PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

TECHNOLOGIES COMPARISON ANALYSIS FOR CLASSROOM MULTIPLAYER CO-LOCATED COLLABORATIVE VIDEOGAMES

MATÍAS M. AMÉSTICA.

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 V.

Santiago de Chile, December, 2011

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To Leeroy Jenkins because he taught me the value of courage and discipline.

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RESUMEN

El aprendizaje colaborativo asistido a través de computadoras es un enfoque pedagógico que se puede usar para desarrollar juegos educacionales para la sala de clases. Sin embargo, no existe una certeza respecto a qué plataforma tecnológica es la que se adapta mejor para desarrollar videojuegos colaborativos presenciales, ni los medios que requieren para ello. En este trabajo se exploran dos plataformas tecnológicas diferentes que se usan para desarrollar videojuegos colaborativos en la sala de clases: una que se basa en la tecnología de realidad aumentada y la otra basada en la tecnología de múltiples-mouse. En cada uno de estos casos, se presentó el mismo videojuego para enseñar electroestática y sus resultados fueron comparados experimentalmente usando una clase.

Los resultados del trabajo experimental señalaron que los estudiantes aumentaron significativamente su comprensión conceptual de electroestática con ambas plataformas. Sin embargo, hubo diferencias importantes entre ellas. Mientras que en la plataforma de múltiples-mouse no se pudo percibir diferencias entre géneros, en la plataforma de realidad aumentada los varones mejoraron significativamente sus resultados al ser comparados a las mujeres. Además, la plataforma de realidad aumentada fue considerablemente más costosa de llevar a cabo que la plataforma de múltiples-mouse. Estos resultados sugieren que, cuando se diseña juegos colaborativos presenciales; se debe prestar una acuciosa consideración al seleccionar la tecnología que se va a utilizar, ya que ésta puede tener efectos que van más allá de los efectos que competen a los juegos en sí.

Esta investigación recibió apoyo del Centro de Estudios de Políticas y Prácticas en Educación (CEPPE), financiado a través del programa Bicentenario CIE01-CONICYT, al instituto Games for Learning y Microsoft Research.

Palabras Claves: Videojuegos educativos, aprendizaje colaborativo, realidad aumentada.

ABSTRACT

Computer Supported Collaborative Learning is a pedagogical approach that can be used for deploying educational games in the classroom. However, there is no clear understanding as to which technological platforms are better suited for deploying co-located collaborative games, nor the general affordances that are required. In this work we explore two different technological platforms for developing collaborative games in the classroom: one based on augmented reality technology and the other based on multiple-mice technology. In both cases, the same game was introduced to teach electrostatics and the results were compared experimentally using a real class.

The results of our experimental work showed that students significantly increased their conceptual understanding of electrostatics with both platforms. However, there were some important differences between these platforms. While in the multiple-mice platform there were no gender differences, in the augmented reality platform boys significantly outperformed girls. In addition, the augmented reality platform was considerably more costly to deploy in a real world setting than the multiple-mice platform. These results suggest that, when co-located collaborative games are designed; careful consideration must be taken when selecting the technology to be used, something which can have effects that go beyond the effects of the games themselves.

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

Keywords: Learning games, collaborative games, augmented reality.

1. INTRODUCTION

1.1 Motivation

1.1.1 Videogames, learning and technology

Nowadays there is a whole and diverse spectrum in videogames like: real time strategy, puzzle, role playing, platform, first person shooters and even dancing games; certainly all of these can create (for the player) an interactive immerse entertainment environment which also is (if the design contemplates it) a powerful new medium with potential implications for schooling (Squire, 2006). When videogames are designed as a learning experience it allows the students to progress at their own rate, provide a secure scenario which enhances discovery and exploration through innocuous failures, give real time feedback to actions and facilitate the transfer of concepts from theory to practice (Gee, 2003; Squire, 2003). What's missing then?

Despite the encouraging potential that videogames hold to the learning process (Clarke & Dede, 2007; Dede, 2009; Klopfer & Squire, 2008), they are not a standard tool in the educational system yet. Several studies have shown that technology alone has no impact in student learning when it's used without a pedagogical structure (Santiago, Severin, Cristia, Ibarrarán, Thompson & Cueto, 2010). Considering the latter, there's room for significant betterment when the technology is used as a tool for developing activities supported by a pedagogical model (Roschelle, Rafanan, Bhanot, Estrella, Penuel & Nussbaum, 2010).

Designing videogames for enhancing learning experience inside a classroom is not an easy task: implies integrating instruction strategies and ludic activities in benefit of certain educational goals (Amory, 2007); therefore the use of guidelines for this purpose is encouraged. As Villalta (2011) describes, we require a set of rules that help to develop an effective tool for educational purposes for defining: teacher's mediator role, face to face interactions, gradual increase in difficulty and so on; however videogames design must also consider *the elemental tetrad* (Schell, 2008), which identifies four basic elements in every videogame: mechanics, story, aesthetics and technology. These related elements are arranged in a diamond shape as shown in Figure 1-1 to illustrate that none of them is more important than the others and also to point out the visibility of each element to the players, from more to less.

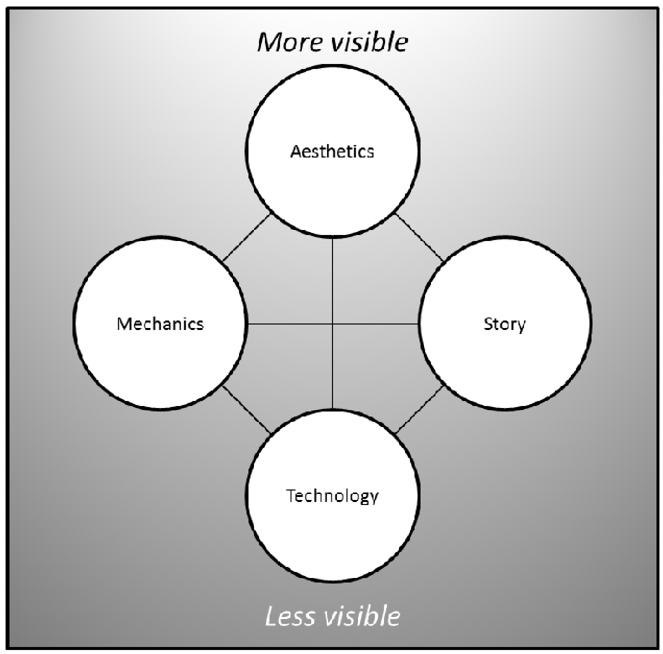


Figure 1-1: Schell's elemental tetrad.

Certainly technology alone isn't enough for improving learning results when it's used without a purpose; although it's unknown the real influence that a technological platform has when it is compared within Classroom Multiplayer Presential Game (CMPG)'s experiences, a model that encourages the students to work in group using a videogame to achieve collaboratively a common objective in a virtual world, which will depend on the specific content being taught.

The constant creation and evolution of new technologies urges the need to identify and measure the repercussions of varying this on classroom multiplayer co-located collaborative videogames.

The experience of “First Colony”, multiple mice CMPG (García-Campo et al, 2010), validated the effectiveness of the game as a tool for teaching electrostatics, but will another platform work for the same pedagogical activity? This research attempts to determine how technology influences student’s game experiences and learning.

This chapter explains the experiment’s hypothesis and objectives (Section 1.2 and 1.3); later on 1.4 it will be described the game development and deployment. Section 1.5 will refer to the discoveries and proposal for future research.

Chapter 2 explores the design of two technological platforms that supports the deployment of co-located collaborative games, taking into account the pedagogical requirements. This chapter will explain the conducted experiment and a series of lessons from the experience that should be taken into account when using these platforms. This chapter was submitted as a paper to the Computers in Human Behavior journal (see E-mail of acknowledgement of submission).

1.2 Hypothesis

The first hypothesis of this work is that classroom multiplayer co-located collaborative videogames can help students to learn a set of specific subjects regardless of the technology being used. This hypothesis will be tested using an updated version of the game of Garcia-Campo et al (2010) on multiple mice platform and an adapted version of the game implemented by Gil et al (2010) on an augmented reality platform; both games teach electrical interactions between charged objects (polarity, intensity and distance) and how their behavior is defined by Coulombs’s law.

The second hypothesis is that user’s game experience and social involvement will not substantially differ between both games; it also considers that the collaboration between students will occur with ease regardless of the platform being used.

1.3 Objectives

Consistent with the proposed hypothesis the main objective of this thesis is to study two comparable CMPG experiences using different platforms: augmented reality and multiple mice, and then discover the influence of technology on student's learning. These similar activities will allow the students to understand interactions between charged physical objects and apply Coulomb's law through exploratory interactions in a virtual world using all the conceptual knowledge provided by the teacher, empowering learners to construct knowledge through active learning (Jonassen, Peck & Wilson, 1999). Both videogames will require the students to collaborate to go through the different levels and it is expected that they'll be amused and motivated in the process.

For the validation of the second hypothesis it will be used a set of pertinent questions from the game experience questionnaire (GEQ) (Ijsselsteijn, Poels, & de Kort, 2008) and the Social Presence in Games Questionnaire (SPGQ) (de Kort, Ijsselsteijn & Poels, 2007). There will be also a guideline for the observers looking the interactions between the students and their strategies.

Additionally, the students will answer a questionnaire about their previous experiences with technological devices and videogames with the purpose of gathering useful information that may explain influences on the experiment's results.

1.4 Methodology

1.4.1 Game Design

Designing two classroom multiplayer co-located collaborative videogames using different platforms to identify technology's influence implies the challenge of adapting both experiences to make them comparable. From game's mechanics to Graphical User Interface (GUI) issues had to be redesigned for this purpose. Each game's aspect could not be overlooked neither on pedagogical nor ludic dimensions.

The original version of *First Colony* was developed by Cristián García-Campo et al (2010) as a CMPG on multiple mice (MM); this game characterized each student as an astronaut collecting fragile electric prisms. In the game these crystals (different in size and polarity) had to be gathered using a device called "TAD" which allowed the pushing and pulling of charged objects by the use of electrical forces. The objective of the missions was simple: gather as much crystals as possible moving them to the corresponding charged portal, two of them located on the map, that attract or repel the prisms depending on the electrical forces produced between them. Figure 1-2 shows the layout of the components described.

Figure 1-2: Original First Colony layout.

Later on, Francisca Gil et al (2010) developed an augmented reality (AR) version of this game designed for low cost tablet computers in a classroom. The idea was basically the same, but the AR version was going to be a puzzle-oriented videogame that could bring the virtual environment into the classroom using a set of markers as the game board. Four big modifications were made to the game's mechanics based on García-Campo's experiences: now the portals wouldn't have any charge at all (it was confusing to the students); asteroids were added to the game, which would destroy the crystals on collisions (to achieve puzzle-oriented design); shooting bullets divided a crystal into two smaller ones (implemented as a way to improve Newton's third law); and, the students could see on their screen an arrow to show them the force being applied to the crystal (to emphasize Newton's third law). The graphical user interface of the augmented reality version is shown in Figure 1-3.

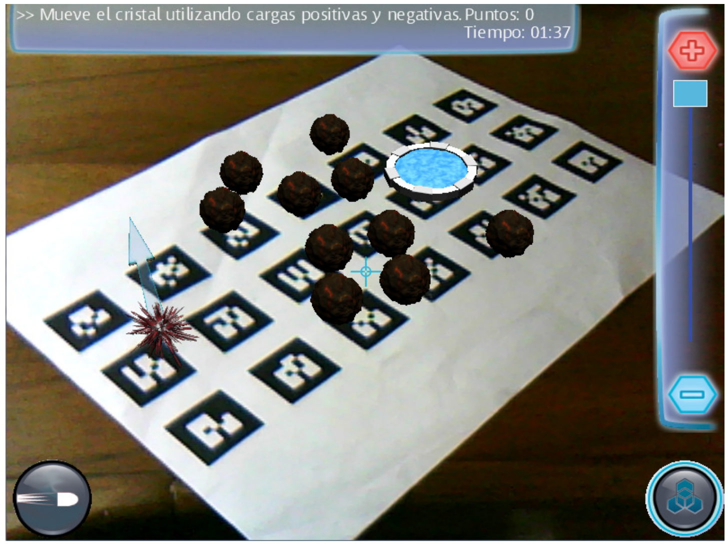


Figure 1-3: Augmented Reality GUI

Analyzing the results of both experiences showed that significant differences appeared due to the use of different technologies. These aspects must be considered into the design of both instruments to ensure the quality of the comparison. The identified issues were:

- *Information overload*: using multiple mice (MM) leads to show the information for all the players into one screen, while, on the other hand every augmented Reality (AR) player has their own device, which displays only his/her information. MM can't exhibit the same amount of data that others; *one screen per user* technologies can present this information without overloading the user with information or confining him into a limited area of the screen (affecting the collaborative aspect of the experience). This advantage of one screen per user technologies must be considered in the design of any tool that makes use of them.
- *Virtual/physical positioning of the players*: if the real physical position of the player is determined by one of the inputs in the game it's also crucial to be aware of the limitations of it. AR brings the virtual objects into real space but the players are restricted in the real world, so they can't be on the same position or

go through the table with the markers. MM grants absolute freedom on the virtual space, which if used correctly may provide an advantage over other platforms because it allows impossible events to happen.

- *Privacy*: Like information overload the differences between both technologies affects the data available for each user on screen. One aspect was how much information is shown to every user; also the visibility of it is important. Students may not agree to show other people their performance or their strategy; on the other hand public strategies may enhance constructive learning, because each student may learn from other student's knowledge and build together a new answer (one of the attributes of constructivism learning). Even if privacy's effects over student's learning are uncertain, the differences between data isolation exist and must be considered.
- *Camera angles*: One screen for many users restriction also affects the point of view of the 3D environment. When using AR each student is free to define his/hers own point of view, but on MM 3D environments the camera must serve to all the players and not interfere with the educational purpose.

1.4.2 Game's mechanics

The identified differences given by the different technologies and Villalta's guidelines for classroom multiplayer co-located games (2010) helped to establish the design of the two activities. Both applications integrated a set of five training levels to familiarize the students with the control of the tool and a set of six missions designed for the learning of conceptual knowledge topics through different collaboration strategies. Additionally the teacher plays a mediator role through the different levels and missions; for this purpose he is able to stop the game to teach specific elements and assist those students with problems to achieve the objectives of each stage. The teacher is also allowed to see on his screen information about each student's performance in real time, so he knows who needs guidance. The students that complete the mission receive another task accordingly to their level, so they can keep practicing and improving until the teacher allows them to go further, when everyone's ready to do so.

The videogame by design encourages face to face collaboration between randomly assigned groups of three students (Nussbaum et al, 2009) using also three different mechanics on the mission levels, these procedures and rules were established to force them to try different group strategies depending on the scenario to be faced. The games asks the students to gather charged objects using electrical attraction and repulsion to position them over a portal after avoiding static and dynamic obstacles. The first mechanic allows the students to change their electrical charge and move the crystal even if just one of them tries to do so, promoting the students to freely explore their contribution to the crystal's movement; the second mechanic sets each user to a fix electrical charge, forcing them to play a specific role in the activity (puller or pusher) and explore the effects of position and distance over crystal's movements; the third mechanic brings back the control of the charge to the students, but takes away the prism's movement if the whole group's devices aren't turned on; this last mechanic forces coordination and participation within the group and also provides an appropriate scenario to predict the magnitude and direction of the net force exerted on a physical object. Each time when one of these mechanics is introduced to the players it is followed by a labyrinth that makes use of that gameplay. This maze's layout is always the same because its purpose is to highlight the differences induced by the changes of procedures and rules when using different technologies; this could help to identify changes in collaboration and learning. The list of levels is shown below in Table 1.1, the order of these levels and their content was established considering a gradual increase in difficulty (Villalta et al, 2010)

Level	Task
T1	Recognize themselves within the game (avatar/marker)
T2	Learn how to turn his TAD on/off
T3	Learn how to attract an then repel an object

T4	Bring crystals into the portals
T5	Bring crystals into the portals (fixed polarity)
M1	Collaborative mission: free exploration
L1	Labyrinth: free exploration
M2	Collaborative mission: fixed polarity
L2	Labyrinth: fixed polarity
M3	Collaborative mission: move it all together
L3	Labyrinth: move it all together

Table 1.1: List of levels

Later on, when game's mechanics were established it was necessary to consider and apply the elements listed above to minimize the gap between both videogames. We considered that the arrows showing the forces being applied to the crystal could be provoking information overload because the users playing the AR version would have to see foreign arrows (from their group's partners) on their screen, which may confuse them. We considered this as a potential risk for the experience so we took off the arrows in both games. Additionally on the MM game the user's avatar could move through the virtual field between the objects, while AR users could only see these objects from outside because of the markers, so we placed a barrier on the MM version to constraint the avatar's movement through the field, so they would have to go around just like the players in the AR version of the game did. The game score by the other hand, was shown to everyone in the classroom to provide immediate feedback of the user or group's actions (considering number of attempts and number of objects gathered), but also because MM can't hide this information as was already pointed out.

1.4.3 Story

The sequence of events that unfolds the game needs a story in the background that allows the participant's immersion (Villalta et al, 2010). The narrative in a videogame provides an environment where players can identify and construct causal patterns that integrate what is known or learned (Dickey, 2006). The activity designed includes a back story where planet Earth is condemned, and humanity needs to find another suitable planet to live on. *Earth-two* is the home for the first human colony in space, but they don't have energy enough to keep living there for too much time, that's true until certain crystals with electrical characteristics called *Tiberium* were discovered.

The students can play as astronauts whose mission is to collect the *Tiberium* crystals, the problem is that these prisms are very fragile and can only be recollected once a year using an electrical device called TAD (Tiberium Acquisition Device), so they are trained for this purpose, travel to the space and face challenges like a meteor shower to gather enough crystals to save the colony… and human race's only hope.

To provide an ongoing narrative we added cut scenes in both experiences between certain levels to develop the story line (a screenshot of one of the cut scenes is shown in Figure 1-4); these are used when learners have successfully accomplished a task or before the introduction of another problem (Dickey, 2006).

Figure 1-4: Cut scene's screenshot

1.4.4 Aesthetics

This element has the most direct relationship to a player’s experience because it’s associated with the user’s senses and how do they feel the game by their looks, sounds and other senses (Scell, 2008).

When the technology used in a game is changed, it will bring differences on the game’s aesthetics, because the experience it not exactly the same. We mentioned that player’s perspective on both games was not identical because of the technology being used. This fact can be seen also in the capabilities of the AR platform to bring virtual elements into reality, because the real background differs from the environment shown on the virtual space, it’s another ambience; in one of them the user goes into the virtual world, and that perception will be different to bring certain objects come into the classroom.

Even though we identified some inherent differences, we used the same 3D models and textures in both games, the cut scenes were identical for each experiment, the sound effects and background music was the same and even the design was similar as shown in Figure 1-5.

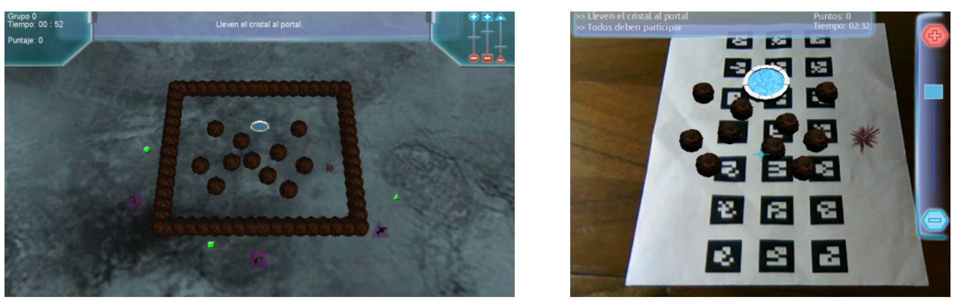


Figure 1-5: First collaborative mission on each game

1.4.5 Technology

The technology is the media where the aesthetics takes place, in which the mechanics will occur and through which the story will be told; that doesn’t mean that technology is more important than the other aspects mentioned on Scell’s elemental tetrad, but it will coordinate them.

In this section we will detail the software design for the two different technological platforms for co-located collaborative games: augmented reality and multiple mice. Later on Chapter 2 both platforms are described.

The original versions of First Colony CMPG had been previously developed by Cristian García-Campo (MM original game) and Francisca Gil (AR version) using Microsoft XNA Game Studio 3.1. This framework contains a set of .NET libraries and enables to create games using C# (technically allows any .NET compliant language, but C# is the only one that's supported by Goblin XNA) that run on both Windows and Microsoft's Xbox 360. XNA simplifies game's development because it encapsulates low level's features, and provides them as game components libraries.

XNA can be seen as a four layer framework (as shown in Figure 1-6), containing: the platform, the core framework, an extended framework and games themselves. The core framework gathers every core's functionality like: graphics (based on Direct3D 9 APIs), audio (built over XACT), input (built over XInput), storage (System.IO and Environment methods on Windows) and math components; the extended framework contains the application model and the content pipeline, while the platform considers the group of APIs where the framework itself is built on top.

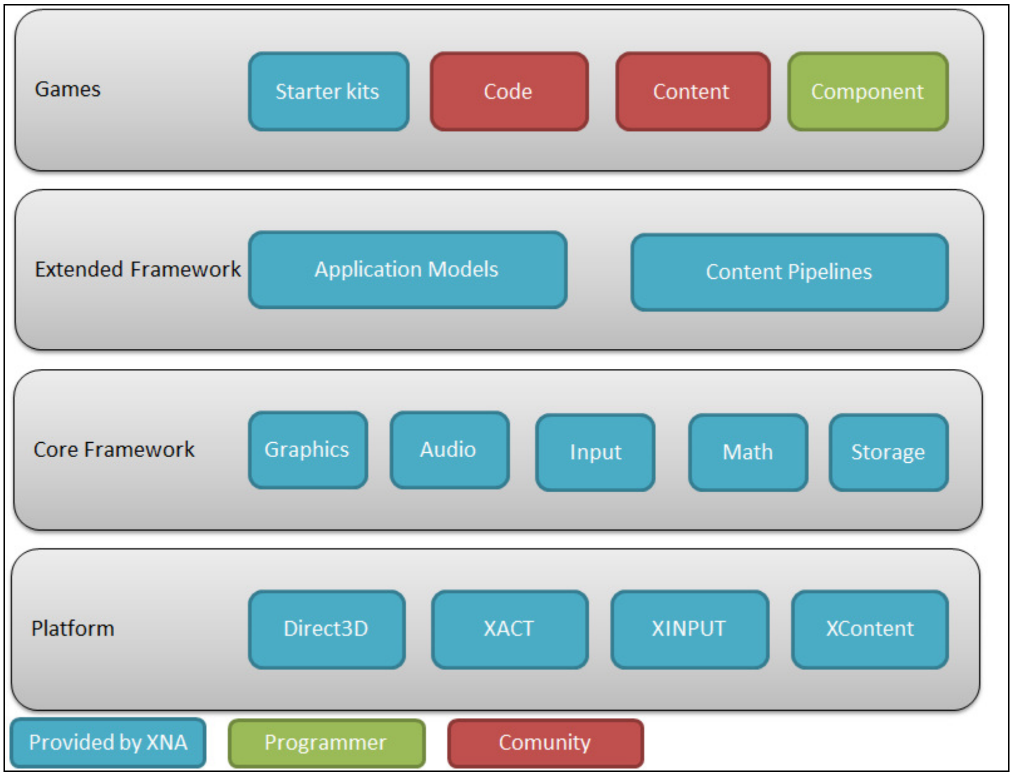


Figure 1-6: XNA Mitch Walker's layers model

Unfortunately XNA does not support multiple mice input, so using Peter Brumblay's raw input sharp library (which uses platform invoke calls to mimic Jake Stookey's work using an object-oriented design) was possible to handle multiple mice on the XNA application.

It was also necessary to use Goblin XNA platform to handle mobile AR on XNA, which supports six degrees of freedom using marker-based camera tracking through ARTag with OpenCV. The research of Goblin was supported by Microsoft Research and developed by Ohan Oda, Steven Feiner et al.

1.4.5.1 Software's architecture

Using Francisca Gil's code as a base and Newton Game Dynamics free physics engine, the original CMPG on MM was rebuilt from the start adding the modified physical engine and an easy configuration system through XML format files. There's one XML file per level, and each one contains a list of objects (crystals, portals, obstacles) with their velocity and position. With the reworked code it was possible to use the same network module and physics' engine on both applications, so the teacher uses the same interface regardless of the videogame being used.

The implemented solution on the new version of the MM application suffered changes to adapt both codes, so instead of the original five modules the software has now only four: Game Logic, GUI, Physic Engine and Network. The Tracking module was removed because the methods provided by it were not necessary anymore; there was no integration between the real and virtual world through markers, and all the input/output was controlled using polling at the game logic module, it wasn't needed to estimate the player's position from the projection matrix of the marker.

The network module follows the client/server architecture, when running the application the server looks for wireless devices, and using the TCP three-way handshake method a connection is established. From that point on the clients wait the signal from the server for running each level. The clients read the XML files and create an array of abstract levels (with own rules) using a factory method pattern (Figure 1-7) and wait the signal from the server. When a signal arrives the level manager takes control and reads each object from the associated file; later on, they are loaded into the level using an abstract factory pattern (Figure 1-8).

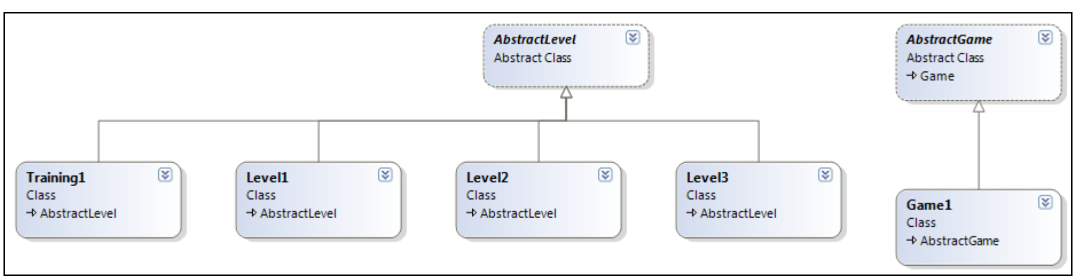


Figure 1-7: UML Class diagram for level's creation

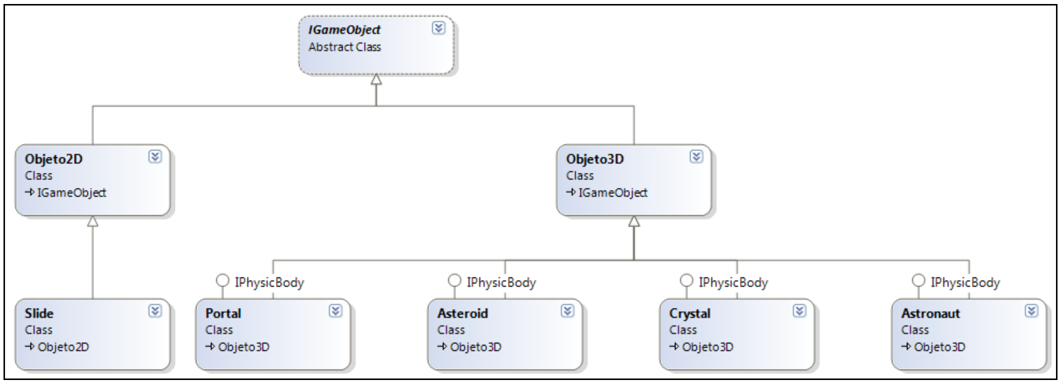


Figure 1-8: UML Class diagram for objects initialization

Each one of the 3D items has an IPhysicBody as an Interface, which is updated by the physicsSolver. The physics engine (Figure 1-9) first task is to look for collisions between each 3D-Object, when two of these objects collide the engine identifies both classes and looks into the Game Logic module what to do in that situation, then fires the associated event (captured by the server module), applies the forces to each kinematic object and updates their data.

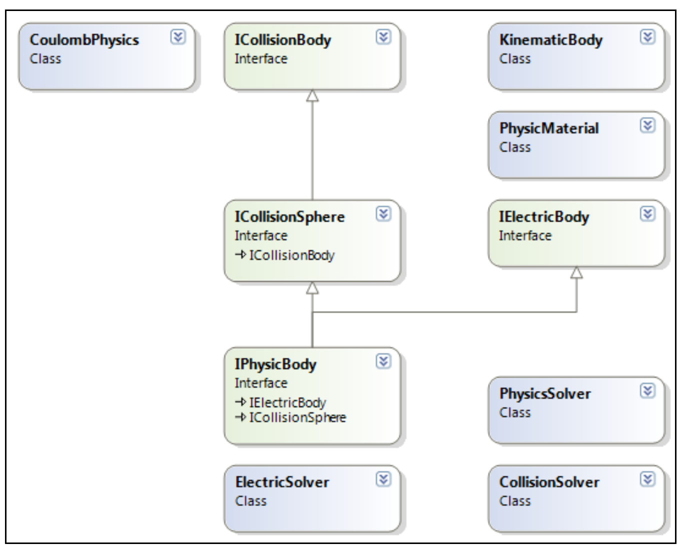


Figure 1-9: UML Class diagram of the physic engine

The game logic depends on the application's current level, because the rules, collisions and actions performed by the astronauts are conditioned by the stage being played. The reading of the I/O devices are handled using polling by this module which relies on the GUI module to display the game on the local screen, while the server show's all groups information in the teacher's projected screen.

The host also has a recovery mode that allows any player who had lost the connection to reconnect to the server during the activity, and also allows starting the game from any level if this it was needed.

1.4.5.2 Difficulties

During the development of the reworked version of the game we found different complications that caused changes from what was planned because of the testing's results; these modifications helped through the evolution of the application to get a refined and stable version of the videogame. The main issues found and how they were solved is described below.

The first problem to face was working with inherited code, because the first videogame was not designed for further modifications, the core of the application was one single class while the other application had a set of modules with specific tasks, so the merging of both codes was difficult. The use of software versioning and revision control systems was necessary for this purpose, it's recommended to build stable versions and regaining functionalities by steps; divide and conquer proved to be an efficient strategy.

Other problem was evidenced when the new version of the AR game was tested with people from outside the development team. It was evidenced that the game was slow and the touch screens were uncomfortable, and that affected the user's experience; it was not pleasing for them. Effectively when the application used the new designed XML-maps for each level the number of dynamic and static obstacles went up in comparison to the old version, and the low cost tablet computers couldn't handle more than seventeen 3D objects being drawn at the same time. It was necessary to reduce the 3D object's models complexity which proved to solve the frames per second problem. For the second issue exposed it was necessary to think another way to play the game, because the tablet was not light enough for the students to play the game while holding it with just one hand during the whole experience, it was failing the ergonomic design, so for improving the relation of the CMPG with the users it was necessary to consider their requirements. A modification was made in which the touchscreen was just optional and the use of the keyboard with the thumbs while holding the netbooks with both hands was encouraged, and it proved to be confortable in the subsequent testing rounds.

1.4.6 Experiments and game results

1.4.6.1 Setup

The experiments designed took place in a public school in Santiago, Chile. The multiple mouse platform was tested with eighteen students (two rounds of nine persons), while the augmented reality platform was tested with twenty seven students (three rounds of nine). The 11th grade students were randomly divided in groups of three to play the game using one platform during a one and a half hour class. The teacher was one of the members of the research team. Figure 1-10 shows how the students played each of the games.

Figure 1-10: Students playing each version of the game

The conditions needed for the augmented reality game were more complex than the multiple mice one; it was necessary to take care of each tablet's battery before the activity took place; also the classroom required an adequate illumination because the tracking of the markers fails both in brightly lit rooms, as in dark ones.

In the MM activity each student sits in front of a laptop computer which had a mouse for each member of the group. Each student played both the training solo levels and the group levels using this configuration. In the AR activity instead, each student was asked to find his/her own marker (there was nine of them) which would be the student's playing area during the tutorial stages, then they had to move to one of the three markers designed for the group levels.

The teacher's computer has his interface projected in one of the classroom's walls to show the game's cut scenes and also the student's game scores to help the teacher to identify who needs his guidance.

Each one of the groups playing the games had a transparent observer with a guide to identify how many times they discuss a strategy and how is made that interaction between them (verbal, physical in the real world or through the technological platform).

1.4.6.2 Results and statistical analysis

The two CMPG created helped to establish two comparable experiences to study the effects of different technological platforms over student's learning.

Considering the in-game results the t-student test for paired samples showed that the win ratio of the players on labyrinth levels (given by the number of successfully gathered crystals over the number of trials made during these levels) showed in Table 1.2, were not affected by the variation of the collaboration rules (free exploration, fixed charge and "all together" mechanics) on none of the platforms.

	L1	**L2**	**L3**
Average	0.5	0.5	0.44
Standard deviation	0.24	0.3	0.25

Table 1.2: Win-ratio on labyrinth levels.

To enlighten this independence we show below the analysis made between the results of the first mechanic versus the third, whose different averages and lower standard deviations illustrate the uninfluenced variation of the win ratio because of the changes in the collaboration rules. The null hypothesis will be that the averages from the win ratio of the first labyrinth stage will be equal to the obtained to those in the third labyrinth level. With the information and using a significance level of 0.05 (5%) for a one-tail test the results are as follows:

Statistical t	0.8883
p (T<=t) one tail	0.2075
t Critical one-tail	2.015

Table 1.3: results for a one tail t-student test, alpha=0.05

The results can't reject the null hypothesis, because the absolute value of the statistical t is lower than the t critical one-tail value, and also because the probability that the null hypothesis is larger than the alpha.

Similarly the number of interactions between the students during these changes in collaboration didn't show any remarkable difference between technologies as shown below.

	MM group interactions per level	AR group interactions per level
Average	45,66	45
Standard deviation	15,55	13,23

Table 1.4: Interactions within the group per level

There were differences in learning due to the use of different technological platforms when considering the gender of the students, those results will be explained in chapter two.

1.5 Conclusions and future work

The results of both experiences demonstrated that, despite of the subtle dissimilitude between the technologies both of them are a viable way to support teaching difficult subject matters to students through videogames when following a strong pedagogical model.

The CMPG model can be used with different technologies successfully, but has to consider each specific constraint that any technology adds to the experience and integrate it as part of the activity. Aspects as privacy, cost, ergonomic design, divergent points of view and even realities involved are affected by the technology being used, so each one of these elements must be covered in the design of every educational exercise.

We saw during the experiments that the same activity awakes different reactions on students and encourages them to achieve different goals; some play for fun, others to cooperate and others to win. The study of different game's mechanics which could merge diverse motivations into a common goal of learning would be an interesting area to investigate.

2 EXPLORING DIFFERENT TECHNOLOGICAL PLATFORMS FOR SUPPORTING CO-LOCATED GAMES IN THE CLASSROOM

2.1 Introduction

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

However, the reality is different: the mere deployment of this technology has no added educational value in itself, and can even be detrimental (Cuban, Kirkpatrock & Perk, 2001). Several studies have shown that without a pedagogical structure associated with the deployment of the technology, the technology has no impact on student learning (Santiago, Severin, Cristia, Ibarrarán, Thompson & Cueto, 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 student learning (Roschelle, Rafanan, Bhanot, Estrella, Penuel & Nussbaum, 2010).

Computer Supported Collaborative Learning (CSCL) is a pedagogical approach that has been successfully integrated into classroom activities using available technology (Zurita & Nussbaum, 2004). In a collaborative learning activity, students work as a group in a coordinated effort to achieve a specific educational goal (Dillenbourg, 1999). There have been several different approaches to deploy this type of activity in the classroom: using one handheld device per child (Zurita & Nussbaum, 2004); using one netbook per child (Nussbaum, Gomez, Mena, Imbarack, Torres, Singer, & Mora, 2010); using one computer for every three children (Infante, Weitz, Reyes, Nussbaum, Gómez, & Radovic, 2010) and even using one computer for the whole classroom (Szewkis, Nussbaum, Denardin, Abalos, Rosen, Caballero, Tagle & Alcoholado, 2010).

In parallel to this growing interest in using technology in the classroom, another simultaneous movement has been pushing for the use of videogames as a learning tool. This movement states that videogames are, in 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 has validated these claims, showing the benefits of games as learning tools (Clarke & Dede, 2007; Dede, 2009; Klopfer & Squire, 2008).

What is generally lacking in previous experiences of using videogames in the classroom is an explicit integration of the game into the pedagogical process of the class. In many cases, games feel like a replacement for the class instructor rather than a tool to be used and controlled by them. This potentially prompts some teachers to reject their use (Kebritchi, 2010). To achieve a successful integration, several elements need to be present. Among others, the game should involve all the students in the class, the teacher must have the ability to control the game, and the duration of the game-play sessions should be adjusted to the length of the class (Susaeta, Jimenez, Nussbaum, Gajardo, Andreu & Villalta, 2009).

In this article we explore the design of technological platforms that support the deployment of co-located collaborative games, taking into account the pedagogical requirements. In order to achieve this we first propose a series of requirements that should be considered when designing these platforms, before applying them to the development of two platforms (Section 2.2). Using both platforms, and so as to understand the advantages and disadvantages of each, we implement a game to teach electrostatics (Section 2.3) and perform an experimental analysis with 45 11thgraders from a public school in Santiago, Chile (Section 2.4). Based on the experimental results, we provide a series of lessons learned from the experience that should be taken into account when using these platforms (Section 2.5).

2.2 Technological platforms for co-located collaborative games

2.2.1 Requirements

To achieve successful collaborative learning among peers, there are several conditions that are required (Szewkis, Nussbaum, Denardin, et al, 2010): the existence of a common goal, positive interdependence between peers, coordination and communication between, individual accountability, awareness of peers' work and joint rewards. However, only three of these conditions are significantly affected by the choice of the technological platform. The first is the coordination and communication between peers, given that some technologies are better suited to face-to-face communication than others. The second is individual accountability, given that some input devices cannot be differentiated by the system in certain technologies (e.g. multitouch tables). The final is awareness of peers' work, given that in some platforms the complete information of the system is shared (e.g. single display groupware), while in others it is not (e.g. individual mobile devices).

In addition to the necessary requirements for achieving collaborative learning among peers, the successful orchestration of these activities in the classroom requires additional conditions regarding the role of the teacher (Dillenbourg, 2010). In particular, the teacher should be aware of the activity status of the students, and should also have control of the flow of the activity during the class (Dillenbourg, 2010). The fulfillment of these teacher-centered conditions will also depend on the technological platform. To allow the teacher to be aware of the students' work, there must be some mechanism in the platform that provides real-time feedback to the teacher. To allow teacher control, there must be some mechanism in the platform that allows the direct intervention of the teacher in the students' actions.

Based on these previous conditions, we propose a list of requirements that must be considered when designing technological platforms for supporting co-located collaborative games in the classroom:

- Facilitate teacher awareness and control of the game: The first essential requirement is that the design of the platform must consider how it will help the teacher in mediating between the game and the students. As previous experiences with classroom games have shown, a participatory role of the teacher is essential (Habgood & Ainsworth, in press; Squire, Barnett, Grant & Higginbotham, 2004), and the platform should explicitly allow for this participation. The teacher must be included in the information loop of the game, allowing them to control the game flow and also receive real-time feedback about the current status of the students.
- Facilitate awareness of peer's work among students: Most educational videogames require the explicit representation of the virtual objects and elements of the game world. The ability to interact with the system and modify these representations is essential so as to take advantage of the feedback loops that the game provides (Gredler, 2004). It is important, then, that the main game elements that are related to the concepts being taught by the game are visible to every player, and that this visualization is consistent among them all in order to achieve peer awareness.
- Allow individual accountability: Individual accountability is one of the essential elements that must be considered in a CSCL activity (Szwekis, Nussbaum, Denardin et al, 2010). In order to achieve this, the system must know which student does which action. Some input technologies such as multi-touch tables or laser pointers do not allow the system to identify each player and thus should not be used in developing this type of platform.
- Allow face-to-face communication and coordination between small groups: Face-to-face interaction is essential for achieving good results in a co-located collaboration environment (Zuirta & Nussbaum, 2004). The technologies used for these platforms should therefore allow for it. In addition, the technology should prefer interaction between small groups because evidence has shown that

groups of three students are better for this type of collaboration (Zurita & Nussbaum, 2004).

According to the characteristics previously described, we designed two platforms using different technologies: one based on using multiple mice connected to a computer; the other based on augmented reality. In the following sections each platform is described, detailing how each one of the previous characteristics is considered.

2.2.2 Multiple mice platform

The multiple mice platform is designed around the central idea of taking advantage of multiple input possibilities provided by regular computers, especially the ability to connect and use multiple mice, something which has been already tried for several classroom-based educational activities (Moraveji, Inkpen, Cutrell & Balakrishnan, 2009; Susaeta, Jimenez, Nussbaum et al, 2009). In this platform, students play in groups of three using one computer, each student controlling one mouse. Each group works with their computer which runs the game logic and graphics independently. The computers are also wirelessly connected to the teacher's computer in order to provide real-time feedback about the students' gameplay and allows the teacher to control the flow of the game, pausing all of the games if necessary. The real-time results of each group are also projected on a screen which allows the teacher to visualize the current state of the game from every location in the classroom, giving them the flexibility to move around the groups and still be aware of the other group's status (Figure 2-1).

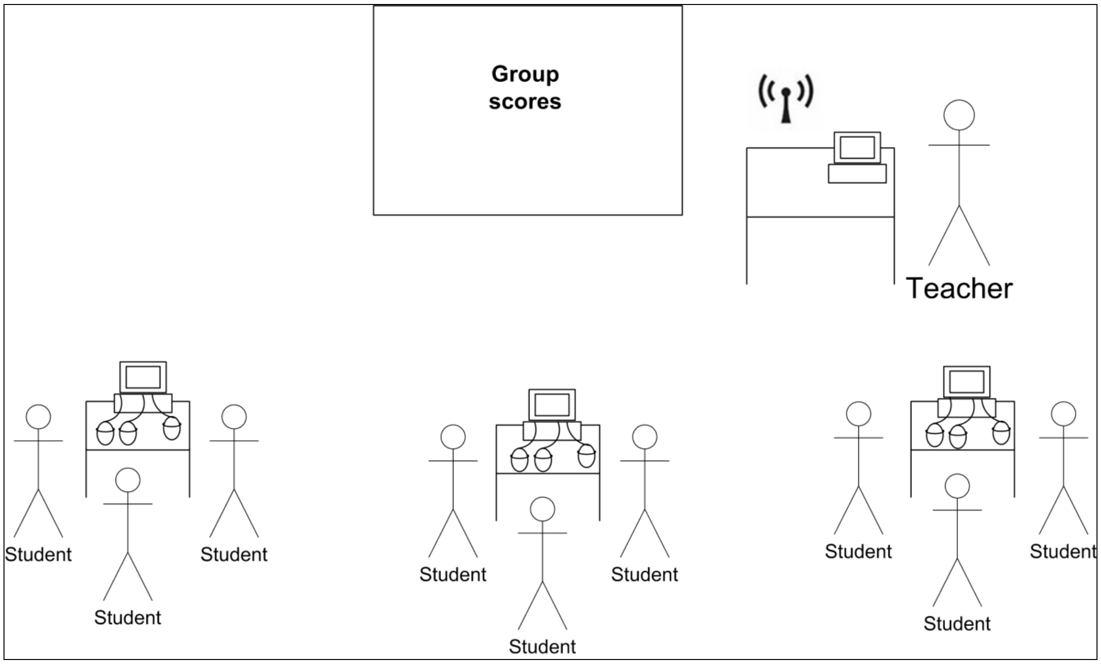


Figure 2-1: In the multiple mice platform, groups of three students play on one computer, each student using a mouse. The computers are networked to a central server that provides real-time information to the teacher and is also projected for every group to see.

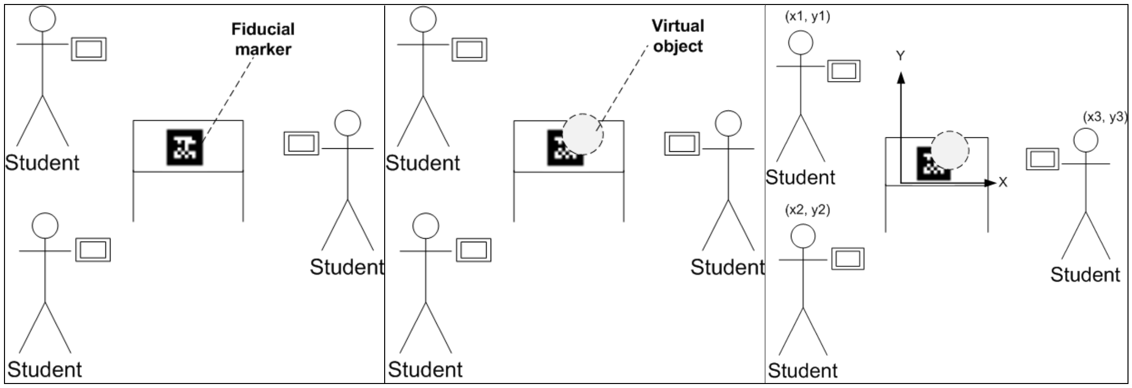
This proposed platform complies with all of the required characteristics previously discussed:

- Facilitate teacher awareness and control of the game: The teacher involvement is explicitly designed in the platform. Each computer is connected to the teacher's device, allowing them to control the game flow, and also receive real-time feedback. This is enhanced by also projecting the results onto a screen which allows the teacher to move around the classroom and still visualize the status of the different groups.
- Facilitate awareness of peers' work among students: By providing one laptop with a common display for each group, every student in the group can visualize the complete representation of the game world and objects. Because the screen is the only information source for every student, the information is shared between the members of the group, making each student accountable for their own work.

- Allow individual accountability: Each student controls one mouse, which serves as their individual input device. Each input device has a symbol associated as a cursor, allowing the student to identify their own device. However, student interaction is limited to the three degrees of freedom of movement of the mouse (left-right, up-down, and mouse wheel), and the three buttons (left, middle, right). The system is able to fully identify the actions of each student, assuming that they remain in control of their mouse.
- Allow face-to-face communication and coordination between small groups: Although the platform is not ideal for eye-to-eye interaction, considering that students are facing the screen most of the time, by being co-located around one computer the platform allows better face-to-face communication between students compared to a one computer per student set-up.

2.2.3 Augmented reality platform

The augmented reality platform uses augmented reality technology (Milgram, Takemura, Utsumi & Kishino, 1994) to create a virtual world inside the classroom. This virtual world can be visualized and explored by each student using a tablet. The interaction with the virtual world is achieved by transforming the classroom into the game world: each desk is covered with a set of fiducial papers (Figure 2-2a), markers that allow the augmented reality system to place virtual objects over the desks (Figure 2-2b). 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 (Figure 2-2c). To interact with a virtual object, each player must first identify the object by looking through their display and then, using a series of interface buttons, perform the different possible actions.



(a) **(b)** **(c)**

Figure 2-2: In the augmented reality platform, paper fiducial markers are placed on each desk (a) allowing the devices to identify the desk's position and add virtual objects to it (b). The markers also provide a frame of reference that allows the players to be located in the virtual world (c).

Each group of three students works around one desk, each of which has a specific fiducial marker. The teacher's computer acts a central server that runs the game logic for every group. Each tablet acts as a client device receiving instruction from the server to update the graphics, and sending the user input back to the server. The teacher's computer is also used to provide real-time feedback about the student's gameplay, and allow the teacher to control the flow of the game, pausing all of the games if necessary. The real-time results of each group are also projected on a screen, which allows the teacher to visualize the current state of the game from every location in the classroom, giving them the flexibility to move around the groups and still be aware of each group's status (Figure 2-3).

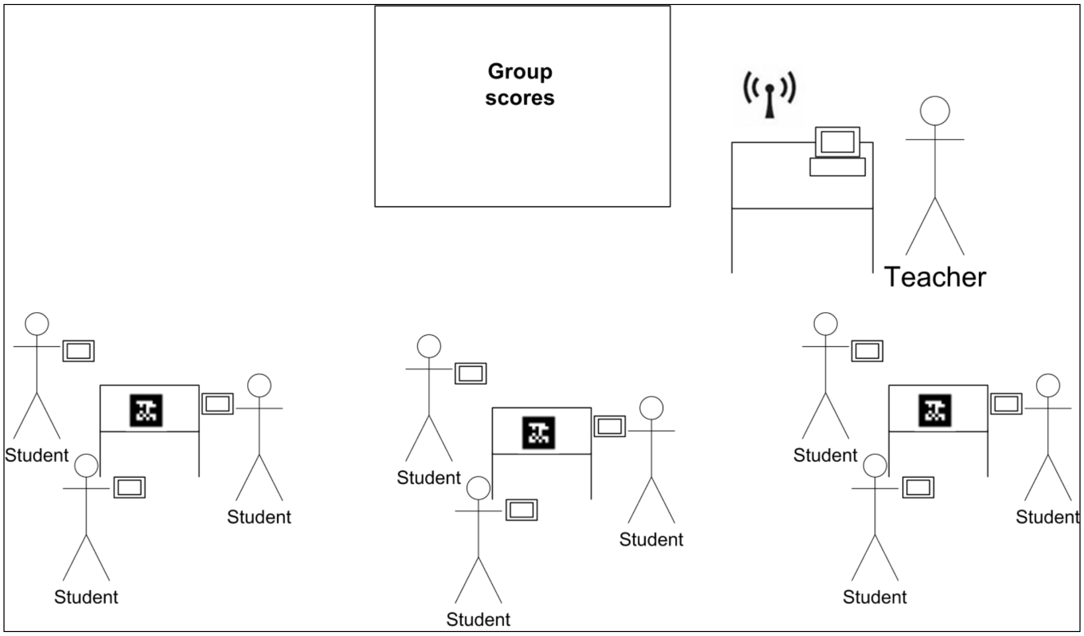


Figure 2-3: In the augmented reality platform, groups of three students play around one fiduciary marker, each using a tablet. The computers are networked to a central server that runs every game and provides real-time information to the teacher, and is also projected for every group to see.

This proposed platform complies with all of the required characteristics previously discussed:

- Facilitate teacher awareness and control of the game: As with the multiple mice platform, the teacher involvement is explicitly designed in the platform. Each computer is connected to the teacher's device, allowing them to control the game flow, and also receive real-time information. This is enhanced by also projecting the results onto a screen which allows the teacher to move around the classroom and still visualize the status of the different groups.
- Facilitate awareness of peers' work among students: The shared representation is achieved by showing the same augmented objects to every player, coordinated by the central server. One difference to the multiple mice platform is that, in addition to the shared world, each player can have individual private information shown on each of their screens. This has to be managed accordingly, taking into consideration accountability and awareness of aspects of peer work.

- Allow individual accountability: Each student controls one tablet, serving as their individual input device. The touch screen plus keyboard in the tablet allows for a richer possibility of interaction compared to a mouse.
- Allow face-to-face communication and coordination between small groups: The platform facilitates face-to-face interaction by allowing students to always be facing each other. Small groups are also required to provide enough space for students to move freely around the desks.

2.3 First Colony: A game to teach electrostatics

2.3.1 Game description

To test the results of integrating a game in a classroom with both platforms, we used a previously developed game called "First Colony", designed with the goal of teaching electrostatics to 11th and 12th graders (Echeverría, Garcia-Campo, Nussbaum, Gil, Villalta, Améstica & Echeverría, 2011). Electrostatics is an interesting area for instructional games as the nature of the interaction is non-intuitive and invisible. For this reason, it has been used in several research projects that designed games and virtual environments for the topic, obtaining successful learning outcomes (Squire, Barnett, Grant et al, 2004; Salzman, Dede & Loftin, 1999).

The scope of our game was more limited than in previous games: we focused only on point charges and static electricity forces, which studies have shown to be difficult topics to grasp conceptually (Maloney, O'Kuma, Hieggelke & Van Heuvelen, 2001). The specific learning objectives of the game were:

1. To understand the interaction between objects with positive, negative and neutral charges.
2. To understand the relationship between charge intensity and electrical force.
3. To understand the relationship between the distance between charges and electrical force.

4. To apply Coulomb's Law in order to predict the magnitude and direction of the force generated between two charges.
5. To apply the principle of linear superposition to predict the magnitude and direction of the net force exerted on a charge in a system with multiple charges.

In the game, players assume the role of astronauts from the first human colony on an extra-solar planet. They have been sent on an important mission to bring back a precious crystal found in space. The colony has limited energy resources and the crystal has the unique quality of storing electrical energy. However, the crystal is fragile so the astronauts can only interact with it from a distance using electrical force.

Each player controls an astronaut that can activate an electric charge around them (simulating a point charge). The player can also select the charge intensity and polarity and move the astronaut through the game world, modeling the relevant variables required to understand Coulomb's law (charge and distance). The player then needs to interact with the crystals, which are also electrically charged and, depending on the values selected, will move in a different direction and with different acceleration. The challenge for the player is to move this crystal to a specific location in the game world, avoiding asteroids that destroy them on contact.

The collaborative mechanic of the game is used to teach the principle of linear superposition: some crystals have to be moved by the three players, each applying an individual electric force. With this mechanic, players are not only required to understand Coulomb's law, but also how their individual force adds to the total force, according to the principle of linear superposition of forces.

2.3.2 Multiple mice version

In the version of the game implemented for the multiple mice platform, each student controls an avatar that represents their astronaut. Each avatar is identified by the cursor symbol associated to each student. The students can move their avatar by locating their cursor in a specific location of the game world and clicking the left mouse button. They can also change their avatar's charge value and polarity with the mouse wheel, and visualize their current charge in the display section of the screen. To activate/deactivate their charge, players have to press the mouse wheel, which will trigger the interaction with the crystal according to the selected parameters (Figure 2-4).

Figure 2-4: Game implemented in the multiple mice platform: each student controls their astronaut with a mouse. They have to collaborate with their electric charges to produce the electric force that will move the crystal to the portal.

2.3.3 Augmented reality version

In the version of the game implemented using the augmented reality platform, each student is represented by an astronaut. By moving around, closer to or farther away from the fiducial marker, the player changes the astronaut's position in the game world. To change their charge value and polarity, the display of each tablet is augmented with a HUD (Head-Up Display) that allows the player using the touch screen to select their charge and also provides a button for activating/deactivating the charge (Figure 2-5).

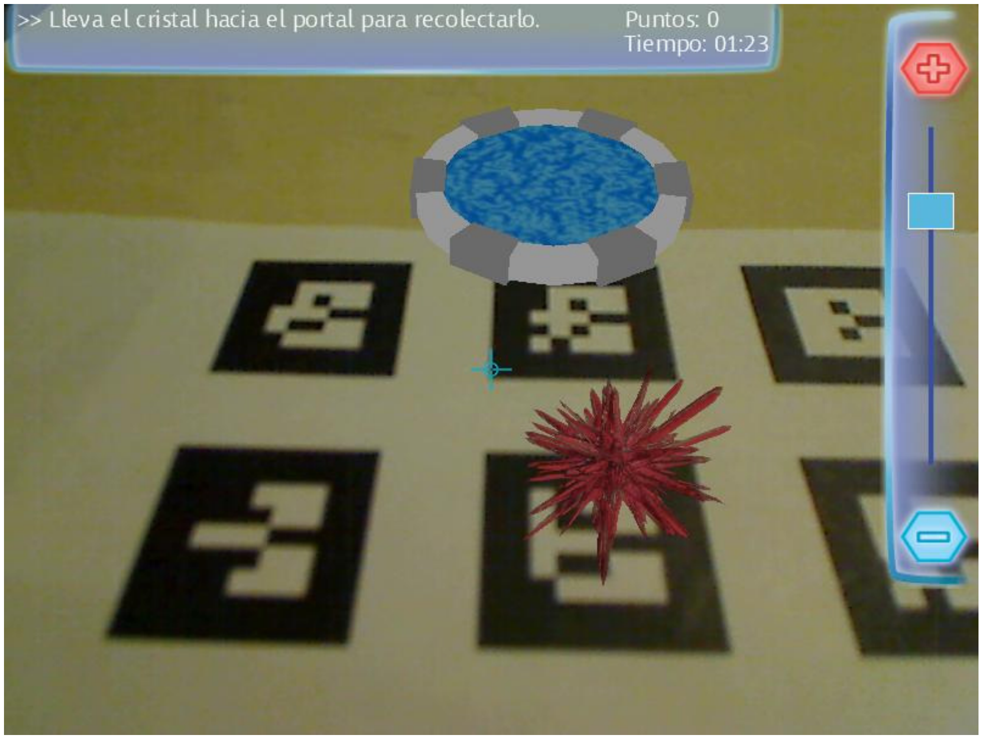


Figure 2-5: Game implemented using the augmented reality platform: each player visualizes the augmented world through their visual display and has to move the crystal to the portal by applying electric force using their personal device.

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 also have a touch-screen which allows the students to interact using a stylus or their finger to perform the actions in the game.

2.4 Experiment

2.4.1 Setup

We designed an experiment in order to answer the two research questions at the heart of this study: (1) is it possible to design educationally effective physics games using these platforms? and (2) are there any differences in the learning outcomes or player experience for students using each platform? The experiment was carried out with 45 11th grade students from a public school in Santiago, Chile. The multiple mice platform was tested with 18 students (11 boys, 7 girls), while the augmented reality platform was tested with 27 students (12 boys, 15 girls). Both groups played the game during a one and a half hour session. In each session, 9 students played and were divided into groups of three. One of our researchers acted as the teacher for the session.

A pre-post test design was used to compare the learning achieved with the game. The instrument used to measure the expected learning outcomes was a specially designed conceptual evaluation that assessed each outcome by asking specific questions. The evaluation was based on the Conceptual Survey of Electricity (CSE) proposed by Maloney et al. (2001), with certain modifications to ensure that all of the desired learning outcomes were covered and any questions on unrelated or more advanced subjects excluded. The test was previously validated with 20 students, yielding a Cronbach's alpha of 0.74, above the minimum value of 0.7 required to prove reliability.

To measure the engagement of players we used the Game Experience Questionnaire (GEQ) (IJsselsteijn, Poels, & de Kort, 2008), a questionnaire that has been validated as an effective tool for assessing experiences with both instructional and commercial games. To measure the social involvement of students we used the Social Presence in Games Questionnaire (SPGQ) (de Kort, IJsselsteijn & Poels, 2007). We translated the English version of both questionnaires into Spanish, using the procedure specified by the developers of the questionnaire (IJsselsteijn, Poels, & de Kort, 2008), in order to maintain valid results for comparison. The Game Experience Questionnaire uses 42 Likert-type questions to measure seven relevant characteristics of the player experience: *competence*, *immersion*, *flow*, *tension*, *challenge*, *negative affect* and *positive affect*. The Social Presence in Games Questionnaire uses 17 Likert-type questions to measure the relevant characteristics of the social experience: *empathy*, *negative feel* and *behavioral involvement*. Each one of the characteristics of both questionnaires is associated to a subset of questions and is measured with a score from 0 to 4. A higher score is considered better for every characteristic, except for *negative affect* and *negative feel* where a lower score is considered a better result.

2.4.2 Results and Statistical Analysis

The results of the conceptual evaluation pre- and post-tests showed an increase in the average number of correct answers from 4.27 (1.74) to 6.22 (3.13) for students who played the multiple mice version, and an increase in the average number of correct answers from 3.51 (2.04) to 6.37 (2.89) for students who played the augmented reality version. To analyze the statistical significance of these results in both cases we performed a Student's t test for dependant variables, the null hypothesis being that the pre-test and post-test averages were equal and the alternative hypothesis that the post-test average was greater than the pre-test average. To reject the null hypothesis, a one-tailed test was used with a significance level (alpha) of 0.05 (5%). The results of the t test rejecting the null hypothesis were statistically significant for both platforms ($p < 0.05$), giving a 95% confidence level that the average number of correct answers in the evaluation increases after students are exposed to both versions of the game.

Additionally, a power analysis was performed to measure the effect size of both versions. The analysis of the multiple mice version resulted in a Cohen's d quantifier value of 0.79 indicating a moderate effect size, while the analysis of the augmented reality version resulted in a Cohen's d quantifier value of 1.17 indicating a large effect size.

To compare the effects of both platforms, we used an ANCOVA analysis with the results of students in the post-test with each version, using the pre-test results as co-variable (Table 2.1). The analysis showed that there were no statistically significant differences between the results obtained by the students who played the multiple mice and augmented reality versions ($F = 0.78$; $p = 0.38$). However, significant statistical differences were found between boys and girls in the augmented reality group, where boys outperformed girls, and also between boys of the augmented reality group and boys of the multiple mice group, where the former outperformed the latter.

Test	Gender	Multiple Mice		Augmented Reality	
		Mean	Std. Dev.	Mean	Std. Dev.
Pre-test	Boys	4.27	1.67	4.08	1.97
	Girls	4.28	1.97	3.06	2.05
	Total	**4.27**	**1.74**	**3.51**	**2.04**
Post-test	Boys	6.27	3.69	7.75	2.66
	Girls	6.14	2.26	5.26	2.65
	Total	**6.22**	**3.13**	**6.37**	**2.89**
Adjusted Post-test	Boys	6.19	-	7.82	-
	Girls	5.90	-	5.38	-
	Total	**5.87**	**-**	**6.60**	**-**

Table 2.1: Test results of comparison between multiple mice and augmented reality version

The results of the Game Experience Questionnaire and Social Presence in Games Questionnaire (Figure 2-6) for students that played on each platform show that in every dimension the results of the multiple mice platform are better than the augmented reality platform. We performed a statistical analysis using the Student's t test for independent variables, comparing the results of both platforms in each dimension of the questionnaire. The analysis showed that in both *immersion* and *behavioral involvement* the best results of the multiple mice platform were statistically significant.

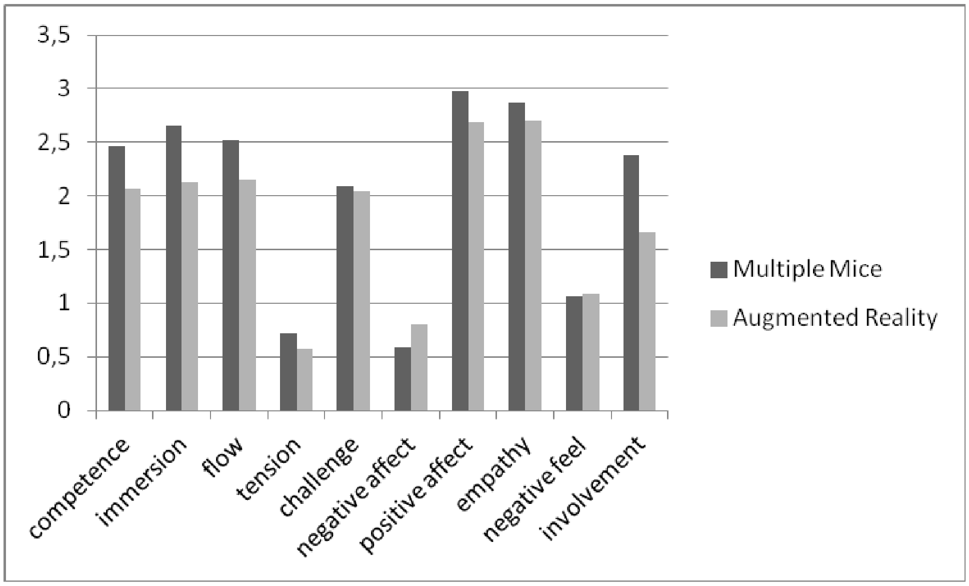


Figure 2-6: Game Experience and Social Presence Questionnaire results of comparison between both platforms

A gender analysis was also performed for the results of the Game Experience Questionnaire and Social Presence in Games Questionnaire (Figure 2-7). The results show that for the augmented reality platform there is a large difference in most dimensions between genders and that boys obtained statistically significant better results in both *competence* and *flow* dimensions.

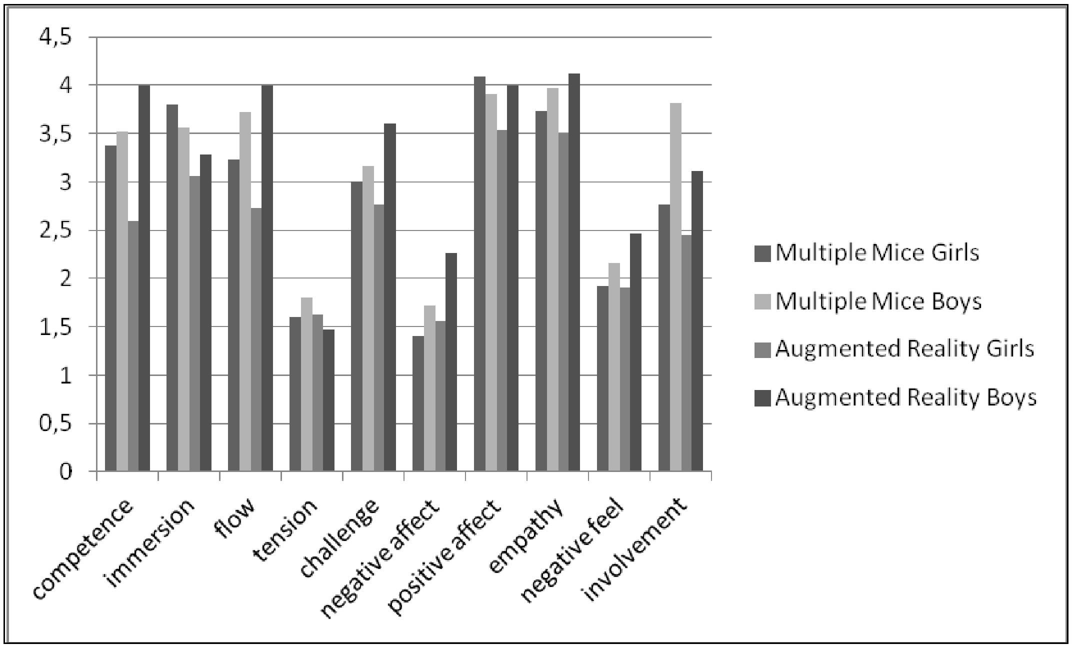


Figure 2-7: Game Experience and Social Presence Questionnaire results of comparison between both platforms with details for genders

2.5 Discussion

Based on the experimental results we outline the lessons learned:

1. The educational effectiveness depends more on game design than technology, but technology can be a factor.

Students that played both games showed an increase in their conceptual knowledge after one session with the game. This suggests that the essential aspects of an effective educational game transcend technology. However, the augmented reality group showed a larger effect in their improvement than the multiple mice group, showing that the technological platform can modify to some degree the amount of learning that can be achieved with the same game and instructional design.

This result suggests that the educational effectiveness of a game is mediated by the technological platform used for its integration in the classroom, showing that careful consideration should be taken when deciding which platform is better suited to which instructional situation, considering the possibilities of each platform.

2. Different technological platforms have different effects on boys and girls.

One of the most important results were the statistically significant differences that were discovered in the post-test between boys and girls using the augmented reality platform. Moreover, this gender gap was also reflected in the player experience, where boys had a significantly greater score than girls in *competence* and *flow*. These results suggest that, for this game at least, the platform is creating a gender gap that is not intrinsic to the game, considering that there wasn't a significant difference in the multiple mice version of the game, neither in the test results nor in the experience questionnaires.

A possible explanation of these results, consistent with observations performed during the sessions, is that girls had more trouble in learning to use the platform, hindering their ability to better understand the concepts and also achieve a better experience with the game. One possibility for this difference is the evidence that suggests that, on average, girls have lower 3D spatial ability than boys (Voyer, Voyer & Briden, 1995). In the case of the augmented reality platform, this was an essential ability to correctly play. However, this issue could be resolved by providing a training session before the game session.

3. Collaboration between small groups plus competition between groups is a good recipe for achieving engagement in both genders.

This lesson is based mostly on the observation performed during the sessions, which showed that both boys and girls were enjoying the game, but differently. When the groups that played together were conformed mostly of boys, their biggest motivator was the competition with other groups. On the other hand, when the groups were conformed mostly of girls, competition with other groups was not very important, rather social interaction and conversations within the group. There were exceptions to both cases, but in the majority of the groups the boys' preference for competition and girls' preference for collaboration was present.

This result is similar to previous experiments and observations made of social games (Schell, 2008). It shows that this mixture of collaboration and competition is ideal for deploying classroom games, because it provides a variety of engaging elements beyond the gameplay itself which will positively affect the player's experience.

4. The overhead in cost and complexity of a specific technological platform should be justified only if the educational benefits obtained by its use are significatively greater than a cheaper and simpler alternative.

The augmented reality platform represents both a more expensive and complicated platform than the multiple mice one. In terms of costs, it requires one suitable tablet device per student, compared to one laptop for every three children. In terms of complexity, it requires a more extensive setup: arranging the desks to provide space for movement by the students, locating the fiducial markers on each desk and adjusting the lighting condition if necessary. There is also the cost of the learnability of the platform itself. As our observations showed, the augmented reality platform was more difficult to learn than the multiple mice platform, especially for girls.

All of these associated additional implicit and explicit costs of the augmented reality platform suggest that its use should only be justified when the benefits are considerably larger than an alternative. For this experience we believe that the benefits obtained were not enough to compensate for the costs and, in that sense, the multiple mice platform is better suited to deploy the presented game.

2.6 Conclusions and Future work

The multiple mice platform represents a simple, yet effective technology that can be leveraged for deploying games inside the classroom. It effectively transforms a class into a fun, entertaining experience by combining collaborative play between students with competitive play among the whole class. To further validate this platform, additional games should be designed using the platform, in order to understand to what extent the obtained results can be applied.

Although the final balance of this experience suggests that the overall cost of deploying the augmented reality platform outweighs any of its possible benefits, we believe that the successful deployment of an augmented reality game in the classroom is a useful precedent for future work. A true augmented reality platform that integrates real objects could provide experiences that cannot be achieved with a traditional computer, allowing for the creation of games that combine virtual simulations with real experiments, and thus allowing an easier transfer of knowledge from the game world to the real world.

2.6.1 Acknowledgments

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APPENDIX

E-mail of acknowledgement of submission

From: **Computers in Human Behavior** <chb@elsevier.com>
Date: Sat, Sep 24, 2011 at 6:07 PM
Subject: Submission Confirmation
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Title: Exploring different technological platforms for supporting co-located collaborative games in the classroom
Authors: Alejandro Echeverria, Ph.D. (c); Matias Amestica; Francisca Gil; Miguel Nussbaum; Enrique Barrios; Sandra Leclerc
Article Type: Full Length Article

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