PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

A CLASSROM MULTIPLAYER PRESENTIAL GAME TO TEACH ELECTROSTATICS

CRISTIÁN A. GARCÍA-CAMPO

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 (or Doctor in Engineering Sciences)

Advisor:

MIGUEL NUSSBAUM

Santiago de Chile, September, 2010

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Members of the Committee:

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DAVID PREISS

RICARDO PAREDES

HUGH RUDNICK

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To Pía, for supporting me with dedicated love

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RESUMEN

Los videojuegos están construidos sobre principios que resultan beneficiosos en contextos educacionales, este es un hecho que se ha convertido lentamente en una práctica aceptada en ambientes de aprendizaje. Sin embargo todos los progresos que se han hecho en el uso de videojuegos como herramientas educacionales aún no han sido transferidos a las salas de clases. Para acortar las distancias entre las aulas y los videojuegos, hemos desarrollado un modelo pedagógico de dos niveles. Este artículo presenta el modelo propuesto, un videojuego para enseñar electroestática diseñado con este modelo y un experimento basado en un pre/post test para validar el videojuego.

El número promedio de respuestas correctas aumentó desde 6.11 a 10 luego de jugar el juego, siendo este un resultado estadísticamente significativo ($p < 0.00001$) con un nivel de confianza del 99%. Estos resultados sugieren que, a pesar de que los conceptos de aprendizaje están contextualizados en un juego con un entorno de fantasía, los estudiantes logran transferir el conocimiento logrando contestar correctamente un test estandarizado. Estos resultados representan una validación inicial del uso de este modelo como una herramienta que ayudará a los profesores a integrar los videojuegos a las salas de clases.

ABSTRACT

Videogames are built under several principles that can be beneficial for an educational context, a fact that is slowly becoming an accepted practice in learning environments. However, all the progress made in the use of games as educational tools has not been transferred to the school classroom, which remains still the most important educational environment. To close this gap between games and classroom, we developed a two level model for integrating educational games in the classroom. This article presents the proposed model, the implementation of a game to teach electrostatics with this model and an experiment based on a pre and post evaluation to validate the effectiveness of the game.

The average number of correct answers after playing the game increased from 6.11 to 10, a result that is statistically significant ($p < 0.00001$) with a confidence level of 99%. The overall good results of the experiment suggest that, although the learning concepts are contextualized in a fantasy-based game environment, the students can transfer that knowledge to answer the questions in the standard tests. These results represent an initial validation of the use of the proposed model as a tool for teachers to integrate games inside the classroom.

Key words: *cooperative/collaborative learning*; *improving classroom teaching*; *interactive learning environments*

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1. INTRODUCTION

1.1 Motivation

1.1.1 Videogames and learning

As research proceeds on video games educational possibilities, the game designers continue to incorporate the latest technological innovations such as high-speed internet connections, increasingly sophisticated graphics and more powerful microprocessors in the push to further their development and capture ever more enthusiasts.(Susaeta et al, 2009). Both technological and conceptual improvements have enabled the development of high quality video games that have been used in classrooms with excellent educational results as shown in the work done by Susaeta et al (2009) and Villalta et al (2010).

Although the use of video games as educational tools is not an extended practice in learning environments (van Eck, 2006) these experiences have shown that the use of video games has an important educational potential inside the classroom since they can be built under playing principles that can be beneficial for the learner: increasing students' interest; improving and strengthening the acquisition of information; awakening and maintaining motivation; giving immediate feedback; allowing the players to progress at individual rates, allowing the transfer of concepts from theory to practice; providing graceful failure; giving freedom of exploration and discovery; etc. (Gee, 2003; Mayo,2009; Squire, 2003).

For teachers, video games could become a valuable tool that incorporates social learning with technology, provided it can achieve a specific learning objective (Aleven et al, 2010; Alvarez, 2006). A good way to classify knowledge and learning is Bloom's revised taxonomy (Anderson et al, 2001), it divides knowledge in four types: factual, conceptual, procedural and meta-cognitive. It also gives a classification of the learning cognitive processes, defining six cateogires: remember; understand; apply; analyze; evaluate and create, that can be sorted in ascendent order forming a pyramid as show in figure 1-1.

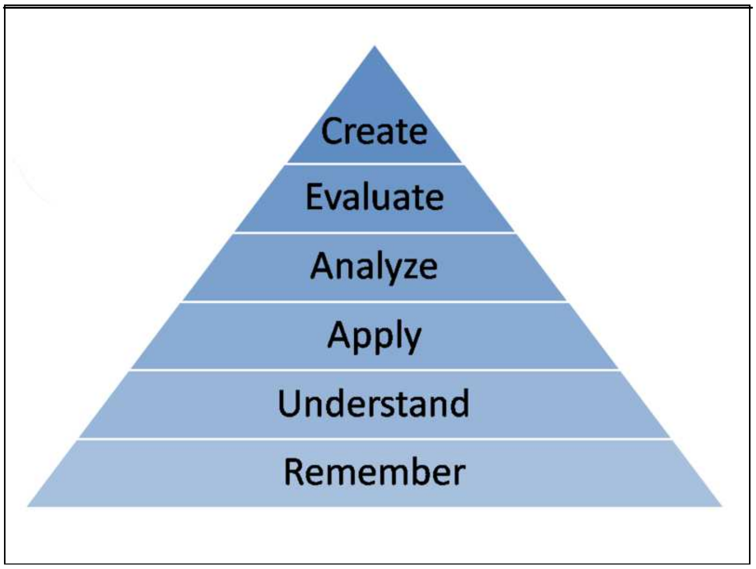

Figure 1-1: Bloom's revised taxonomy for cognitive processes.

This research attempts to bring the video games one step further than the experiences previously mentioned, showing that they can be used successfully in tranfering specific leaning objectives that involve complex cognitive processes such as Applying and Analyzing. The basic concepts of charge interaction and Coulomb's Law have been chosen as a specific subject for teaching since they have been proven to be difficult for the student (Maloney, 2001). The main aim of this work is to bring Classroom Multiplayer Presential Games (CMPG) (Susaeta et al, 2009) to schools and develop activities that allow students to deeply understand the procedures behind the electrostatic theory showing that CMPG are very powerful educational tools that can be used even in complex subjects.

1.1.2 Face to face collaborative learning

Social interactions are very important to educational development because they allow the sharing of ideas and the construction of understanding. It is necessary to set forth social and communicational skills inside the educational processes in order to teach students these abilities (Echeverría, 2009). Individuals working together on a common problem communicate and mobilize knowledge, sharing different ideas and views that allow them to build together a better solution (Zurita & Nussbaum, 2004).

Collaborative learning is a pedagogical model that considers social interaction as one of its key elements. It promotes group interaction in a coordinated effort to achieve an educational goal (Dillenbourg, 1999) based on the evidence that shows that if a group of students work collaboratively together, they will have better academic results (Johnson & Johnson, 1999).

Computer supported collaborative learning (CSCL) uses the computer as a tool to mediate de collaboration to control the sequences of activities (Dillenbourg, 2002). In this context, the computer is considered more as a guide than as a teacher (Zurita & Nussbaum, 2007) providing a support environment for the social network between students, which ideally should be transparent to the interaction.

Most existing CSCLapplications are implemented for personal computers requiring that the students be behind the screen not allowing the development of face-to-face collaboration (Inken et al, 1999). An option is to use multi-mice technology in which each student controls a mouse on a common workspace while simultaneously permitting each child to contribute to the collaborative activity (Susaeta et al 2009). The use of multiples inputs have shown to be effective when peers work together in a single screen (Infante et al 2009). Children controlling their own input device in a collaborative setting display less boredom and off-task behavior and are more active, suggesting better engagement in the activity (Scott et al, 2003)

The CMPG model is based on the CSCL model but in this case the students in a class play at the same time in a virtual world projected by one computer onto the wall of the class, in a one-to-many computing model thus adding the advantages of multi inputs, allowing student to interact with the in-class projected virtual world, and verbally with his/her peers just by using the mouse.

Another important element of the CMPG model is the teacher who acts as a cognitive mediator having control of the game flow and controlling game speed, explaining situations and giving tips to the players in order to perform the learning processes. We see the game then as a tool for the teacher, that can be controlled as he considers best for his class.

1.2 Hypothesis

The first hypothesis is that a CMPG can be used to teach subjects that have been proven to be difficult for students such as the basic concepts of charge interaction and the law of forces between charges (Maloney, 2001) by giving them the tools to apply conceptual knowledge and analyze the results of their work.

The second hypothesis is that despite the difficulty of the tasks the students must perform, they will collaborate with their classmates and that collaboration, which is desirable and an objective by itself (Johnson & Johnson 1999), will help student to achieve their goals in the game.

1.3 Objectives

Consistently with the hypothesis proposed, the general objective is to develop a collaborative environment to teach electrical forces contextualizing it in an action/puzzle game (Kirriemuir & McFarlane, 2004) with a narrative that provides a high level on immersion **(** Ermi L. & Mäyrä F.,2005)**.** This game must allow students to explore complex physical models with the assistance of a computer while keeping them motivated and entertained. It also must help them to develop some transversals abilities such as collaboration, leadership, effective communication, teamwork, etc. A more concrete objective is to develop a face to face collaborative learning activity to be used with multiple mice and test it in a classroom.

The second hypothesis will be validated both quantitative and qualitatively. For the latter, an external observer will look for some patterns commonly described in the literature such as existence of common goals (Johnson & Johnson 1999), positive interdependence (Zagal et al 2006 , Zurita, & Nussbaum 2007), communication (Dickinson and McIntyre 1997 , Gutwin, C & Greenberg, S. 2001) coordination (Malone & Crowston 1990, Johnson & Johnson 1999), individual accountability (Johnson & Johnson 1999), social and environmental awareness (Harrison & Dourish 1996 , Gutwin, C & Greenberg, S et al. 2008) and join rewards (Johnson & Johnson 1999). An observation guideline must be created in order to adapt the semantics of the game to the above patterns, to facilitate the work of the observer and to unify some criteria about which of the patterns are applicable to the game.

Additionally, a poll regarding previous video games experiences will be made in order to see how these variables influence the academic results.

1.2 Methodology

1.4.1 Game design

Designing a CMPG implies integrating both ludic and pedagogical processes, in benefit of certain educational goals (Amory, 2007). The lack of the pedagogical component is a factor that difficults the integration of videogames in the classroom (Baek, 2008). Ludic processes refer to the mechanics of the game and their relation with the players that keeps them motivated and ensure playability (Fabricatore et al 2002). On the other hand, pedagogic processes specifically refer to the development of methods that make the learning objectives operative in game context, also allowing collaborative learning (Serin et al, 2009).

Based on the work done by Villalta et al (2010) several design rules were used in the development of this CMPG, considering both pedagogical and ludic dimension, the most important rules are described below:

- *The teacher is a mediator:* The teacher must lead the learning process in the classroom, taking care of pedagogic objectives to be achieved and filling the gaps that exist between the game and the students, promoting reflection, analysis and discussion (Moreno-Ger et al., 2008). This implies that the game must be designed with a flexible structure that allows teachers to control the activities and the flow of the game, be able to pause the game and guide students through different paths, thus enriching the teaching practice (Cuban et al 2001).

- *Interlayer individual and collaborative activities while increasing game difficulty:* CMPGs must have a script with a complexity structure linked to pedagogical objectives in order to define situations with different and progressive levels of difficulty (Dillenbourg, 2002), thus keeping students motivated to develop some skills that help them gradually learn the game concepts. (Villalta et al 2010).

- *Organizing face to face interactions:* CMPGs must allow face to face interactions between players so that collaboration can happen (Villalta et al 2010). Although technology can´t replace the richness of face to face interactions (Dillenbourg, 2002) it is possible to generate conditions that facilitate direct participation between students: for example, many players working together in a single shared screen controlling individual mice (Susaeta et al., 2009).

- *Feedback and interactivity:* Action feedback is inherent to videogames: it maintains participation, and informs players of their achievement. In the same way, constant feedback works as reinforcement to participants' partial achievements (Villalta et al 2010). Both individual and collective feedback are important, they help in the learning processes by giving precise, timely and constant information regarding successes and failures of participants´ performance (Rosas et al., 2003).

Villalta et al 2010 describes other seven rules that were integrated in the different areas of the game design, for example a *clear narrative* was built using and *accessible language* and *avoiding information overload*, game scenarios and objects were made in order to be *easy to recognize* and facilitate the *spatial distribution* in the virtual word. At last, the game script was developed considering mechanics *linked to learning content* and *collaboration.*

1.4.1.1 Narrative

CMPGs must be linked to a literary script in order to give continuity to its quests. This script defines the sequences of activities and introduces game elements giving cohesion, joining them with the history, thus promoting immersion (Amory, 2007). The clarity of the narrative sequence allows the construction of hypotheses and strategies, and also gives contextual meaning to the elements of the virtual world thus helping synchronicity of actions between players (Zagal et al., 2000).

In this game the narrative places the students in the distant future, where humans have managed to establish their first colony on a planet outside our solar system. This colony gets its power from a strange electrical mineral called tiberium, which is very fragile and must be manipulated only with a special device called TAD (Tiberium Acquisition Device). Every year a cluster of tiberium gets near the colony and a group of experts is send there to gather some resources.

Students are presented as new collectors ready to start their training in order to become experts and go to a mission during next year. Their first training introduces them in basic elements of the game, such us recognizing their avatars, controlling their TADs and walking in the space. The second training is designed so that players are able to explore using their new knowledge. Students must understand the principles of the electrostatic and Coulomb's Law in order to complete it, but also the concept of vector force addition is introduced during this level forcing them to work together collaboratively in order to move heavy weights as shown in figure 1-2.

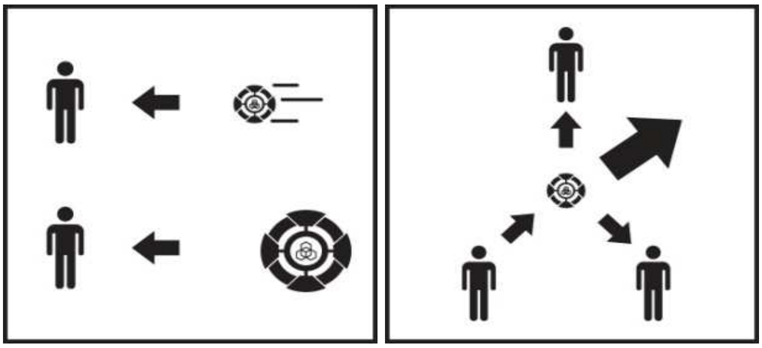

Figure 1-2: Students must discover the relation between mass and force. When they discover that they can´t move heavy objects they have to work together using the knowledge of vector force addition.

Finally when the students end their training and they become expert gatherers, they take a ship to start their mission. During the trip a storm damages the ship and all its instruments including the TADs, leaving them charged, but in an indeterminate level. Due to the importance of the mission it must be finished anyway, so students must first collaborate in order to get information about their charges based on the interaction with the rest of the players. This forces them to plan strategies together so that they can gather all the necessary resources and complete the mission

1.4.1.2 Graphics design

To support all the narrative elements presented above an entire virtual world was created using high quality 3D models and scenarios as shown in figure 1-3, thus better capturing the students' attention, and allowing for more exploration of the virtual world (Lim, 2008). All game elements and maps were especially designed for this experience using Autodesk 3D Studio max, one of the most used software for 3D modeling and animation that provide compatibility with Microsoft Windows platforms.

Both scenario and object design are important issues in the development of a CMPG because an appropriate distribution of elements on the screen favors aspects such as: playability (Fabricatore et al, 2002), immersion (Dede, 2009), verbal communication and cooperation between players (Greiffenhagen & Watson, 2009). Also easy-to-recognize game objects boost learning and playability in terms of linking the narrative with the elements that composes it, reducing learning times and allowing player to identify their avatar increasing fantasy and immersion. (Amory, 2007).

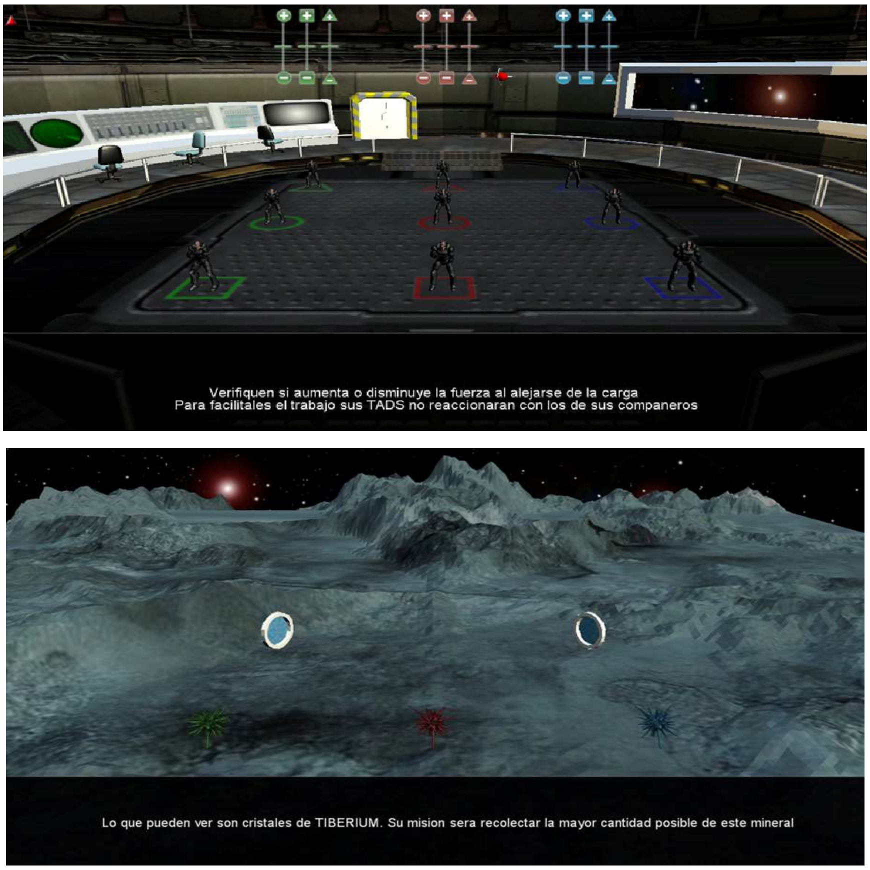

Figure 1-3: Training base and tiberium cluster virtual word representation

1.4.1.3 Software design

The entire software was developed using Microsoft XNA game studio 3.0, a set of tools based on .NET Framework 3.0 for Windows with a managed runtime environment that facilitates computer game development. XNA framework includes a set of libraries that are specific for the game development promoting maximum code reuse across target platforms. Games that run on the framework can technically be written in any .NET-compliant language, but only C# and XNA Game Studio Express IDE and all versions of Visual Studio 2008 are officially supported (Reed A , 2009) making programming very easy since it uses a high level object-oriented language that is widely used for software developments.

Basically is possible to see XNA as a native API distributed in series of layers
as shown in figure 1-4.

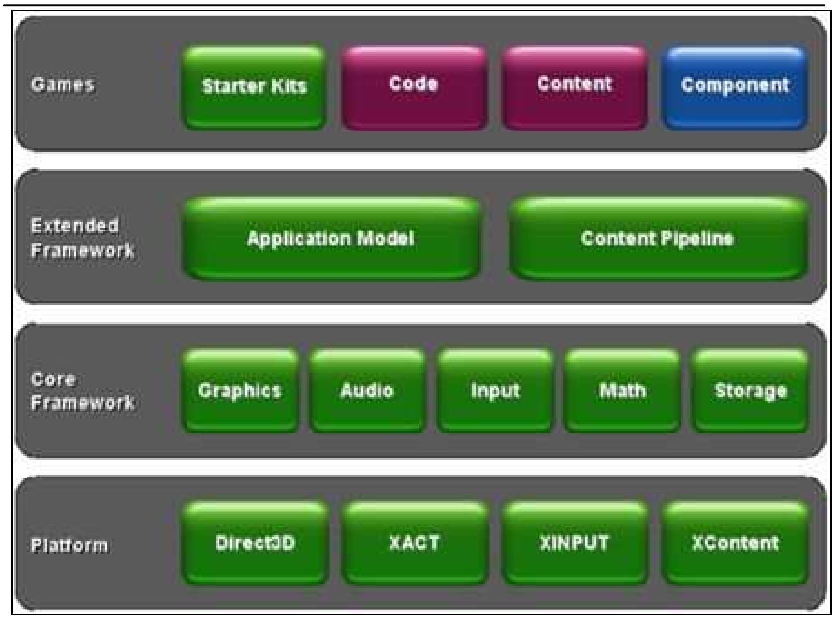

Figure 1-4: XNA layer model

In the first layer we find some natives APIs such as Direct3D, XACT, XInput and XContent supporting 3D graphics, audio, input devices such as mice, and multimedia content respectively. Then comes the core framework of XNA, this layer provides graphics, audio, input, storage and mathematical functionality to be used for the next layers that are the content pipeline and the application model. This two layers provide abstractions that facilitate program development and multimedia content handle.

At last we find the code, content, components and starting kits used to create de game experiences; these are provided by the community or self developed for and specific game. As mentioned above all game elements and scenarios were designed specifically for this game and this also applies to the source code which was completely written by the author and his team.

The only part of the code that needed external support was the class in charge of controlling the mice, this because XNA does not support multi input natively. We developed a library based on the work done by Brumblay P. (2010) adapting it to the needs of the game and making possible to handle multi-mice using a C# solution compatible with XNA. The rest of the software was designed as shown in the UML diagram in figure 1-5:

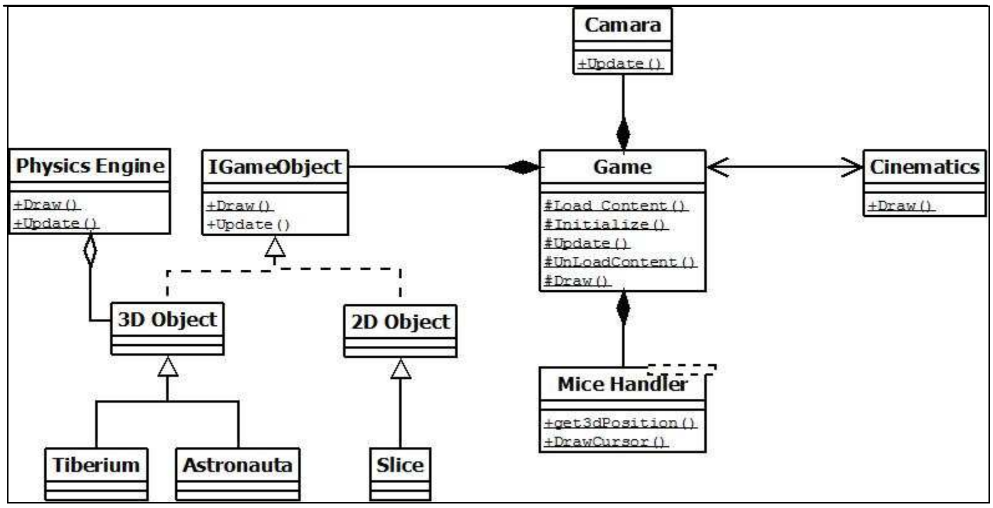

Figure 1-5: UML Class diagram for the CMPG

As shown, the class design of the game was very simple: the Game class had all necessary elements to perform the videogame experience. It uses a MiceHandler class whose function is to update each one of the nine mice that are used in the game and draw the mice cursors in the correct position. Cursors had a geometrical symbol and a color that were identically to a mark at the foot of every avatar thus relating the player and his astronaut and facilitating the recognition of these. Also teams were made using cursors, grouping the students by different colors: green, blue and red.

A Camera class was in charge of controlling the visual elements and the game view. In this CMPG the camera was not static but instead had an active role following the action of the game. It was able to rotate it in 180 degrees providing views for the action from different sides; it could also get farther or closer in order to show activities in different distances.

Moreover a cinematic class helped showing some videos and instructions for the game: this was a key element in terms of immersion because most of the narrative was told using videos and texts. This class also represented a big effort for the graphics designers since videos and 3D animation were developed very carefully in order to improve the visual effects and the narrative itself.

At last an interface was created for the purpose of controlling both 2D and 3D elements such as the tiberium, astronauts and scenerios. A physics engine was developed in order to create the simulations needed for the game, because XNA only provides basic mathematical libraries but it doesn´t incorporate support for physics.

Elements in the game interacted with each other under several rules; for example:

- Electrostatics rules of attraction and repulsion
- Coulomb´s law to describe the force between two charges, the relation of the magnitude of the force with the magnitude of individual charges and the relation between force and distance.
- Newton´s second law: the relation between mass and force.
- Newton´s third law: action and reaction, in this case, of electrical forces.
- Vector addition of forces, that were limited to a 2D plane in the 3D environment.

All this rules were grouped in one software solution called Physics Engine that worked on 3D Objects class changing the attributes of some instances depending on the relations that took place in the virtual world.

1.4.2 Experimental design

In order to prove our hypothesis and take our GMPG to a real classroom an activity was designed with twelfth-grade students from a public school in Santiago. The experience consisted of three sessions for a group of nine students each time, totalizing an experimental sample of twenty-seven students.

The players were positioned in a semi circle in front of a wall where the game view was projected. Each of them had a mouse that allowed them to control their avatars and so interacted with the game. During one pedagogic hour students played the entire game guided by a member of the research team that was acting as teacher controlling and pausing the game flow in order to explain game situations or help students that were falling behind.

Figure 1-6: Class distribution. Teacher is guiding the game

All this sessions were properly recorded with tree different cameras: the first one pointing to the screen to see collaboration patterns in the virtual world; a second one in one side of the classroom recording students and their interaction; and a last one controlled by a member of the team, recording situations that needed detailed study. Two observers analyzed these tapes after the experiment in order to understand if the game fostered collaboration and to explore possible links between different collaboration attributes and specific learning outcomes. For this purpose an observation guide was developed to measure different aspects of collaboration. Based on a literature review we identified five aspects to asses:

- Positive interdependence: students work together to accomplish the shared goal, seeking outcomes beneficial to all (Dillenbourg, 1999; Johnson & Johnson, 1999; Zurita & Nussbaum, 2007; Zagal et al, 2006)
- Communication: students get information directly by talking with their partners, and indirectly by listening to other conversations, and seeing non verbal indications both in the real and virtual world (Johnson & Johnson, 1999; Dickinson & McIntyre, 1997; Gutwin & Greenberg, 2001),
- Coordination: students discuss strategies, and make decisions based on the agreement reached after the discussion (Dickinson & McIntyre, 1997; Malone & Crowston 1990; Johnson & Johnson, 1999; Dillenbourg et al, 1996),
- Social and environmental awareness: students can determine who is part of their group or community and who is available for possible interaction both in the real world and the virtual world (Gutwin & Greenberg, 2001; Johnson & Johnson, 1999; Zagal et al, 2006; Dillenbourg, 1999; Harrison & Dourish, 1996)
- Individual accountability: each student knows his/her role and is responsible for the consequences of his/her actions (Johnson & Johnson, 1999; Zagal et al, 2006; Zurita & Nussbaum, 2007)

The observation guide developed consisted in of 25 quantitative and qualitative measures showed in Table 1-1, each one related to one of these variables.

Observation	Collaboration aspect
Motivational comments between students	Communication
Positive comments between students	Communication
Negative comments between students	Communication
Recommendations between students	Communication
Dialogues between pairs of students	Communication
Number of times students point to the screen with a finger	Communication
Number of times students use the mouse to indicate something	Communication
Number of verbalizations of game actions	Communication
Number of planification conversations before doing an action	Coordination
Number of conversations referring to previous strategies	Coordination
The spatial distribution in the game is equal for all players	Envir. awareness
The activities of the game are not only in one location	Envir. awareness
The virtual word allows interaction between players	Envir. awareness
Student recognize the user interfaces of the game an can interact with them	Envir. awareness
Students maintain their focus on the game when there are text instructions	Envir. awareness
The actions of the rest of the students are useful for understanding the game	Envir. awareness
The player acts confused while he interacts with the game (	Envir. awareness
Students identify their group and group peers in the real world	Social awareness
Students identify their group and group peers in the virtual world	Social awareness
Number of errors trying to achieve an individual action	Ind. accountability
Number of correct results trying to achieve an individual action	Ind. accountability
Number of errors trying to achieve a group action	Positive Interdepence
Number of correct results trying to achieve a group action	Positive Interdepence

Table 1-1: measured used to quantify collaboration

With the purpose of measuring the level of knowledge obtained by the students, a pre post test was taken. The first was administered just before students began to play and the post test was taken a few minutes after the students complete the activity. The test itself was developed using the curricular contents that are seen in the game based in a test of Conceptual Survey of Electricity (more details of the construction of the test can be found in section 2.4.1). It is important to say that after choosing the questions the whole test was validated by twelfth-grade teachers whose specialty is physics

Additionally a small questionnaire was administered before the sessions in order to control students' previous experience with technology and games, asking them the number of times that they perform several activities such as playing video games in their PC or game consoles. The result of this questionnaire can be found in table 2.2.

1.2 Results

The comparison between the pre and post test results show an important increase in the number of correct answers after playing the game as show in table 1-1:

	PRE	**POST**
Mean	6.11	10
Standard deviation	5.03	7.54

Table 1-2: means and standard deviation of pre and post test

The means increased from 6.1 to 10 which was found to be statistically significant when a t-student test was performed. Formally we develop a t-student test for dependant variables to contrast averages differences posing the hypothesis as follow:

$$H_0: \mu_{pre} = \mu_{post}$$

$$H_1: \mu_{pre} < \mu_{post}$$

With the null hypothesis being that the averages from the results of the pre and post test are equal and the alternative hypothesis being that the average of the post test is greater than the average of the pre test results.

A one tail test for a significance level alpha of 0.01% was developed giving the results showing in table 1-2:

Statistical t	5.75
p (T<=t) one tail	2.3 e-6
critic valúe of t (one tail)	2.48

Table 1-3: results for a one tail t-student test, apha=0.01

Based on these results we can reject the null hypothesis with a statically confidence of 99% (p <0.00001) concluding that students results increase after being exposed to the game.

A gender analysis was also performed dividing the sample and analyzing each one separately giving the results shown below:

	PRE	POST
Female	5.57	10.36
Male	6.69	9.62

Table 1-4: gender pre-post test results

	Female	Male
Statistical t	5.09	3.12
p (T<=t) one tail	0.0001	0.0044
critic value of t (one tail)	2.65	2.68

Table 1-5: gender results for t-student

The results for both group showed an increase higher in females than in males, improving their averages from 5.57 to 10.36 and 6.69 to 9.62 respectively showing statistically significant in both cases (Males: p = 0.0044; Females: p = 0.0001). Despite the evident differences in gender averages no statistical significance was found (p = 0.24).

An exhaustive analysis regarding the results of individual questions was also performed; it gave us an idea about what kind of knowledge we could teach and were to center future efforts. Comparison of the specific learning objectives results show that the game must be improved in some areas: explaining the relation between charge intensity and force and the vector sum of forces in two dimensions. More specific results of this subject can be found in section 2.4.2.

The results of the questionnaire regarding previous experience with technology and video game use were also analyzed. Pearson’s correlation coefficient was used to quantify this relation. We did not find evidence that allow us to conclude any relation between the level of improvements while playing the game and the previous experience with technology or cell phones (r < |0.3|).

Respecting to the observation guide we can see a high correlation between the variable “Number of verbalizations of game actions” and the improvements in the test (r=0.79) this could show that there was not a problem for students to pass from game narrative language to test language.

To quantify the power of this test a post-hoc analysis was made obtaining a Cohen’s d value of 1.58; wish means a very large effect size. Is important to note that with this value, our t-test has a statistical power of 99% (beta=0.01) for the confidence level of 99% (alpha= 0.01) making this a very reliable test.

1.6. Conclusions and future work

The result from the statistical analysis of the pre-post test show a significant increase of the students averages once they are exposed to the game, thus validating the effectiveness of this CMPG for the teaching of complex subjects such as electrostatics. Spite of that there are several specific learnings where the results aren’t good enough and must be improved such as vector addition of forces in two dimensions and the relation between charge intensity and force. For future work the game must provide more quests in these two specific areas, explaining these relations even better and giving more activities to explore these concepts. In the first case, for example, another training activity should be incorporated to the game forcing students to understand the concepts before they start the last mission. In the second case it could be possible to show some arrows indicating the net force and the forces that compose it, something similar to waht figure 1-2 shows, but incorporated in the virtual word.

Considering gender results it is striking that female students improve more than male students, although this difference is not significant it goes against what is commonly thought about videogames for learning i.e. that videogames for learning are more effective in male students with previous experience in technology. In this line we also notice that the second perception was also incorrect, we didn´t find any evidence that allow us to conclude that the previous experience in video games or technology influences in the results of the pre-post test.

One of our main concerns during the development of this CMPG was the uncertainty about how quickly students could learn to play the game and how hard it would be to transfer the acquired knowledge through the narrative to a formal language contained in a test of electrostatic. The results coming from the observation guide show that the game learning is very fast, observations like “Student recognize the user interfaces of the game and can interact with them” and “Number of correct results trying to achieve a group/individual action” where increasing their results quickly just after a few minutes showing that the playability objectives of the game were very well achieved. On the other hand the high correlation between the observation “Number of verbalizations of game actions” and the test improvements is a good indicator that students were making a transfer between the game language and the test language. We think this transfer is largely due the presence of the teacher; the game itself was thought as an educational tool so the teacher knowledge in both areas is essential to achieve an adequate transfer that show that this is not just a game, but also a lecture.

In this case the lecture was performed by a member of our team; in a real class a real teacher should deliver the knowledge. How long and how much it takes to train a teacher are things that have to be exploredin future work.

As a main conclusion we could say that we succeed in bringing games to the classroom with a strong pedagogic model behind,;we proved that CMPGs could be used as an educational tool supporting the teachers work. Even more, we gave CMPGs a hard task with difficult subjects and complex concepts and it greatly passed the test. We hope that this work opens the doors for more initiatives bearing the use of technology and video games into the classrooms, so we can move towards to an adequate education for the twenty-first century.

2. A model for the design of collaborative games inside the classroom: Teaching electrostatics

2.1 Introduction

The use of video games as educational tools is slowly becoming an accepted practice in learning environments (Van Eck, 2006). There is an increasing recognition of the fact that games are built under several principles that can be beneficial for the learner: they give immediate feedback, allow the players to progress at individual rates, 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 shown the benefits of games as learning tools, through the use of immersive virtual environments (Dede, 2009; Clarke & Dede, 2007) and location-based games (Klopfer & Squire, 2009; Mitchell, Dede & Dunleavy, 2009) for example.

All the progress made in the use of games as educational tools, however, has not been transferred to the school classroom, which remains still the most important educational environment in our current system. Evidence suggests that there is a general lack of classroom-based educational games for relevant subject-based learning (Kirriemuir & McFarlane, 2003). The main reason for this situation is that creating a classroom-based educational game is a difficult task. As with any educational game it must accomplish two goals: create a fun experience for the player and achieve a specific learning objective (Aleven, Myers, Easterday & Ogan, 2010). The design of a fun game is in itself a complex process and if the game must also allow the player to learn a specific subject, the task gets even more complex. Implementing an educational game in a classroom context adds additional challenges: the game should involve all the students in the class, the teacher must have the ability to control the game, the duration of the game-play sessions should be adjusted to the length of the lecture, and others.

To close this gap between games and classroom, we developed a two level model for integrating educational games in the classroom. The first level represents the pedagogical model used to support the game in the class. We based this pedagogical model on a previous work (Susaeta, Jimenez, Nussbaum, Gajardo, Andreu & Villalta, 2009) which defined a model for developing collaborative educational classroom games. The second level represents the specific characteristics of the game and how they support the learning objectives. To accomplish this, we defined the learning objectives using Bloom's revised taxonomy (Anderson, Krathwohl, Airasian, Cruickshank, Mayer & Pintrich, 2001) and based on those objectives we specified the characteristics of the game.

This article is structured as following. Section 2 presents the two-level model developed to integrate games in the classroom, describing both the pedagogical model level and the learning objectives level. Section 3 describes a 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 results obtained. The last section presents our conclusions and possible future work.

2.2 A model for classroom games

Our proposed model aims to integrate the dynamics of a game in the context of a traditional classroom both at a macro and a micro level. At the macro level, we present a pedagogical model based on a previous work (Susaeta et al, 2009) to support this integration. At the micro level, we present a model that helps to specify the requirements of the game based on Bloom's revised taxonomy of learning objectives (Anderson et al, 2001).

2.2.1 Macro-level: Pedagogical model

The successful integration of a game in the classroom must be supported by a pedagogical model that considers all the challenges of developing a computer-based activity inside a classroom. Our aim is that all students within the classroom are active participants of their learning in a collaborative environment. Therefore, to support team work and help the teacher to keep track of each student simultaneously, all kids should be playing in a common game world. A suitable pedagogical model should incorporate the previous constraints and also define how and what interactions should occur between the students.

Susaeta et al (2009) developed a model that fulfills the previous requirements. Their work aimed to translate the Massive Multiplayer Online Game (MMOG) concept into the classroom. Since the number of students in this context is not massive and play takes place within a single room rather than on the Internet, they changed the terms “massive” and “online” to “classroom” and “presential” respectively, thus giving the new designation: “Classroom Multiplayer Presential Games” (CMPG).

The CMPG model is based on the Computer Supported Collaborative Learning (CSCL) model (Dillenbourg, 1999), where the computer is used as a tool to mediate the collaboration between the students and to control the steps or script that defines the activity (Dillenbourg, 2002). In a CSCL activity, there is a coordinated effort among a group of students to achieve an educational goal that can only be accomplished by the coordinated work of every member. The CSCL model has been successfully implemented in the classroom (Zurita & Nussbaum, 2004; Nussbaum, Álvarez, McFarlane, Gómez, Claro & Radovic, 2009) and the work of Susaeta et al (2009) extended this by successfully incorporating the use of collaborative games in the classroom.

In the CMPG model, the students in a class play at the same time in a virtual world projected by one computer onto the wall of the class, in a one-to-many computing model. The interaction of the students with the game is achieved by providing each student an input device, namely a mouse, connected to the computer. With his/her mouse, each student interacts with the in-class projected virtual world, and verbally with his/her peers. The interaction of the student in the virtual world is accomplished by an avatar that each player controls through his/her mouse. The players can explore freely the virtual environment using their in-game character. They can interact with different objects place in the world and also with the characters of their classmates.

During the game, the students have to work in group to achieve collaboratively a common objective, which will depend on the specific content being taught. The different goals of the game will only be accomplished if the players coordinately participate in the action, thus the students will need to discuss verbally to make agreements and strategize as a group.

The teacher plays a central part in the CMPG model acting as an omnipotent being in the virtual scenario. Being in control of the only computer involved in the game, the teacher has full control of the system. For instance, he can make a pause in the game to reinforce a particular content or encourage discussion. The game then, becomes a tool to be used by the teacher, that can be controlled and paced as particular needs and circumstances appear.

2.2.2 Micro-level: Learning objectives

The macro level model for integrating a game in the classroom is not enough: to successfully implement an educational game it is essential to map the learning objectives that are expected from the game to the specific activities, mechanics and story that will be the essence of that game. To accomplish this, the first step is to define the learning objectives. A useful tool for this is Bloom's revised taxonomy (Anderson et al, 2001), which categorizes the learning objectives in two dimensions: types of knowledge and cognitive process. For the first dimension, the taxonomy defines four types of knowledge: factual, conceptual, procedural and meta-cognitive. For the second dimension, it defines six types of cognitive processes: remember, understand, apply, analyze, evaluate and create. With these two dimensions, the taxonomy encompasses 24 different combinations of knowledge and cognitive process that a given educational activity can have as its learning objective.

The explicit definition of the learning objectives of the game using this taxonomy, defines the specific requirements that the game designer must consider when creating the game. Based on the objectives, the designer can choose the genre, mechanics, story and aesthetics for the game that best help the students to achieve the desired learning goals. As an example, the game described by Susaeta et al (2010) was developed to teach ecology and the interplay of herbivores and carnivores. Using Bloom's revised taxonomy, we can speculate that one specific learning objective of the game was to "understand the conceptual knowledge" of the ecological balance. In this case, the way the game was designed maps correctly to this learning objective: an exploratory role playing game, where each student has a role in the game (hunter or gatherer) and needs to explore how their actions in the world (planting, hunting herbivores, hunting carnivores, etc) affect the balance of an ecosystem.

2.3 Game developed

Using the proposed model, we designed and developed a game, named First Colony, to teach 12th graders basic concepts of electrostatics. We focused specifically on charge interaction and the law of forces between charges (Coulomb's Law), which have been proven to be a difficult subject matter for students (Maloney, O'Kuma, Hieggelke & Van Heuvelen, 2001).

For the design of the game we considered first the micro-level of the model, specifying the learning objectives and based on these, the characteristics of the game. To specify the learning objectives we used as a basis the expected learning outcomes for 12th graders on the subject of Coulomb's Law, proposed by the Chilean Ministry of Education (MINEDUC, 1998), which we categorized by Bloom's revised taxonomy (Table 1).

[1]	**[2] Understand**	**[3] Apply**
[4] Conceptual	[5] Compare the concepts of positive, negative and neutral charged object based on their interaction	[6]
	[7] Infer the concept of action and reaction in a forceful interaction of two objects	
	[8] Understand the concept of inverse relation between distance and the electric force	
	[9] Understand the concept of direct relation between charge intensity and the electric force	
[10] Procedural	[11]	[12] Apply the procedural knowledge of Coulomb's Law in one dimension
		[13] Apply the procedural knowledge of Coulomb's Law in two dimensions

Table 2-1. Learning objectives of the electrostatic CMPG First Colony, categorized according to Bloom's revised taxonomy.

After specifying the learning objectives, we analyzed what kind of game we should develop to best support these and decided to make First Colony an action/puzzle game, loosely inspired in the game Portal (Valve Software, 2007), based on two reasons. First, specific puzzles allowed us to work the individual concepts of the "understand" learning objectives. Second, the “apply” learning objectives involved the procedural application of all the concepts combined, something that could be achieved in an action game, where players must directly interact with objects.

Although electric charge is a real and observable phenomenon, the specific topic of Coulomb’s law is hard to contextualize in a real scenario. Because of this, the game could be set in either a realistic but abstract world of electric particles, or in a fantasy-based but concrete world with imaginary electric objects. We choose this second option, and developed the story for the game as follows: The students take the role of astronauts of the first human colony in an extra-solar planet that are on a mission to recover a precious mineral found in space. The mineral has the unique quality of storing electrical energy and, due to the limited resources of the colony, it is essential that the astronauts capture these. Because of the fragility of the mineral, the astronauts can only interact with it at a distance, using a special device that creates an electric field surrounding them (the concept of field is not actually used in the game, to avoid confusion). The idea of this setup is that both the crystals and the astronauts will represent electric charges that can interact according to Coulomb’s law which is accurately simulated in the game.

At the macro-level of the model, we designed the game as a CMPG, structured as a series of individual and collaborative puzzles. The game is divided in two main parts: a training session followed by a mission. The training session allows the players to get acquainted with the game-play. It starts with a sequence of simple individual tasks to help them familiarize with the controls and interfaces of the game. After these initial tasks are completed by all students, the training focuses on introducing the conceptual knowledge topics (Table 1.) In this part, several individual and collaborative activities have to be performed. In each one, a new concept is introduced first by the teacher using a white or blackboard, and then applied in the game. Once this sequence of introductory concepts is completed, the training ends.

The second part of the game is the mission. This part is structured as puzzle-like levels, where in each level the students must collect one or more minerals pushing it through a special portal. The first goal of this part is to reinforce the conceptual knowledge explained in the training. To achieve this, when the mission starts the current charge of each player is hidden, forcing them to collaborate with each other and interact with the charged objects to rediscover their charge. The second goal of this part of the game is to allow the students to apply their procedural knowledge of Coulomb’s law, both in one and two dimensions. The one-dimensional version of the law is explored through individual interaction between one astronaut and one crystal. In the two-dimensional version crystals are too big to be moved by one player, forcing them to work in small groups of three to generate the necessary force to move the crystal (Figure 1). In these levels the players must develop a clear understanding of the vector addition of forces to achieve the goal of moving the crystal in the desired direction through the portal.

Figure 2-1. In some levels, students the crystals are too big to be moved by only one student. The students must work in groups of three to achieve the desired goal.

2.4. Experimental work

The game was tested in a real classroom setting to study its 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 an experiment with twelfth-grade students from a public school in Santiago, Chile. The experiment consisted in 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.

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. The instrument used to measure the expected learning outcomes was a specially designed conceptual evaluation that assessed each one of these (Table 1) with specific questions. The evaluation was based on the Conceptual Survey of Electricity (CSE) (Maloney et al, 2001) making the necessary modifications to cover the desired learning outcomes, and taking out the questions on unrelated or more advanced subjects. We used questions 3 to 10 from the CSE and added 13 additional questions, totalizing 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 the same school as the ones used in 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 of the school (6 male, 3 female) 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 of value 1.18, which represents a large effect. From this quantifier we estimated a sample size of 27 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 (13 male, 14 female). The experiment was conducted during three sessions: in each session, a different group of nine students played simultaneously the complete game. For the collaborative levels of the game, the nine students were randomly assigned in 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 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 (only one student used computer a couple of times a month) and cell phones (only three students didn't use cell phones weekly). The video game usage questions showed a difference between males and females: only three male students didn't play videogames every week in at least one of the platforms, compared to eight 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	38.4 %	71.4%	46.1%	21.4%	0%	7.1%	15.3%	0%	0%	0%
Computer	76.9 %	71.4%	23.1%	21.4%	0%	7.1%	0%	0%	0%	0%
Videogame	23.1 %	7.1%	53.8%	35.7%	7.6%	7.1%	15.3%	35.7%	0%	14.2%

Table 2-2. The questionnaire to control students' previous experience with technology and games show that most students in the sample use frequently computers and most male students play frequently videogames.

To complement the results of the experiment, each session was videotaped with three cameras. Two observers analyzed the recordings after the experiment, annotating every five minutes any relevant observation related to the engagement of the students, the ease of use of the system and any other significant aspect.

2.4.2 Results

The results from the pre and post conceptual evaluation showed an increase in the average number of correct answers from 6.11 to 10, with standard deviations of 5.03 and 7.54 respectively. To analyze the statistical significance of this result, we performed a t-student test 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 0.01 (1%). The results of the t-student test to reject the null hypothesis were statistically significant ($p < 0.00001$) meaning that we can conclude with a 99% of confidence that the average number of correct answers in the evaluation increase after being exposed to the game.

Additionally, a post-hoc analysis was made to obtain a Cohen's D quantifier value of 1.58, which represents a large effect size. Considering this value, the sample size and the significance level desired (alpha=0.01) we developed a power analysis to obtain the exact power value of the instrument. The results from this analysis show that the instrument has a power of 99% (beta=0.01) for a confidence level of 99% (alpha=0.01).

A detailed analysis was performed for the results of the individual questions and their relation to the learning objectives. For each student, the results of all the questions associated to one learning objective of Table 1, were averaged, obtaining one value that measured the performance of the student in that learning objective. A t-student test was performed for all the six learning objective values with a significance level (alpha) of 0.01, comparing the pre and post test results. The results were statistically significant ($p < 0.01$) for four of the six learning objectives: only the "understand the concept of direct relation between charge intensity and the electric force" objective and the "apply the procedural knowledge of Coulomb's Law in two dimensions" objective did not significantly improved.

The possibility of a gender effect was controlled by dividing the sample and analyzing each group (males and females) separately. The results for both group showed an increase in the average number of correct answer: 5.57 to 10.36 with the female students and 6.69 to 9.62 with the male students. A t-student test was performed for the groups, which showed that the results were statistically significant for both groups (Males: $p = 0.0044$; Females: $p = 0.0001$). The difference between each group was also compared, but no statistical significance was found ($p = 0.24$).

The effect of previous experience with technology and video game use was also analyzed. 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 neither the previous experience with technology (Cell phone use: r=-0.3; Computer use: r=0.12) or the previous experience with video games (Computer games: r=0.06; Console games: r=0.16; Cell phone games: r=-0.03).

2.5 Discussion and Conclusions

The statistical analysis of the pre and post evaluation results validates the effectiveness of this game as tool for teaching electrostatics. However, the detailed comparison of the specific learning objectives results show that the game has deficiencies in some areas: explaining the relation between charge intensity and force and the vector sum of forces in two dimensions. The first problem may be caused by the absence of explicit moments in the game were the students need to compare how different charge intensities affect in the movement of the charges. The second problem can be explained by the lack of explicit visualization of vectors in the game, which makes it hard for the students to understand how the forces add up. We plan to develop a second version of the game that includes explicit levels to explore the difference in the force when charge intensity changes and that integrates force vectors visualizations, which we expect will help understand better the concepts that this game couldn't.

The analysis of the relation between the student's characteristics and their results in the test show that there was no relation between gender, previous use of computer or previous use of games and the improvement in the evaluation. This result is significant, because it contradicts the general conception that games can only be useful for male students with previous game experience. An additional piece of evidence that supports this was the excitement showed by female students while they were playing (one female student even asked “Where can I download this game?”). A possible explanation of the success of this game with female students is the social component: the collaboration required in some levels adds a social dynamic to the game that traditional challenge-based games do not have.

The results of the observation made to the video recordings add three additional conclusions to this work. First, the motivation of the students was high and remained the same during the whole session, which shows that the students are engaged in the game and that they don’t lose this engagement until the game is finished. Second, the results of the observations also demonstrate the fast learnability of the system. Measures like number of error in the actions and confusion with the interfaces decline quickly after a few minutes of game-play. This decline suggests that the students are able to learn how to play the game during the tutorial levels, and can use that knowledge in later levels of the game. The fast learnability proves that it is possible to develop games that can be learned and effectively used in only one session. However, an unanswered question is how much training time does the teacher need to master the tool and give adequate pedagogic support. Third, the experimental work was performed with nine children that worked simultaneously on the same projected virtual world, arranged in three groups of three children each. Although these groups played independently, our observations showed us that there were positive interactions between the groups.

The overall good results of the experiment suggest that, although the learning concepts are contextualized in a fantasy-based game environment, the students can transfer that knowledge to answer the questions in the standard written tests. The possibility that students could not be able to transfer the knowledge was one of our main concerns when developing the game, but the results give solid evidence that the transfer did occur. We believe that the successful transfer is possible mainly because the guidance and explanation given by the teacher acts as a link between the fantasy world of the game and the real world of the test. Thus, if games are used as an educational tool, the teacher knowledge of both the tool and the concepts are essential, and that is something we plan to analyze further in our future work.

A conclusion that goes beyond the game itself is the validation of the proposed model as a pedagogical tool. The initial identification of the learning objectives through Bloom's revised taxonomy, its use as a design guide for the game and the analysis we presented of the specific results in each of them, validates the micro level of the model as a powerful tool for both designing educational games and understanding the possible problems they may have. The macro model based on the CMPG also proved to be successful, helping to sequence a set of puzzles and structure the collaborative interaction of students within a classroom, putting the teacher at the center of the game-play.

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APPENDIX: mail of acknowledgment of submission

From: **Computers & Education** <cae@elsevier.com>
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