Classroom Augmented Reality Games: A model for the creation of immersive collaborative games in the classroom

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Abstract

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

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

1. Introduction

1.1 Technology in the classroom

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

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

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

1.2 Videogames as an educational tool

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

One particular aspect of videogame that has been singled-out as a key element in helping the learner is immersion, which can be defined as the subjective impression of being involved in a comprehensive and realistic experience that does not take place in the real world (Stanney, 2002; Lessiter et al 2001). There are three main components that help to build an immersive experience: the sensorial component, the challenge component and the imaginative or narrative component (Dede, 2009; Ermi & Mäyrä, 2005). Sensorial immersion corresponds to the physical cues that can be provided to fool our senses in believing that what we are experiencing is real (Ermi & Mäyrä, 2005). Challenge based immersion is closely relate to the concept of flow (Csikszentmihalyi, 1990) where the cognitive task being performed puts the player in an optimal experience state. Lastly, the imaginative or narrative immersion represents the feeling of being captured in a fantasy world, where the environment, characters and story is so powerful that it feels as real. (Dede, 2009)

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

1.3 Augmented reality for games and learning

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

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

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

2. Classroom Augmented Reality Games

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

We propose a model that combines face-to-face CSCL as the pedagogical model (Zurita & Nussbaum, 2004)) and class 1 AR as the supporting technology to create what we call Classroom Augmented Reality Games (CARGs). As described previously, CSCL is a pedagogical model that fulfills the requirements for classroom use and previous experiences have used this model successfully to develop games in the classroom (Susaeta et al, 2010). Augmented reality, in the other hand, is well suited for creating immersive environments, and also allows face-to-face collaboration between players (Henrysson et al, 2005).
A CARG creates a virtual world inside the classroom, which can be visualized and explored by each student using his or her device. This device can be any mobile computing platform that has a display, a camera, wireless network capabilities and enough processing power to render 3D graphics. The devices are connected using a wireless network to a server that synchronizes the virtual elements in the augmented world.

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

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

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

The teacher has also the ability to control the group’s activities by pausing or advancing to a given level, to intervene when necessary and provide additional explanations to a group or the whole class. In this way technology is a complement of the lecture and not a replacement of the teacher.
3. Case study: A game to teach electrostatics

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

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

1. Compare the concepts of positive, negative and neutral charged object based on their interaction
2. Infer the concept of action and reaction from a forceful interaction of two objects
3. Understand the concept of inverse relation between distance and electric force
4. Understand the concept of direct relation between charge intensity and electric force
5. Apply the procedural knowledge of Coulomb’s Law in one dimension
6. Apply the procedural knowledge of Coulomb’s Law in two dimensions
To fulfill this list of learning goals, we developed a puzzle-based game, were the players have to move electrically charged objects (crystals) through special locations (portals), avoiding a series of obstacles (asteroids). To move the crystals in the virtual world, the player uses his/her computer as an electric charge, which the player can turn on/off, change its intensity and polarity, and modify the distance between his/her charge and the virtual charge, by physically moving closer or farther away from the AR marker (Figure 2).

![Figure 2: In the game, students must attract/repel electrically charged crystals to a portal avoiding hitting the asteroids. To move the crystal, the player can activate his/her electric charge, select its intensity and polarity with specific interface components.](image)

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

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

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

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

4.1 Experimental design

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

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

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

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

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

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

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

<table>
<thead>
<tr>
<th>Usage of:</th>
<th>Every day</th>
<th>Some days in a week</th>
<th>Some days in a month</th>
<th>Rarely</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Phone</td>
<td>25%</td>
<td>33.3%</td>
<td>33.3%</td>
<td>53.3%</td>
<td>25%</td>
</tr>
<tr>
<td>Computer</td>
<td>50%</td>
<td>40%</td>
<td>50%</td>
<td>46.6%</td>
<td>0%</td>
</tr>
<tr>
<td>Videogame</td>
<td>33.3%</td>
<td>20%</td>
<td>50%</td>
<td>33.3%</td>
<td>8.3%</td>
</tr>
</tbody>
</table>

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

5. Results

The results from the pre and post test performed by the control group showed an increase in the average number of correct answers from 4.6 to 8.6, with standard deviations of 2.21 and 3.84 respectively. In the case of the experimental group, the students showed an increase in the average number of correct answers from 4.6 to 8.7, with standard deviations of 2.32 and 3.71 respectively. To analyze the statistical significance of both results, we performed two t-student tests for dependant variables with the null hypothesis being that the averages are equal and the alternative hypothesis that the average of the post test result is greater than the average of the pre test. To reject the null hypothesis, a one tail test was used with a significance level (alpha) of 0.05 (5%). The results of the t-student test to reject the null hypothesis were statistically significant for both the control group (p < 0.00001) and experimental
group \( (p < 0.000001) \) meaning that we can conclude with a 95% of confidence that the average number of correct answers in the evaluation increases after being exposed to both the class and the game.

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

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

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

For the experimental group, the possibility of a gender effect was controlled by developing an additional ANCOVA test. For this test, the gender (male or female) and group (control or experimental) were used as classification factor, the results of the pre-test of both groups was used as a covariate and the only dependent variable was the result of the post-test of both groups. The result of the test showed that the gender-treatment F-test value was found to be 3.014 \( (p = 0.09) \) at an alpha of 0.1, indicating that there existed significant differences between the posttest scores of the male and female students. To analyze which group performed better, the estimated marginal means of the post-test result was observed: for the male students it was 10.25 for the experimental group and 8.66 for the control group; for the female students it was 7.46 for the experimental group and 8.50 for the control group. These values show that in the experimental group, although both female and male students increased their scores in the post-test compared to the pre-test, the male students increased significatively more than the female students, with a confidence level of 90%. 
The effect of previous experience with technology and video game use was also analyzed for the experimental group. To quantify this relation, the Pearson’s correlation coefficient was used, which measures the lineal relation between two random quantitative variables. The result of this analysis showed no relevant correlation between the results in the post test and either the previous experience with technology (Cell phone use: \( r = 0.14 \); Computer use: \( r = 0.17 \)) or the previous experience with video games (Computer games: \( r = -0.10 \); Console games: \( r = -0.02 \); Cell phone games: \( r = 0.18 \)).

6. Discussion & Conclusions

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

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

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

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

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

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

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References


