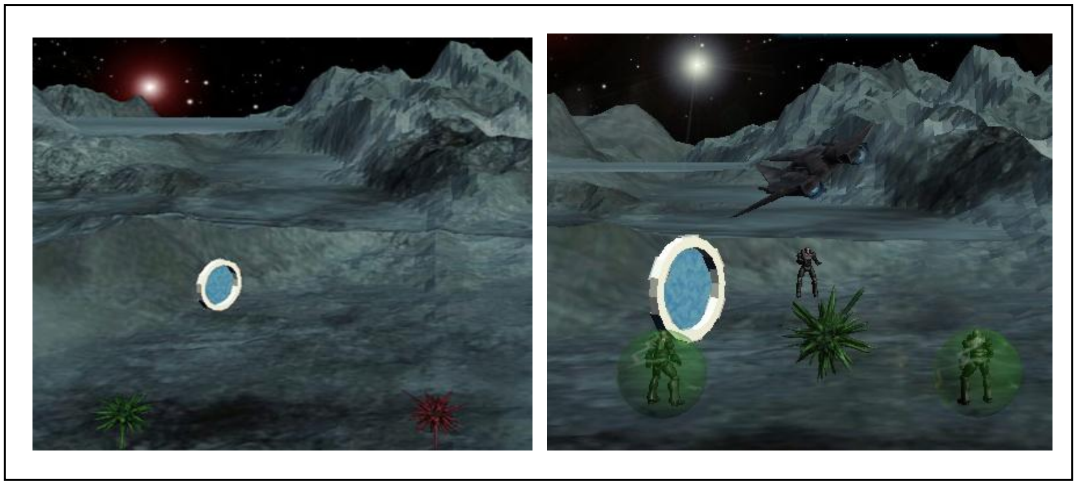


Figure 1-1: Tiberium cluster virtual word representation.

Continuing the work done by Garcia-Campo et al (2010) on this field, we developed a puzzle-based game where players have to move electrically charged objects (crystals) to a goal (portals), avoiding a series of obstacles (asteroids). Our game extends Garcia-Campo' game experience into the real world, using a set of markers as the game board where actions take place. Each student has his/her own tablet computer that works as a window to this world where he/she can see the crystals, portals and asteroids.

1.4.2 Redesign of the Game

One of the challenges we had during the design of the game was to keep it as similar as possible to Garcia-Campo's game (to be able to compare the two games in future work), but taking advantage of the mechanics provided by augmented reality.

The original game has three main actions for the players: they can move their avatars, can select a charge for their TAD, and can activate the TAD to interact with other charged objects.

Our first approach to implement these actions was to continue using virtual players or avatars whose position would be determined by a special marker. In this model, students have to shift the marker to the desired position in order to move the player; another marker is used to select a charge, using the information about its rotation; to activate the TAD the player must tap the charge-marker for a small period of time. Figure 1.2 shows a prototype interface of this model.

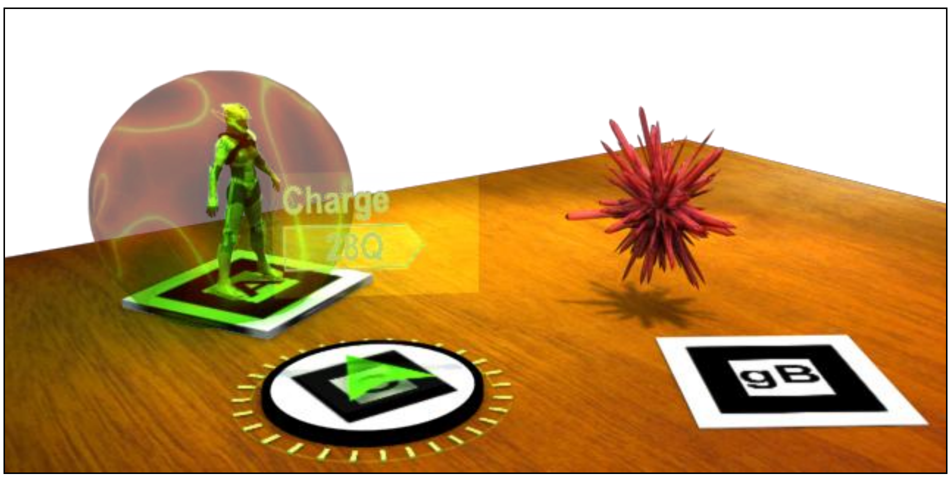


Figure 1-2: Prototype interface first approach.

One of the main reasons why the game was not implemented this way was that students have to leave the Tablet PCs on the table to have free hands to move the markers. This distribution is really uncomfortable when playing in groups of three and does not take advantage of unconstrained mobility or position-awareness.

Our second and final approach was to use students as the players themselves (Cheok, et al., 2004; Thomas, Close, Donoghue, Squires, De Bondi, & Piekarski, 2002). Using this model, the students and the virtual objects have the same coordinated system, defined by a set of markers. This means that the position of the *collector* in the virtual world is determined by the position of the player in the real world. Similar to the work done by Rohs M with *Kick Penalty* (Rohs, 2007), the perspective, rotation and scale of the marker, captured by the Tablet PC's camera, allows us to determinate the position and orientation of the player. To select and activate the charge a simple 2D GUI is added to the main window of the game. Figure 1.3 shows the prototype of this interface.

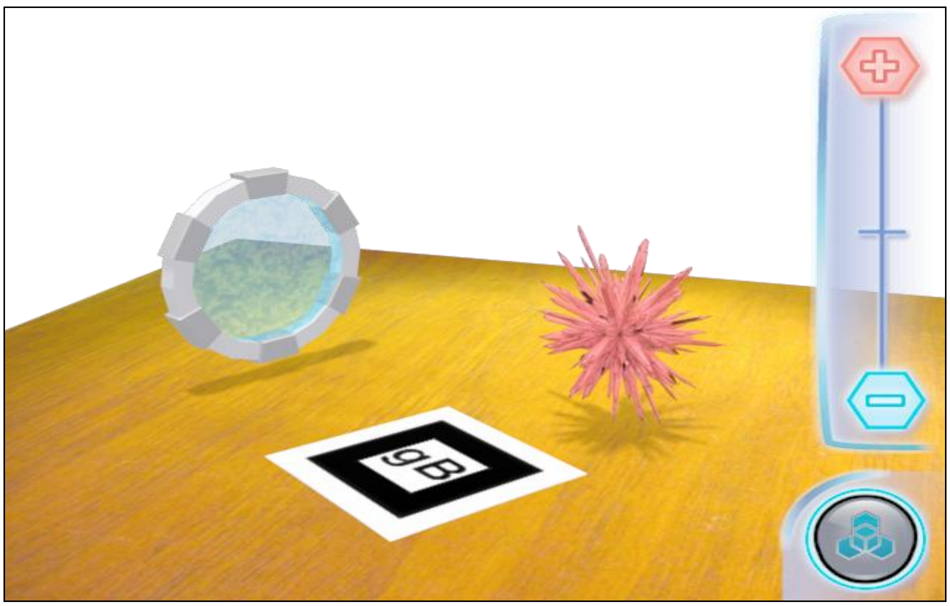


Figure 1-3: Prototype interface second approach.

1.4.2.1 Interactions Design

One of the main problems we had using this approach was that we didn't find a way to include Newton's third law in the interactions with the player. This law, sometimes referred to as *action-reaction law,* stipulates that whenever a first body exerts a force *F* in a second body, the second body exerts a force –*F* in the first body. This means, that when a player exerts a force *F* over a crystal, the crystal exerts a force –*F* over the player, but in our game, the player doesn't feel nor receives any feedback of the existence of this force.

To fulfill this particular learning goal, we implemented new levels to allow players to explore *action and reaction* on interactions between crystals. The levels and progression of the game are discussed in section 2.3.

1.4.2.2 Narrative and Graphic Design

Experiments have shown that the narrative gives contextual meaning to the elements of the virtual world, thus helping synchronicity of actions between players (Zagal, Nussbuam, & Rosas, 2000). The narrative from the original game (Garcia-Campo et al, 2010) takes the students to a distant future on a planet outside our solar system. We made an effort to maintain this narrative, but the game "never went to space", it stayed in the classroom.

One of the main characteristics that differences Augmented from Virtual Reality is that VR technology immerses the player inside the virtual world, completely replacing the real world (Kaufmann, 2003). In contrast, AR uses the real world as the background of the game, making it impossible for the classroom to disappear. Therefore, to keep the narrative intact the classroom could have been transformed into a planet outside our solar system, but the intervention would have been too expensive. Another possibility was to create the illusion in the virtual world, but the graphic capacity of the tablets didn't measure up.

1.4.2.3 Software Design

The software was developed using Goblin XNA, an open source platform for research on 3D applications, including augmented reality and virtual reality, with an emphasis in games (Oda O., Feiner S. 2010). It is based on Microsoft XNA Game Studio 3.1, a runtime environment provided by Microsoft that facilitates computer game development. Games programmed using this framework can be written in any .NET-compliant language, although Goblin XNA only supports C#.

XNA Framework encapsulates low-level details involved in programming a game, such as input device handling, content pipeline and the basic game loop among others, allowing game developers to focus in the content and game experience. On the other hand, Goblin XNA focuses on providing support for 3D scene manipulation and rendering, mixing real and virtual objects. This library uses its own implementation of a scene graph for organizing a 3D scene and it also includes a 2D GUI system to create simple 2D interaction components. Goblin currently supports 6DOF (six-degrees-of-freedom) tracking, which includes 3 degrees for translation and 3 degrees for orientation, using ALVAR or ARTag marker-base camera tracking packages.

The implemented solution includes five modules: Game Logic, Tracking, GUI, Physic Engine and Network. The *Game Logic* module handles the current state of the game and the corresponding rules; it uses the *Network Module* to gather information of the state of each player (we will discuss this module further on in next sections) and the *GUI* module to provide feedback to the user; the *Tracking* module provides methods to integrate information of the real and virtual world, such as estimate the player position from the projection matrix of the marker; the *Physics Engine* module handles the update of the virtual objects, simulates the physics interactions and calculates the position of each object.

1.4.2.3.1 3D Scene Design

The design of Goblin XNA scene graph consists of ten nodes: geometry, transform, light, camera, particle, marker, sound, switch, level of detail and tracker. The *Geometry* node is the simplest node, for it contains a geometric model to be rendered in the scene. The *Transform* node modifies the transformations (translation, rotation and scale) of its descendant nodes. One of the most important nodes for our application is the *Marker* node, which modifies the transformations (translation, rotation and scale) of its descendant nodes, based on the 6DOF pose matrix computed for an array of markers.

In our game all 3D objects (portal, crystal and asteroid) are referenced to a unique coordinate system, therefore all of them are descendants of a unique array of markers which defines the game board (figure 1.4). This way, the objects will move and rotate as a result of the change of view of the marker. Each 3D object has at least one transformation and geometry nodes which determinates its position and 3D model respectively.

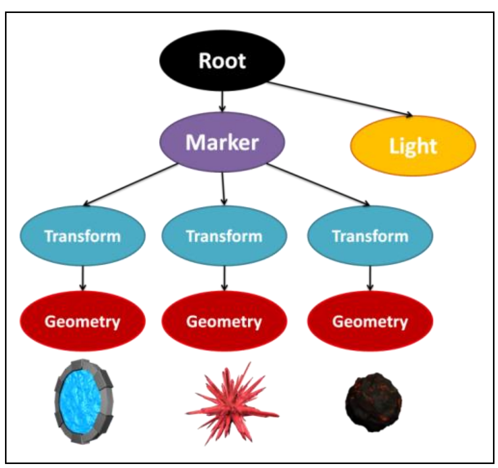


Figure 1-4: Scene graph of the game.

During the development of the game we decided to add an arrow to show the player the force applied to the crystal. The arrow is below the crystal and shows the magnitude and direction of the force. To implement the arrow we added a branch to the transform node of the crystal. The first child of the branch is a transformation node used to rotate the arrow; next child, also a transformation node, is used to scale the arrow; last child is a geometry node with the model of the arrow.

The physic engine (see below) calculates the force $\vec{F} = f\hat{f}$ applied over the crystal. The model of the arrow (blue arrow of figure 1.5) points to the *x* direction, so is necessary to rotate the arrow $\theta°$ counter-clock wise. We calculate θ as follows:

$$\cos(\theta) = \hat{f} \bullet \hat{x} \quad (1.1)$$

$$\theta = \arccos(\hat{f} \bullet \hat{x}) \quad (1.2)$$

where $\hat{f}$ is the direction of $\vec{F}$ and $a \bullet b$ denotes the dot product between vectors *a* and *b*. The sign of the *y* direction of the force determinates if the rotation is *CW* or *CCW*. The scale of the arrow depends only of the norm of $\vec{F}$.

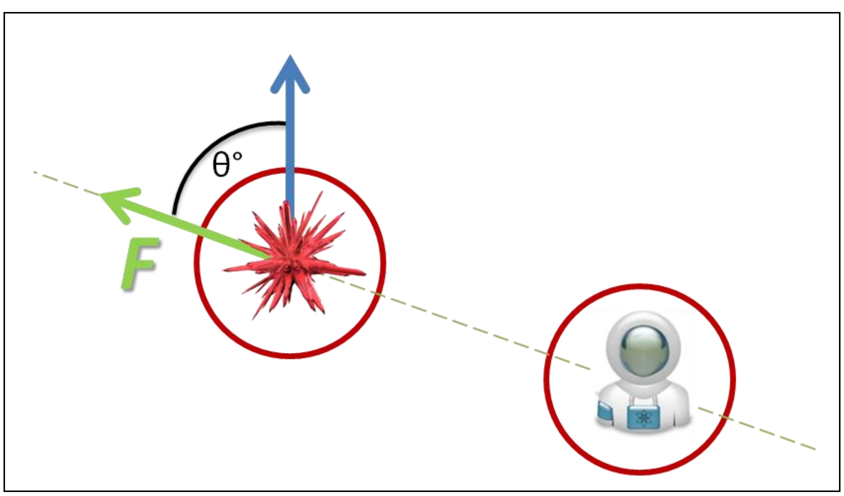


Figure 1-5: Arrow rotation estimation.

1.4.2.3.2 Physic Engine

A physic engine is a software that provides an approximately simulation of physical systems. Most games use real-time physics engines that simulate rigid body dynamics, soft body dynamics and fluid dynamics. Goblin XNA is well integrated with the Newton Game Dynamics library (Jerez J., Suero A., 2007), a free physic engine for real-time applications which, in contrast to most of the real-time engines, focuses on accuracy over speed. This engine proved to be inadequate for the processing capacity of the tablets, as it made them run very slowly. Moreover, our application needed a slightly modified simulation of Newton's law as it did not include the effects of inertia, and it was necessary to incorporate the interactions given by Coulomb's laws. Because of this, we implemented our own simplified physic engine for the game specifications which can be seen in figure 1.6.

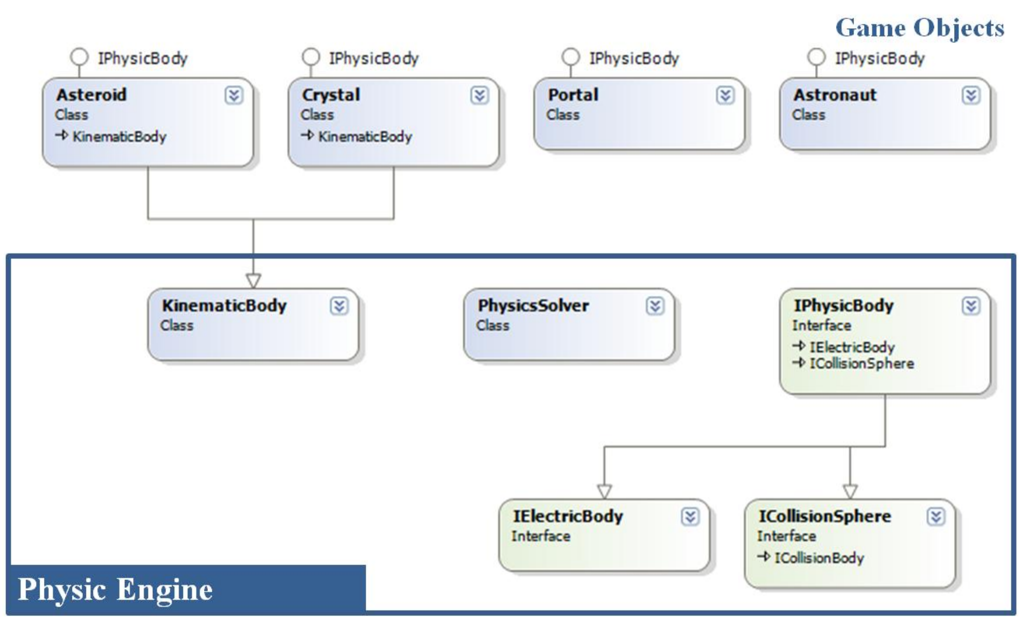


Figure 1-6: Class Diagram of the Physic Engine.

The main class of physic engine is *KinematicBody* which represents an object that moves according to the laws of motion, but can break the law of inertia. The state of the *kinematic body* is determined by its position and linear momentum (angular momentum is not considered in our simulation). Therefore, the position of the body is updated depending on the elapsed time, the current applied force, and the last state. The basic rule to update the components of the state of the body is defined by equation (1.3), derived from the Newton's difference quotient used to estimate the derivative of a continuous function.

$$State_{t+\Delta t} = State_t + \Delta t \frac{d}{dt} State_t \tag{1.3}$$

The main relations that define the behavior of the kinematics bodies are equations (1.4) and (1.5), where $\vec{x}_t$, $\vec{v}_t$, $\vec{a}_t$ are the position, velocity and acceleration of the body at time *t*.

$$\vec{v}_{t+\Delta t} = \vec{v}_t + \Delta t \vec{a}_t \tag{1.4}$$

$$\vec{x}_{t+\Delta t} = \vec{x}_t + \Delta t \vec{v}_t \tag{1.5}$$

We can rewrite (1.4) to a more accurate description that allow us to include Newton’s second law, conservation of momentum.

$$m\vec{v}_{t+\Delta t} = m\vec{v}_t + \Delta t m\vec{a}_t$$

$$\vec{p}_{t+\Delta t} = \vec{p}_t + \Delta t \vec{F}_t \tag{1.6}$$

To eliminate the effect of inertia equation (1.6) is rewritten as

$$\vec{p}_{t+\Delta t} = \Delta t \vec{F}_t \tag{1.7}$$

The *PhysicSolver* class has the responsibility to calculate the overall force, $\vec{F}_t$, applied over the *KinematicsBodies*. This force is calculated as the sum of all electrostatic forces applied over the body, following Coulomb's Law. The force between two charged objects *a* and *b* is calculated using equation (1.8), where *Q* and *x* are the charge and position of the body.

$$\vec{F}_{ab} = k\frac{Q_a * Q_b}{\left\|\vec{x}_a - \vec{x}_b\right\|} \tag{1.8}$$

For collision management we implement a structure similar to Newton Game Dynamics, in which the behavior is associated to a pair of materials instead of to a pair of objects (Seugling & Rolin, 2006). The collisions are detected by the *PhysicSolver* and are handled by each level.

Each object of the game has its own class as they determined different dynamics. The *asteroids* and *crystals* inherit the properties of *KinematicBody* because they can move. All objects implements the *IPhysicBody* interface to provide methods for collision detection and charge interactions calculation.

1.4.2.3.3 Network Module

Distributed simulations have three principal limitations: network bandwidth, network latency, and host processing power. To tackle these problems it's necessary to choose proper architectures for communication, data and control (Smed, Kaukoranta, & Hakonen, 2002). The two most common communication architectures used in distributed games are *peer-to-peer* and *client/server* architectures. In *peer-to-peer* architecture all nodes are equals and each broadcasts its message to every node in the network. In contrast, in *client/server* architecture one node acts as *server*, and the others remain as *clients* that communicate only with the server.

When using peer-to-peer architecture in game scenarios, the data transferred between nodes is the status of each player, and the control of the world is managed on each node using the information gathered from all nodes in the network. Using client/server architecture the status of the game is controlled by the server, who sends it to each client node.

The Tablet PCs used don't have a great processing capacity as they are based on the Intel Atom 270 processor with a frequency of 1.6 GHz and 1Gb RAM. Therefore we decided to use a *client/server* architecture, where the *server* is controlled by the teacher, and each student is a *client*. Thus, the weight of the processing will be carried out by the server and not by the tablet PCs, and network traffic will be relatively low.

When playing single-player levels the server receives only the status of the level of each client, as each player has its own virtual world, and therefore it's not necessary to synchronize information to update its state. In multiplayer stages, the client processes the status [position, charge] of the player and sends it to the server which updates the world given the gathered information. The state of the world is send to each client, which updates the position of the objects of its world. The teacher also receives real-time feedback of the actions, can monitor the progress of each group, and can control the flow of the game.

If one of the player looses the connection to the net, the server receives notices and has the ability to reinstate the player without pausing the game for the rest of the players. Additionally the game can be started from any level in case we need to stop the game.

1.4.3 Experiments and Results

To test the game we designed an activity for eleventh-grade students from a public school in Santiago, Chile. The experience consisted of three sessions for a group of nine students each time.

The players played six individual levels (approximately 10 minutes), and four group levels (approximately 20 minutes). Each player used a personal tablet computer with the rotating camera pointing outwards as shown in figure 1.7 (a). Using the tablet in the display mode (figure 1.7, b) was not possible as tablet would obstruct the view of the camera.

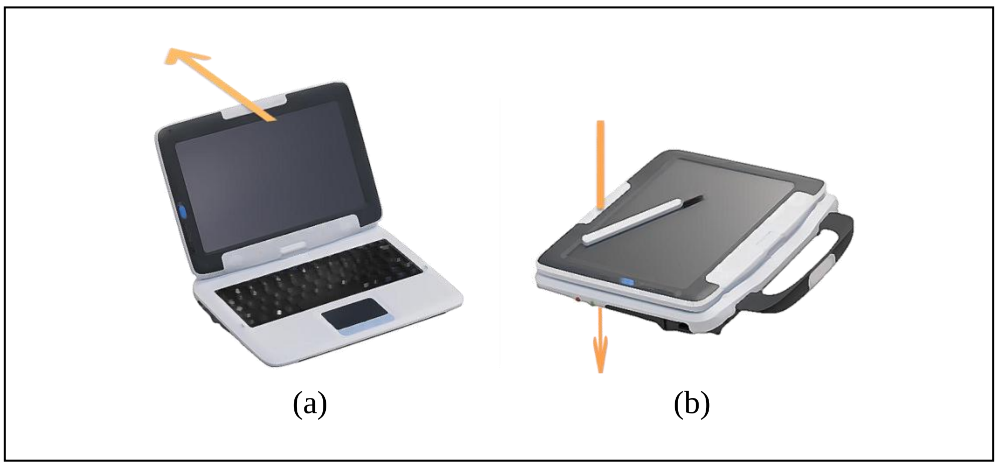


Figure 1-7: Tablet PCs with camera.

Even though the tablet's touch-screens were calibrated before the sessions students had problems to use them. The touch screen is fairly unresponsive to fingers thus a lot of pressure is needed to use them in this way. On the other hand, they work fine with pointy objects like the incorporated stylus or students' nails.

To use the full potential of the tablets, we changed the default power scheme to favor performance over battery life. The game would run really slowly with low battery, and using the *performance* scheme the battery runs out fast. Therefore the battery had to be completely charged at the beginning of the activity to run the game smoothly.

The tracking of the markers worked robustly, without the need to modify the conditions of the classroom, allowing a good estimation of the position of the players. The markers were fixed into the table, so the player had to move around, closer or farther from the table to interact with the crystals. In individual levels each player worked with a unique set of markers and in group levels all team members shared a single set of markers. As shown in figure 1.8, the board defined by the markers is very small when playing in groups of three, and students bump into one another.

Figure 1-8: Classroom distribution problems.

1.5 Conclusions and future work

The results of experiments in the classroom showed that we successfully ported the game developed by Garcia-Campo et al (2010) to a location-aware pervasive augmented reality game.

One of the main concerns we had during the development of the game was the network instability. Previous experiences with wireless networks have shown that devices lose connection frequently affecting the experience of the player. Even thought this actually happened in more than one session of our activity, the recovery mechanisms implemented worked successfully and allowed us to reintegrate players that had temporally lost connection. This way, all students were able to play the game from the beginning to the end without major problems.

The usability and playability of the game was evaluated positively by students. Marker-based tracking prove to be robust enough to estimate the position of the player allowing the students to move freely and appropriately explore the electrostatic relations of the objects. Despite of the fact that the game board was too small for group play, the students were able to work and collaborate face-to-face.

Observations made during the game experience showed that students properly manage the mechanics of the game after the 3rd level, approximately 5 minutes. After that period of time the students looked completely immersed in the game, discussed their ideas with their group and expressed themselves using sentences like: “use a positive charge to attract the crystal”, “move closer to move the crystal faster”, etc. However, they had trouble giving ideas that include location information, like “move there”, because they point at the screen and not at the real world position. We believe that this is due to the fact that the game didn’t have real objects to interact with, so there was a poor connection of the real and virtual worlds. Future work can study this effect using different levels of connections; a simple and basic one could be to use real physical objects as portals. This should be possible as portals are not kinematic bodies, they don't move during the game, therefore they can be physically grounded to the game board.

In conclusion, our work showed that augmented reality games can be implemented in low cost handheld devices, allowing the player to interact freely with the physical world and to have face-to-face interactions with other players. Additionally, we proved that these games can be used in educational environments as they can be developed using hardware that is available today in most classrooms. We hope that this research will promote the use of technology and videogames as a support in classrooms activities.

2. CLASSROOM AUGMENTED REALITY GAMES: A MODEL FOR THE CREATION OF IMMERSIVE COLLABORATIVE GAMES IN THE CLASSROOM

2.1 Introduction

2.1.1 Technology in the classroom

In recent years, many technological devices and systems have been deployed in the classroom and schools in general, with the goal of improving the quality of the education. Interactive whiteboards and projectors for every class, netbooks for every child, last generation computer labs for every school, among others, are being delivered and installed all around the world with the hope that the availability of this vast amount of technology will somehow improve current educational practices (Kraemer, Dedrick, & Sharma, 2009).

The reality, however, is different: the mere deployment of these technologies has no added educational value in itself, and it can be even detrimental (Cuban, Kirkpatrick, & Peck, 2001). Several studies have shown that without a pedagogical structure associated with the deployment of the technology, the technology does not make any impact in the learning of the students (Santiago et al, 2010). The good news is that studies have also shown that when the technology is used as a tool for developing activities supported by a pedagogical model, there can be significant improvement in the student learning (Roschelle et al, 2009).

Computer Supported Collaborative Learning (CSCL) is one pedagogical model that has been successfully integrated for classroom activities using available technology (Zurita & Nussbaum, 2004). In a collaborative learning activity, students work in group through a coordinated effort to achieve a specific educational goal (Dillenbourg, 1999). There have been several different approaches for deploying this type of activities in the classroom: using one handheld device per child (Zurita & Nussbaum, 2004); using one netbook per child (Nussbaum et al, 2010); using one computer every three children (1-3) (Infante et al, 2010) and even using one computer for the whole classroom (Szewkis et al, 2010).

2.1.2 Videogames as an educational tool

In parallel to this increasing interest in using technology in the classroom, another similar movement has been pushing the use of videogames as a learning tool. This movement states that videogames are, in their essence, learning environments, and that many of their characteristics can be applied for educational purposes: they allow the players to progress at their own rate, give immediate feedback to actions, allow the transfer of concepts from theory to practice, provide graceful failure and give freedom of exploration and discovery (Gee, 2003; Squire, 2003). Empirical research by many groups have validated this claims, showing the benefits of games as learning tools (Clarke & Dede, 2007; Dede, 2009; Klopfer & Squire, 2009; Mitchell, Dede & Dunleavy, 2009).

One particular aspect of videogames that has been singled-out as a key element in helping the learner is immersion, which can be defined as the subjective impression of being involved in a comprehensive and realistic experience that does not take place in the real world (Stanney, 2002; Lessiter et al 2001). There are three main components that help to build an immersive experience: the sensorial component, the challenge component and the imaginative or narrative component (Dede, 2000; Ermi & Mäyrä, 2005). Sensorial immersion corresponds to the physical cues that can be provided to fool our senses in believing that what we are experiencing is real (Ermi & Mäyrä, 2005). Challenge based immersion is closely relate to the concept of flow (Csikszentmihalyi & Larson, 1980) where the cognitive task being performed puts the player in an optimal experience state. Lastly, the imaginative or narrative immersion represents the feeling of being captured in a fantasy world, where the environment, characters and story is so powerful that it feels real. (Dede, 2009)

According to several studies, immersion can improve learning by two mechanisms: allowing the learner to experience multiple perspectives and through situated learning. The multiple perspectives allow the learner to understand complex systems, by exploring different physical points of view, first person or third person, and different psychological points of view, by taking the role of different characters in the game (Salzman et al, 1999). Situated learning helps the player contextualize the experience in a concrete environment (Brandsford et al, 2000). It has been shown that using immersive activities students are more involved and learn the same or more than similar but non-immersive activities (Dede, 2009). Additionally, digital immersion allows the students to gain confidence in their academic skills by projecting their real identity into a virtual character.

2.1.3 Augmented reality for games and learning

Augmented reality is a particular technology that is well suited to create immersive environments and games. In an augmented reality system, virtual objects are super-imposed over the real world, using cameras and detectable markers that allow the correct integration of both worlds (Milgram et al, 1994). This technology has had an explosive growth in the last years, made possible by the improvement in the capabilities of mobile devices, allowing the development of many activities and games using handheld devices (Wagner & Schmalstieg, 2003; Billinghurst et al, 2006) and mobile phones (Schmalstieg & Wagner, 2007; Henrysson et al, 2005).

There have been several approaches to use augmented reality (AR) as an educational tool, which can be broadly categorized in three groups. The first approach (class 1) uses augmented reality as a replacement for virtual reality, creating interactive virtual objects in a virtual world that is only linked to reality through the point of reference given by the markers (Kaufmann & Schmalstie, 2003). A second group of activities (class 2) uses AR to augment real objects in the real world, allowing students to interact with physical objects adding virtual data (Khine, Saleh, Dillenbourg, & Jermann, 2010). Finally a third approach (class 3) is a middle point between the previous two: in these types of activities, the objects are virtual, but they interact with properties of the real world, such as gravity (Oda & Feiner, 2010).

In this article we present a model for the integration of educational games in the classroom, based on the CSCL model as pedagogical frame and class 1 AR as supporting technology. To test the model, we present a game developed to teach electrostatics and an experiment to validate the game's learning effect. The structure of the article is the following: Section 2 presents the model, describing how it can be used to develop augmented reality learning games inside the classroom; Section 3 describes the game developed with this model to teach electrostatics; Section 4 describes an experiment developed to test the use of the game in a real classroom context, presenting the obtained results in Section 5. The last section presents our conclusions and future work.

2.2 Classroom Augmented Reality Games

To successfully integrate learning games in the classroom, two elements must be considered: a pedagogical model that provides the learning structure and a specific technology that supports the visualization and interaction with the game environment. The pedagogical model selected needs to be suited for classroom use and must consider all the challenges of developing a computer-based activity in said context (Dillenbourg & Jermann, 2010). The technology, on the other hand, must facilitate game-play and create an immersive environment for the students.

We propose a model that combines face-to-face CSCL as the pedagogical model (Zurita & Nussbaum, 2004)) and class 1 AR as the supporting technology to create what we call Classroom Augmented Reality Games (CARGs). As described previously, CSCL is a pedagogical model that fulfills the requirements for classroom use and previous experiences have used this model successfully to develop games in the classroom (Susaeta et al, 2010). Augmented reality, on the other hand, is well suited for creating immersive environments, and also allows face-to-face collaboration between players (Henrysson et al, 2005).

A CARG creates a virtual world inside the classroom, which can be visualized and explored by each student using his or her device. This device can be any mobile computing platform that has a display, a camera, wireless network capabilities and enough processing power to render 3D graphics. The devices are connected using a wireless network to a server that synchronizes the virtual elements in the augmented world.

The interaction with the virtual world is achieved by transforming the classroom in the game world: each desk is covered with a set of fiducial papers, markers that allow the augmented reality system to place virtual objects over the desks (Figure 1). With the use of the device's camera, the system can detect the relative position of each player to the paper marker, knowing the location of each player in the game world. To interact with a virtual object, each player must first identify the object by looking through his/her display, and then, using a series of interface buttons to perform the different possible actions.

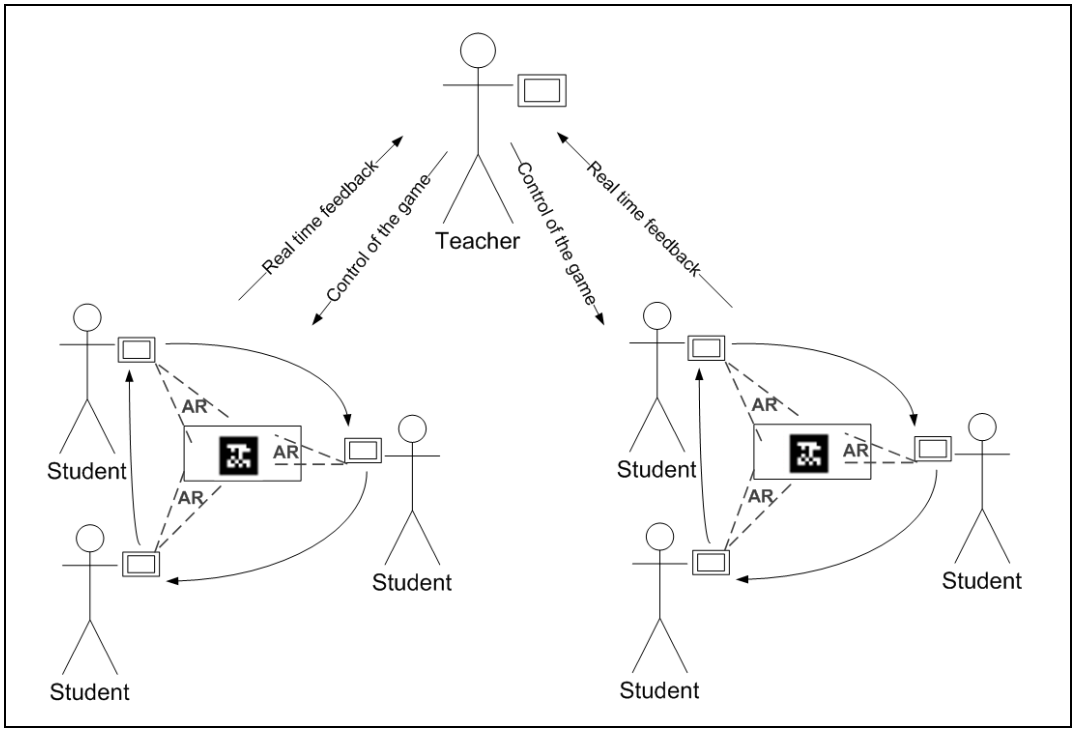


Figure 2-1: Diagram of a Classroom Augmented Reality Game.

In a CARG, the students play in small groups (e.g three), which has been proven to provide the best results for face-to-face collaboration (Nussbaum et al, 2009). To achieve collaboration among peers in a group, the game mechanics must fulfill the main conditions to achieve collaboration: positive interdependence, common goal, coordination and communication, awareness and joint rewards (Szewkis, Nussbaum, Denardin, Abalos, Rosen, Caballero et al, 2010).

During the game, the teacher has a central role in the process. He/she controls the server, which is centralizing all the interactions in the game. In this computer the teacher receives real time feedback of the actions and monitors the progress of all the groups in the class, allowing him/her to see if any group is having trouble with a specific activity. If one of the student's devices is disconnected from the network, the teacher receives a message allowing him/her to identify which student has the problem. With this information, the teacher can reset the device of the student, which will automatically recover to the level were he/she was playing.

The teacher has also the ability to control the group's activities by pausing or advancing to a given level, to intervene when necessary and provide additional explanations to a group or the whole class. In this way technology is a complement of the lecture and not a replacement of the teacher.

2.3 Classroom Augmented Reality Games

To test the concept of a CARG, we developed a game to teach basic concepts of electrostatics. We focused specifically on charge interaction and the law of forces between charges (Coulomb's Law). This subject is taught at the beginning of 12th grade; in order to isolate the effect of how the subject was actually delivered in the school, we focused our experiment on 11th graders, who hadn't received any instruction on the subject.

The learning goals of the game were obtained from the expected learning outcomes for 12th graders on the subject of Coulomb's Law, proposed by the Chilean Ministry of Education (MINEDUC, 1998). We categorized these outcomes using Bloom's revised taxonomy (Anderson, Krathwohl, Airasian, Cruickshank, Mayer & Pintrich, 2001), resulting in the following lists of learning goals:

1. Compare the concepts of positive, negative and neutral charged object based on their interaction
2. Infer the concept of action and reaction from a forceful interaction of two objects

3. Understand the concept of inverse relation between distance and electric force
4. Understand the concept of direct relation between charge intensity and electric force
5. Apply the procedural knowledge of Coulomb's Law in one dimension
6. Apply the procedural knowledge of Coulomb's Law in two dimensions

To fulfill this list of learning goals, we developed a puzzle-based game, where the players have to move electrically charged objects (crystals) through special locations (portals), avoiding a series of obstacles (asteroids). To move the crystals in the virtual world, the player uses his/her computer as an electric charge, which the player can turn on/off, change its intensity and polarity, and modify the distance between his/her charge and the virtual charge, by physically moving closer or farther away from the AR marker (Figure 2).

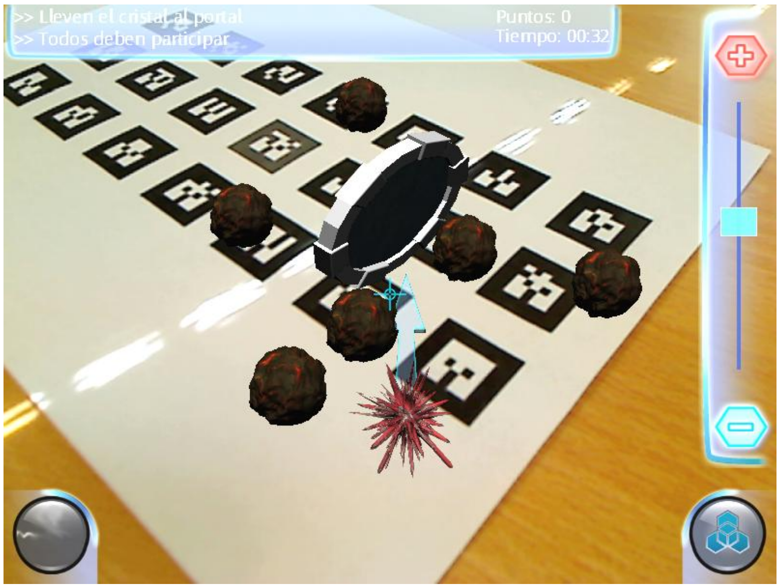
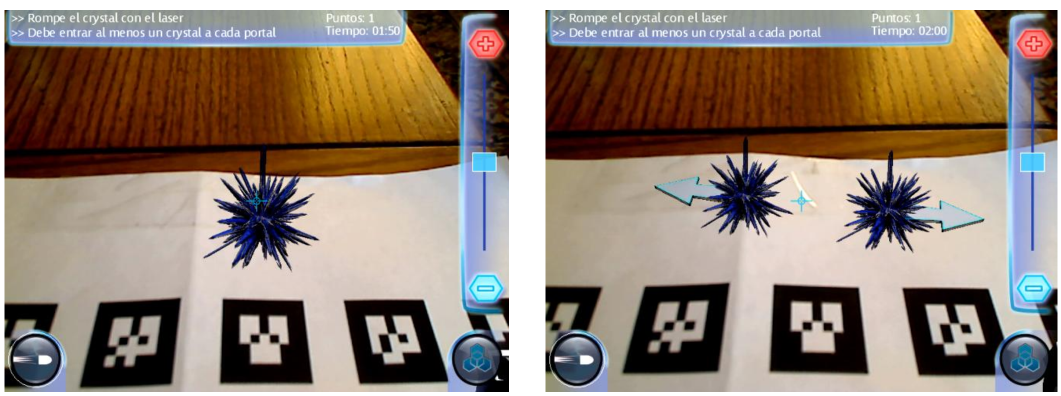


Figure 2-2: Main interface of the game.

Polarity, intensity and distance are the key elements of Coulomb's law. By giving the player direct control of these we allow each student to explore the phenomena of interaction of electric charges, directly related to learning goals 1, 3, 4, 5 and 6. We added an additional game mechanic to help the players visualize the second learning goal (infer the concept of action and reaction), which is independent of Coulomb's law and wasn't observable through the basic mechanics. This additional mechanic allowed the player to shoot a bullet into the electrically charged crystal, which when hit splits in two, showing how both recently created objects have the same force in magnitude, but in opposite directions, considering that both have the same charge (Figure 3). To help visualize the electrical force between the charges, we added the visualization of an arrow that represented the direction and intensity of the force.



(a) (b)

Figure 2-3: Action and reaction Level. The player can shoot a crystal by aiming his/her device and pressing a button (a), splitting it in two halves, allowing him/her to observe the principle of action and reaction (b).

The game has two clearly defined parts: an individual tutorial and the collaborative game played in small groups. In the individual tutorial each player had to advance through a series of short quests, that introduced a new game mechanics and/or concept, which was complemented with the teacher's explanation of the concept while the students played. The teacher controlled the pace of the tutorial, moving to the next level when everyone finished the current level. The players that finished before, continued playing with differently configured activities of the same rule, while they waited for the rest of the class to finish.

Once the tutorial part was completed, the system randomly created groups of three students (Nussbaum et al, 2009) that played collaboratively together, applying the learned concepts in the AR setting. To solve each puzzle, the group had to develop collaborative strategies to move the crystals with the student's personal charges.

2.4 Experimental work

The game was tested in a real classroom setting to study the learning effects on students. This section presents the design of the experiment developed and the results obtained from it.

2.4.1 Experimental design

To analyze the effectiveness of the game as a learning tool, we designed a quasi-experiment with eleventh-grade students from a public school in Santiago, Chile. The experiment consisted of delivering an electrostatic class of one hour to a group of students, using the game as the main pedagogical tool. During the class, the students played the game, which was guided by one of our researchers who had the role of the teacher. Depending on the performance of the students in the game, the teacher could pause the game-play and use the blackboard to explain specific concepts.

We used Intel's tablet classmate PCs (Intel, 2010) as the mobile platform for the students to play the game. The devices are low cost tablets, specially developed for classroom use, with a 1 GHz processor and 1GB of RAM. The tablets have a flippable webcam at the top of the screen which was ideal for the requirements of our platform. The devices have also a touch-screen which allows the students to interact using a stylus or their finger to perform the actions in the game.

In order to assess the learning accomplished by the students, a pretest-posttest design was used. The pretest was administered just before they played the game, and the posttest right after they finished playing, as is usually done when this kind of questionnaire is used (Papastergiou, 2009; Mitnick et al, 2009). For the control group we delivered a traditional class to a group of students (n=25, 11 female, 14 male), who answered the same pre and post test. The content of the class was the same as the one taught with the game. To make the control group as comparable as possible, the same researcher who gave the game-based class also delivered the one for the control group; the different puzzles of the game were presented as exercises in the class which the students solved with the help of the teacher, individually and on the blackboard.

The instrument used to measure the expected learning outcomes was based on the Conceptual Survey of Electricity (CSE) (Maloney et al, 2001), translated to Spanish, making the necessary modifications to cover the desired learning outcomes, and leaving out the questions on unrelated or more advanced subjects. We used questions 3 to 10 from the CSE and added 13 additional questions, for a total of 21 questions in the survey. Before the experiment, the test was validated by two teachers of 12^{th} grade physics. The internal consistency of the evaluation was measured by giving the test to 20 (13 male, 7 female) students of a similar school to the one where we carried out the experiment, obtaining a Cronbach's alpha of 0.74 which is better than the minimum value necessary to prove reliability, 0.7.

An initial pilot study was performed with nine students (3 female, 6 male) with the objective of measuring the effect size and estimating a minimum sample size to obtain the desired significance and power level. The results of the pilot test gave a Cohen's D value of 2.09, which represents a large effect. From this quantifier we estimated that a sample size of 27 was enough to obtain a significance level of 95% and power of 99% with a t-Student test of one tail.

Based on the results of the pilot study, we designed an experiment with 27 students (12 male, 15 female). The experiment was conducted during three sessions: in each session, a different group of nine students played the entire game, simultaneously. For the collaborative quests of the game, the nine students were randomly assigned into three groups of three.

To control the student's previous experience with technology (computers and cell phones usage) and videogames (computer, console and cell phone games), we developed a brief questionnaire which was answered by each student of the experimental group before the sessions. The results of this survey showed (Table 2) that most students in the sample, both male and female, are frequent users of computers. The video game usage questions showed a difference between males and females: only two male students didn't play videogames every week in at least one of the platforms, compared to six female students that didn't play weekly.

Usage of:	*Every day*		*Some days in a week*		*Some days in a month*		*Rarely*		*Never*	
	Male	*Fem.*	*Male*	*Fem.*	*Male*	*Fem.*	*Male*	*Fem.*	*Male*	*Fem.*
Cell Phone	25%	33.3%	33.3%	53.3%	25%	6.6%	8.3%	6.6%	8.3%	0%
Computer	50%	40%	50%	46.6%	0%	6.6%	0%	6.6%	0%	0%
Videogame	33.3%	20%	50%	33.3%	8.3%	26.6%	8.3%	20%	0%	0%

Table 2-1: Questionnaire to control students' previous experience with technology and games shows that most students in the sample frequently use cell phones and computers and most male students frequently play videogames.

2.5 Results

The results from the pre and post test performed by the control group showed an increase in the average number of correct answers from 4.6 to 8.6, with standard deviations of 2.21 and 3.84 respectively. In the case of the experimental group, the students showed an increase in the average number of correct answers from 4.6 to 8.7, with standard deviations of 2.32 and 3.71 respectively. To analyze the statistical significance of both results, we performed two t-student tests for dependant variables with the null hypothesis being that the averages are equal and the alternative hypothesis that the average of the post test result is greater than the average of the pre test. To reject the null hypothesis, a one tail test was used with a significance level (alpha) of 0.05 (5%). The results of the t-student test to reject the null hypothesis were statistically significant for both the control group ($p < 0.00001$) and experimental group ($p < 0.0000001$) meaning that we can conclude with a 95% of confidence that the average number of correct answers in the evaluation increases after being exposed to either the class and the game.

Additionally, a post-hoc analysis was carried out to obtain a Cohen's D quantifier value to determine the effect size of the treatment for both the control group and the experimental group. For the control group, the Cohen's D value obtained was 1.31, which represents a large effect size. For the experimental group, the Cohen's D value obtained was 1.48, which also represents a large effect size.

To compare the performance of the control group with the experimental group, we performed an Analysis of Covariance test (ANCOVA), which allows controlling the possible difference of the two groups in the pre-test. For the ANCOVA test, the group (control or experimental) was used as classification factor, the result of the pre-test of both groups was used as a covariate and the only dependent variable was the result of the post-test of both groups. The result of the ANCOVA test showed that the treatment F-test value was found to be 0.003 ($p = 0.95$) at an alpha of 0.05, indicating that there are no significant differences between the results of both groups.

A more detailed analysis was performed to compare the performance of the control and experimental group in specific learning outcomes. For this purpose, the questions associated to each of the stated outcomes were grouped, and the improvement in each group of questions between the pre and post test for both the control and experimental group was compared using a t-student test of independent samples. The analysis showed a statistically significant difference for two learning outcomes: *infer the concept of action and reaction from a forceful interaction of two charged objects* ($p < 0.02$) and *apply the knowledge of Coulomb's law in two dimensions* ($p < 0.05$). In the case of the first outcome (action and reaction), it was the experimental group that increased more in average. For the second outcome (Coulomb's law in two dimensions), on the other hand, it was the control group the one that increased more in average.

For the experimental group, the possibility of a gender effect was controlled by developing an additional ANCOVA test. For this test, the gender (male or female) and group (control or experimental) were used as classification factor, the results of the pre-test of both groups was used as a covariate and the only dependent variable was the result of the post-test of both groups. The result of the test showed that the gender-treatment F-test value was found to be 3.014 ($p = 0.09$) at an alpha of 0.1, indicating that there existed significant differences between the posttest scores of the male and female students. To analyze which group performed better, the estimated marginal means of the post-test result was observed: for the male students it was 10.25 for the experimental group and 8.66 for the control group; for the female students it was 7.46 for the experimental group and 8.50 for the control group. These values show that in the experimental group, although both female and male students increased their scores in the post-test compared to the pre-test, the male students increased significatively more than the female students, with a confidence level of 90%.

The effect of previous experience with technology and video game use was also analyzed for the experimental group. To quantify this relation, the Pearson's correlation coefficient was used, which measures the lineal relation between two random quantitative variables. The result of this analysis showed no relevant correlation between the results in the post test and either the previous experience with technology (Cell phone use: $r= 0.14$; Computer use: $r=0.17$) or the previous experience with video games (Computer games: $r=-0.10$; Console games: $r=-0.02$; Cell phone games: $r=0.18$).

2.6 Discussion & Conclusions

This work presents a first experience in the use of collaborative augmented reality games inside the classroom to teach a specific subject matter. The technological aspect of the experience was very successful: we were able to deploy an augmented reality network-based game, using low cost mobile devices and without modifying the classroom conditions. During all the sessions every student was able to complete the game, and even when unexpected circumstances happened (e.g. students powering off a device by accident), the backup and recovery mechanisms implemented in the platform allowed the students to continue their game-play.

From a usability and playability dimension, the developed game can also be considered successful. The observations made during the sessions and the analysis of the video recordings showed that the majority of the students were able to understand the different mechanics of the game during the first levels of the tutorial, showing a fast learnability of both the platform and the game. Although the devices used were not ideal, being too heavy to be carried during the whole session and having a somewhat unresponsive touch-screen, the students were able to overcome these difficulties, allowing them to perform all the actions in the game, and being immersed in the experience of the game. From the observations gathered and the comments made by the students, playing the game was considered a fun and engaging experience.

The educational results of the game provide a series of valuable conclusions. The first one is that the improvement shown by the students validates that the model proposed and the game implemented helped both male and female students to learn the subject of electrostatic, generating a large effect in their increased knowledge. The correlation analysis showed also that the previous experience with technology and videogames was not relevant in the performance of the students, showing that although the platform and the game-play are complex, most students didn’t have a problem in learning how to use them.

The comparison between the control and experimental group provides additional insights regarding the experience. The difference among both groups was not significant, showing that the students that played the game learnt as much as the students that had a traditional class. Although this can be seen as negative result, considering that the effort in developing and delivering the game is orders of magnitude larger than the effort of preparing a class, it is important to notice that this is the first experience using this particular technology and platform, so it is possible that with incremental refinement of the platform and the game, better results can be obtained. As future work we plan to study how modifications in different aspects of the game (mechanics, narrative, aesthetics, etc) could affect the learning of the students. We also plan to test modifications in the platform and their impact, for example adding a projected scoreboard, which shows the current results for each student and group while playing the game.

Another important conclusion can be obtained from the comparison of the effects of the game and the class in male and female students. Although in both treatments, female and male students increased their learning significatively, the statistical analysis showed that for the experimental group, the male students performed better than the female students in the post-test. There are many possible explanations for this gender gap, which is commonly reported when educational games are used (Boyle & Conolly, 2008). One that may be particularly interesting to consider, and that is supported by the observations of the sessions, is that the nature of the game may have been more suited for the male students than the female students: each level of the game was devised as a series of increasingly more difficult challenges focused on the same concept, and in our observations we saw that most male students kept playing these sublevels until the teacher changed all the class to the next level, while many female students were content with finishing only the first sublevel, and didn’t find interesting to continue playing the next challenges. This analysis suggests that to avoid the gender gap, the nature of the players must be considered in the design of the game, choosing mechanics and incentives that are equally attractive for both male and female students, or providing a variety of game options that allow the different students to choose the more suitable and interesting activities for them (Steiner et al, 2009).

Lastly, additional important conclusions can be obtained from the detailed analysis of how specific learning outcomes were affected by both the class and the game. The statistical analysis showed that the law of action and reaction was better understood by the students who played the game, while on the other hand the concept of Coulomb’s law in two dimensions was better applied by the students who received the traditional class. The most obvious conclusion is that there is room for improvement in the game, and additional elements should be considered to help the students understand better the concept Coulomb’s law in two dimensions. For example, a top-down view of the virtual space and its elements could be included as an optional interface in the player screen, allowing them to visualize more clearly the effect of the multiple forces over one object. Another more relevant conclusion is that a design-based research approach (Reeves, 2006) could be used to improve the game, considering that the use of the learning outcomes for the design of the game and their validation with the tests provide concrete feedback on what aspects of the game can be improved. Finally, a more general conclusion that can be obtained is that it may be the case that for specific learning outcomes a traditional class is best suited than an interactive game, and vice-versa, so it is important to know when it is best to intervene with an educational game and when it is not. This implies that a more fine-grained analysis should be done when studying the impact of educational videogames, comparing only one specific learning outcome at a time.

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APPENDIX: mail of acknowledgment of submission

Date: Thu, 23 Dec 2010 17:24:01 -0500 (EST)
From: jcal.editor@lboro.ac.uk
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Cc: aaecheve@uc.cl, fegil@puc.cl, mn@ing.puc.cl
Subject: Manuscript ID JCAL-10-306 - Journal of Computer Assisted Learning

23-Dec-2010

Dear Mr. Echeverría:

Your manuscript entitled "Classroom Augmented Reality Games: A model for the creation of immersive collaborative games in the classroom" by Echeverría, Alejandro; Gil, Francisca; Nussbaum, Miguel, has been successfully submitted online and will be given full consideration for publication in the Journal of Computer Assisted Learning. You have confirmed that no substantial part of this manuscript has been published elsewhere or is under consideration for publication.

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