



A framework for the design and integration of collaborative classroom games

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ABSTRACT

The progress registered in the use of video games as educational tools has not yet been successfully transferred to the classroom. In an attempt to close this gap, a framework was developed that assists in the design and classroom integration of educational games. The framework addresses both the educational dimension and the ludic dimension. The educational dimension employs Bloom's revised taxonomy to define learning objectives and applies the classroom multiplayer presentational game (CMPG) pedagogical model while the ludic dimension determines the gaming elements subject to constraints imposed by the educational dimension. With a view to validating the framework, a game for teaching electrostatics was designed and experimentally implemented in a classroom context. An evaluation based on pre/post testing found that the game increased the average number of correct answers by students participating in the experiment from 6.11 to 10.00, a result found to be statistically significant. Thus validated, the framework offers a promising basis for further exploration through the development of other games and fine-tuning of its components.

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1. Introduction

The use of video games as educational tools is slowly becoming an accepted practice in learning environments (Van Eck, 2006). There is growing recognition that several principles underlying these games can be beneficial to the learner: they give immediate feedback, facilitate transfer of concepts from theory to practice, enable the players to progress at individual rates, allow them to fail gracefully and give them freedom to explore and discover (Gee, 2003; Squire, 2003). Empirical research by many groups has shown the benefits of video games as learning tools (Clarke & Dede, 2007; Dede, 2009; Klopfer & Squire, 2008; Mitchell, Dede, & Dunleavy, 2009).

Different approaches to the integration of games as educational tools for primary, secondary and college level education have been studied. One of the most common is the use of multiplayer online games, which are usually contextualized in virtual spaces called multi-user virtual environments or MUVES (Clarke & Dede, 2007; Dede, 2009). In this type of game each student plays on his/her computer and interacts virtually through the game with his/her classmates and the teacher (Paraskeva, Mysirlaki, & Papagianni, 2010). Another approach utilizes location-based or ubiquitous games. In these, students work collaboratively in an exploratory environment to achieve different goals, assisted by mobile handheld devices that are wirelessly networked and usually enhanced by additional technologies such as GPS and augmented reality (Dede, 2009; Klopfer & Squire, 2008; Liu & Chu, 2010; Mitchell et al., 2009).

Although these two approaches have shown good results in creating engaging learning experiences, they are not well suited to the school classroom, still the most important educational environment in our current system. This is reflected in a number of recent attempts to employ games in the classroom for subject-based learning. Original games have been developed to teach mathematics (Lee & Chen, 2009), biology and genetics (Annetta, Minogue, Holmes, & Cheng, 2009), electrostatics (Squire, Barnett, Grant, & Higginbotham, 2004) and history (Watson, Mong & Harris, 2011), and existing games have been tested for teaching social science topics (Cuenca López & Martín Cáceres, 2010). What is generally lacking in these experiences is an explicit integration of the game into the pedagogical process of the class. To achieve such integration, several elements need to be assured. Among others, the game should involve all the students in the class, the teacher must have the ability to control the game, and the duration of the game-play sessions should be adjusted to the length of the lecture

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(Susaeta, Jimenez, Nussbaum, Gajardo, Andreu & Villalta, 2010). In many cases games feel like a replacement for the class instructor rather than a tool to be used and controlled by him/her, potentially prompting some teachers to reject their use (Kebritchi, 2010).

This article presents a framework for the design of educational games and their integration in the classroom that is analyzed through a case study of a game to teach electrostatics. The structure of the article is the following: Section 2 introduces the framework and the different components for designing and integrating the game; Section 3 outlines the game developed within this framework to teach electrostatics; Section 4 describes an experimental application developed to test the game in a real classroom context and sets out the results obtained; and finally, Section 5 presents our conclusions and some suggestions for future research.

2. A framework for the design and integration of classroom games

The design and integration of classroom-based educational games must incorporate both an educational dimension, which defines how to build and integrate the game as a learning tool, and a ludic dimension, which determines how to create an engaging and fun experience (Aleven, Myers, Easterday, & Ogan, 2010). The educational dimension addresses two questions that are central to the creation of learning environments: First, what are the learning objectives of the activity? And second, how is the activity integrated pedagogically in the class? (Dillenbourg & Jermann, 2010). The ludic dimension, on the other hand, must tackle the central question in the design of any game: What elements should be included in the game in order to achieve the desired experience? (Schell, 2008). In an educational game the “desired experience” is the fulfillment of the learning goals by the students in the context of the class through an engaging and challenging experience. The ludic dimension of the design process is therefore subject to the educational dimension, meaning the game elements chosen must be constrained by both the learning objectives and the need for pedagogical integration.

Both dimensions are incorporated in our proposed framework for the design and integration of classroom games, shown here schematically in Fig. 1. As can be seen, the educational dimension is divided into two components. The first focuses on establishing the learning objectives of the game, defining the specific learning objectives it must achieve, while the second aims at determining how the game is pedagogically integrated in the class, specifying the pedagogical model to be used and the technology to support it. As for the ludic dimension, it identifies the specific elements the game should have to achieve the desired experience. These elements must incorporate the constraints implied by the educational dimension components.

2.1. Ludic dimension: game elements

To identify game elements that will reflect the desired educational experience we must first define the main elements in the design of any game. One way of categorizing game elements is the “elemental game tetrad” defined by Schell (2008), which divides all elements into four categories: mechanics, story, aesthetics and technology.

The mechanics of a game describes its procedures and rules, defining how players can achieve the game’s goal. They are the key elements differentiating games from other kinds of media in that they give the former their interactivity (Schell, 2008).

The story describes the sequence of events that unfolds during a game. It can be very simple and linear, or highly complex and branching. The level of storytelling will vary, ranging from games that are completely abstract with very low narrative elements to story-driven games that more closely resemble interactive movies (Schell, 2008).

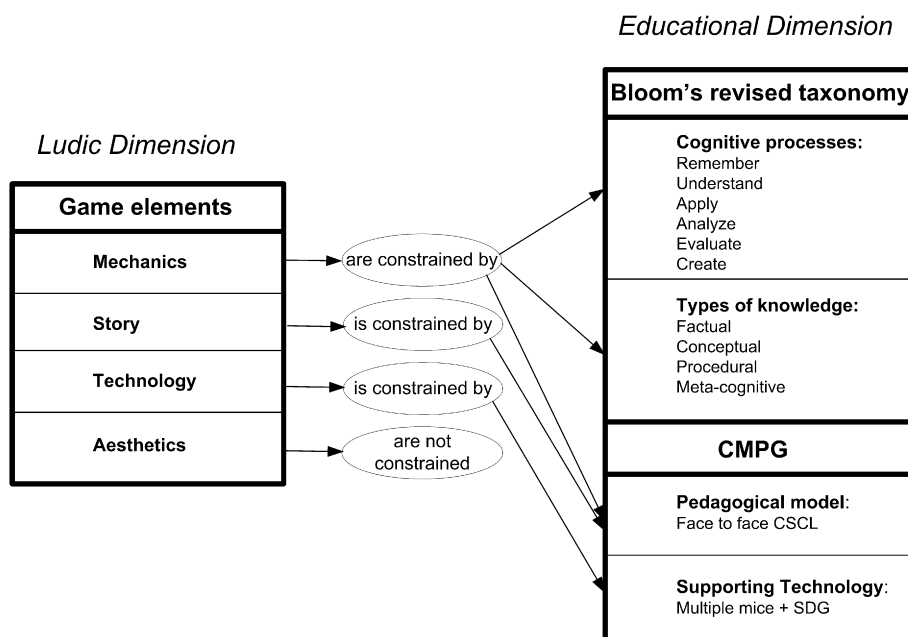


Fig. 1. The two dimensions of the proposed classroom games design framework. The educational dimension defines the pedagogical structure of the game, constraining the elements of the ludic dimension.

The aesthetics, as defined by Schell (2008), describe how the game looks (graphic design, colors) and sounds (music, sound effects). They define its general tone, which will affect the feelings a player experiences when playing (Schell, 2008).

Finally, the technology defines the materials and interactions that make playing the game possible, and includes such elements as input devices and displays. It enables the game to do certain things while banning it from doing certain others (Schell, 2008).

2.2. Educational dimension

2.2.1. Learning objectives

The specific learning objectives of an educational activity represent the expected goals the students must have achieved once the activity is completed. A useful tool for defining and classifying learning objectives is Bloom's revised taxonomy (Anderson, Krathwohl, Airasian, Cruickshank, Mayer & Pintrich, 2001), which categorizes them in two dimensions: knowledge and cognitive process. In the first dimension, the taxonomy defines four types of knowledge: factual, conceptual, procedural and meta-cognitive. In the second dimension, six types of cognitive processes are defined: remember, understand, apply, analyze, evaluate and create. The two dimensions together form a taxonomy of 24 different categories for classifying the learning objectives of a specific educational activity.

The game element directly affected by the learning objectives is the mechanics (Aleven et al., 2010). By directly mapping these objectives onto the mechanics, the student is forced to fulfill them in order to successfully complete the game. The actual mapping in any particular case will depend on the subject the game aims to teach, but for any given learning objective category in Bloom's revised taxonomy we can define specific characteristics the game mechanics should have.

The cognitive process categories can be associated with specific types of activities and actions that may be included in the game mechanics as follows:

- Remember: repetitive tasks with auxiliary rewards, keeping the student constantly confronted with the knowledge that must be remembered, keeping him/her engaged with the rewards.
- Understand: free exploration of interactions between objects that provide clear feedback, allowing the student to observe how a given process or concept works.
- Apply: direct action over objects with a specific goal, allowing the student to directly apply the specific knowledge.
- Analyze: problem-solving tasks and puzzles that involve integrating and selecting different elements.
- Evaluate: activities that allow the player to modify and correct existing objects, processes or simulations, check how something works and modify it if necessary to improve it.
- Create: activities that enable the player to build new artifacts, design new processes and test them experimentally.

The knowledge categories determine a number of additional characteristics that the game mechanics must include:

- Factual: an explicit fact must appear as content in the game that can be visualized by the player.
- Conceptual: a specific concept must emerge explicitly from interaction with the game, through its mechanics.
- Procedural: the game mechanics must force the player to explore, execute, modify or create the specific procedure associated with this type of knowledge.
- Meta-cognitive: the game mechanics should provide long-term strategic actions based on the meta-cognitive knowledge.

2.2.2. Pedagogical model and supporting technology

To be successful, the classroom integration of a game must be supported by a pedagogical model that accounts for all the challenges of developing a computer-based activity in a classroom context (Dillenbourg & Jermann, 2010). Although there are many pedagogical models for developing classroom activities, our aim here is to apply one that ensures all students in a class are active participants in their learning within a collaborative environment. To support such teamwork while enabling the teacher to track each student simultaneously, the activity must take place within a single game world. A suitable model would incorporate these conditions and define what interactions between the students are possible and how they are achieved.

Susaeta et al. (2010) have developed a model that fulfills all of these requirements. Their approach is intended 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, resulting in the new designation "classroom multiplayer presential games" (CMPG).

The CMPG model describes a combination of a pedagogical model and its supporting technology. The pedagogical model is based on the computer supported collaborative learning (CSCL) model (Dillenbourg, 1999) in which the computer is used as a tool to mediate collaboration between students and control the steps or script defining an activity (Dillenbourg, 2002). In a CSCL activity a group of students attempts to achieve an educational goal that can only be accomplished by coordinating the work of each individual member.

The CSCL model has been successfully implemented in the classroom (Nussbaum et al., 2009; Zurita & Nussbaum, 2004) and the work of Susaeta et al. (2010) has built upon this work by incorporating collaborative games in the classroom. In a CMPG game students must work in groups to collaboratively achieve a common objective related to the specific content being taught. The various goals of the game can only be accomplished if the players coordinate their participation in the action, which means in turn that they will need to verbally discuss issues in order to reach agreements and strategize as a group.

The supporting technology of the CMPG model is a one-to-many computing environment. A single computer is shared by all students through a common display, a type of interaction commonly known as single display groupware or SDG (Stewart, Bederson, & Druin, 1999). In the case of CMPG, the shared display is generated by projecting the information from the computer onto a wall. Interaction of the students with the game is then enabled by providing each of them with a mouse connected to the same computer. This multiple mice system has

already been utilized in educational applications (Moraveji, Inkpen, Cutrell, & Balakrishnan, 2009; Moraveji, Kim, & Pawar, 2007). With his/her mouse, each student interacts with the in-class projected virtual world while communicating verbally with his/her peers.

The teacher plays a central role in the CMPG model, acting as an omnipotent being in the virtual scenario. Being in control of the only computer, the teacher has full control of the system. For instance, he/she can pause the game whenever necessary to reinforce particular content or encourage discussion. The game then becomes a tool in the hands of the teacher that can be controlled and paced as particular needs and circumstances arise.

Given the above-described characteristics, the CMPG pedagogical model and its supporting technology in effect define a series of constraints on the different elements of the game. The multiple mice and SDG technology of the CMPG model specify both the input technology and the display technology to be used. The CSCL pedagogical model, on the other hand, imposes the following constraints:

- Story. A CSCL activity is defined by a linear script specifying a series of small tasks with specific goals (Dillenbourg, 2002). The story must therefore also be linear and divided into tasks with specific goals, which in the context of a game are called quests.
- Mechanics. A collaborative learning activity must implement collaborative mechanics that force the group to work together to solve a task. Some of the game mechanics have also therefore to be collaborative, and in addition must satisfy the main conditions for achieving collaboration: positive interdependence, a common goal, coordination and communication, awareness and joint rewards (Szewkis, Nussbaum, Denardin, Abalos, Rosen, Caballero et al., submitted for publication).

3. Case study: a game to teach electrostatics

The framework just described was used to design and develop a game called First Colony for teaching final-year secondary school students the basic concepts of electrostatics. We focused specifically on charge interaction and the law of forces between charges (Coulomb's Law). This topic is a difficult one for most students, who even after college level physics courses are often unable to apply Coulomb's law as well as one would expect (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001). Previous educational games developed to teach this subject have failed to correct students' misconceptions regarding the interaction between charges (Squire, Barnett, Grant, & Higginbotham, 2004).

In the following subsections we detail the design process of the game, relating it to the two dimensions of the framework and its components. The order of the process is the reverse of that employed above in describing the framework, however. We begin with the educational dimension, specifying the game's learning objectives and pedagogical model, and then proceed to the ludic dimension, defining the elements of the game subject to the constraints imposed by the educational components.

3.1. Educational dimension

3.1.1. Learning objectives

As noted earlier, the first component of the educational dimension is the establishment of specific learning objectives. Once the subject of First Colony was decided, the objectives were identified. This was done based on the expected learning outcomes regarding Coulomb's Law established by the Chilean Ministry of Education (MINEDUC, 1998) for final-year secondary school students. Categorized in Table 1 according to Bloom's revised taxonomy, the objectives were then used to define the main game mechanics.

From this set of learning objectives and the game mechanics characteristics associated with the two dimensions of the framework taxonomy, we derived the following basic list of actions the game players should be able to perform:

- Understand, through exploration and interaction, the concepts of:
 - Positive and negative charges
 - The force between two charges
 - Charges of different intensity
 - Charges located at different distances
- Apply the procedure of:
 - Coulomb's law in one dimension
 - Coulomb's law in two dimensions

3.1.2. Pedagogical model and supporting technology

The second component of the educational dimension involved analyzing how the CMPG model affected the different game elements. As previously stated, the CMPG's supporting technology defines both the input device (mouse) and the display technology (projected screen).

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

	Understand	Apply
Conceptual	Compare the concepts of positively, negatively and neutrally charged objects based on their interaction. Infer the concept of action and reaction in a forceful interaction of two objects. Understand the concept of the inverse relationship between distance and electric force. Understand the concept of the direct relationship between charge intensity and electric force.	
Procedural		Apply procedural knowledge of Coulomb's Law in one dimension. Apply procedural knowledge of Coulomb's Law in two dimensions.

Thus, the players' actions were limited by the actions of the mouse: moving it in two dimensions, clicking two buttons (left and right) and moving the wheel.

The CSCL pedagogical model constrained both the structure of the game's story and its mechanics. The game's story must be linear with clear and well-defined quests. Also, since there are several learning objectives, each quest should focus on just one objective so that the activity advances step by step. As for the mechanics, they must reflect the collaborative aspect of CSCL, meaning the students have to play in groups with a common goal.

3.2. Ludic dimension: game elements

The next step was to specify the elements of the First Colony game in such a way that it would ensure a unified and engaging experience for the players while satisfying the constraints imposed by the educational dimension. In what follows we detail the specifications for each game element included, explaining how the corresponding educational dimension constraints were incorporated.

3.2.1. Mechanics

To satisfy the mechanics requirements defined by the learning objectives, it was decided that each player should control a character that can activate an electric charge around him/her, allowing him/her to directly control the character's intensity and polarity. The players can electrically interact with each other and explore the concepts of positive and negative charge, the force between two charges and its relationship to charge intensity and distance. We also included electrically charged objects that offered a second element of interaction so that the players can directly execute the Coulomb's law procedure on an object and receive clear feedback on the process of the object's movement.

Finally, a mechanic was developed to satisfy both the collaborative constraint and the constraint requiring that the players be permitted to execute Coulomb's law in two dimensions. Three players must work together to move an electric object by applying Coulomb's law in two dimensions such that the object moves in the desired direction.

3.2.2. Technology

Various actions were defined for the mouse, the specified input device. To move a character to a given location the cursor is positioned at that spot and the left button is clicked. The right button activates a player's electric charge and the mouse wheel defines charge intensity and polarity.

The game world was developed as an immersive 3D environment, taking advantage of the size of the projected screen which can accommodate up to nine students working simultaneously.

3.2.3. Story

Although an electric charge is a real and observable phenomenon, the specific topic of Coulomb's law is hard to contextualize in a real scenario. The game could therefore be set in either a realistic but abstract world of electric particles or in a fantasy-based but concrete world with imaginary electric objects.

Opting for the second approach, we developed a storyline for First Colony that incorporates all of the required mechanics described above in a concrete game world. The players assume the role of astronauts from the first human colony on an extra-solar planet. They have been sent on an important mission to bring back a precious crystal found in space. The colony has limited energy resources and the crystal has the unique quality of storing electrical energy. It is fragile, however, so the astronauts can only interact with it at a distance using a special device that creates an electric field surrounding them (to avoid confusion, the concept of field is not actually used in the game).

The structure of the game is implemented as a series of quests grouped into a training phase and a mission phase. The training phase consists of several brief quests that explore a specific learning objective. In each quest a new concept is first introduced by the teacher on



Fig. 2. Each player controls a character that can activate an electric charge around him/her (the spheres in the image), allowing him/her to interact with other players.



Fig. 3. Collaboration was achieved by requiring the players to interact with an object (the crystal in the image) using their electric charges, thus forcing them to coordinate their actions as a group in order to achieve a specific goal.

a whiteboard or blackboard and then applied in the game (Fig. 4). The students must solve different tasks by controlling their electric charge and working with their classmates. Once this sequence of introductory concepts is completed, the training phase ends.

The mission phase consists of a series of more advanced quests in which the students must collect one or more crystals and push them through a special portal. The first goal of this part of the game is to reinforce the conceptual knowledge covered during the training phase. Thus, when the mission starts the polarity of the players' charges is hidden, forcing them to collaborate with each other and interact with the charged objects to rediscover their polarity (Fig. 3).

The second goal is to have the students 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, each astronaut working with a different crystal. In the two-dimensional version, however, the crystals are too big to be moved by a single player, forcing the students to work in small groups of three in order to generate the necessary force to move them (Fig. 4). To succeed in moving a crystal through the portal in the desired direction, the players will necessarily develop a clear understanding of vector addition of forces.

3.2.4. Aesthetics

The visual aesthetics of First Colony were designed to match the storyline, with space environments and astronaut-like characters (Figs. 2–6). Sound effects were kept to a minimum and no background music was added so that the students can talk among themselves and the teacher can explain the different concepts without interference.



Fig. 4. In the training quests, the teacher introduces the conceptual knowledge topics to the students. In this scene, the concept of the direct relationship between charge intensity and electric force is being tested by each student.



Fig. 5. In the first quest of the mission phase, students must discover their current polarity, which is hidden. This requires them to interact with each other and complete certain information in their respective group's interface, identified by color and displayed on the screen either at the top or in the bottom left or bottom right corner.

4. Experimental application

The game as described in the previous section was tested in a real classroom setting to study its impacts on students and analyze its effectiveness as a learning tool. In this section we present the design of this experiment and the results obtained.

4.1. Design of experiment

The experiment was designed for application to a class of final-year students at a public secondary school in Santiago, Chile. It consisted of a 1-h class on electrostatics using our game as the main pedagogical tool. The activity took place under the guidance of one of our researchers who assumed the role of the teacher, pausing game-play whenever the students' performance indicated it was necessary to explain or clarify specific concepts on the blackboard.

In order to assess what the students had learned during the experiment, a pre-test/post-test questionnaire design was adopted. As is usual with this approach (Mitnik, Recabarren, Nussbaum, & Soto, 2009; Papastergiou, 2009), the pre-test was administered just before the game was played and the post-test immediately afterward. It should be noted here that the principal goal of the experiment was to determine the usefulness of the proposed framework as a design aid for the development of classroom games by determining whether the game improved students' knowledge. This experiment was designed as an initial step, centered more on studying the utility of the framework than on comparing the results of the game with traditional methodologies. No control group was therefore used.

The instrument used to measure the expected learning outcomes was a specially designed conceptual evaluation that assessed each outcome (Table 1) by asking specific questions. The evaluation was based on the Conceptual Survey of Electricity (CSE) proposed by Maloney



Fig. 6. In the mission quests, students must work together to move the crystal, applying their knowledge of Coulomb's law in two dimensions.

Table 2

The questionnaire controlling for students' previous experience with technology and games showed that most students in the sample frequently used computers and most male students frequently played video games.

Use of:	Every day		At least once a week		At least once a month		Less than once a month		Never	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
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%

et al. (2001), with certain modifications to ensure all of the desired learning outcomes were covered and any questions on unrelated or more advanced subjects were excluded. The modified version used questions 3 to 10 from the CSE plus 13 additional ones for a total of 21. Before conducting the experiment the test was validated by two final-year physics teachers. A check of the internal consistency of the evaluation, measured by giving the test to 20 students at the school (13 male, 7 female), yielded a Cronbach's alpha of 0.74, above the minimum value of 0.7 required to prove reliability.

An initial pilot study was performed with 9 students (6 male, 3 female) to measure the effect size and estimate a minimum sample size that would yield the desired significance and power levels. The result was a Cohen's *d* value of 1.18, indicating a large effect. From this quantifier we estimated a sample size of 27 to obtain a significance level of 95% and power level of 99% with a one-tailed Student's *t* test.

Based on these values we designed an experiment with 27 students (13 male, 14 female) that was conducted over three sessions. In each session a different group of 9 students played the entire game simultaneously. For the game's collaborative quests, the 9 were randomly assigned to three groups of 3.

To control for the student's previous experience with technology (computers and cell phones) and video games (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 (Table 2) showed that most students in the sample, both male and female, were frequent users of computers (only one student used a computer just once or twice a month) and cell phones (only three students did not use cell phones at least once a week). The video game usage questions showed a difference between males and females: only three male students did not play video games at least once a week on one or more of the platforms, compared to eight female students who played equally infrequently.

To complement the results of the experiment, each session was videotaped with three cameras. Two observers analyzed the recordings after the experiment, making notes every 5 min on important observations related to the students' engagement, the ease of use of the system and any other item of significance.

4.2. Results

The results of the conceptual evaluation pre- and post-tests showed an increase in the average number of correct answers from 6.11 to 10.00, with standard deviations of 5.03 and 7.54 respectively. To analyze the statistical significance of these results we performed a Student's *t* test for dependant variables, the null hypothesis being that the pre-test and post-test averages were equal and the alternative hypothesis that the post-test average was greater than the pre-test average. To reject the null hypothesis, a one-tailed test was used with a significance level (alpha) of 0.01 (1%). The results of the *t* test rejecting the null hypothesis were statistically significant ($p < 0.00001$), meaning we can conclude with 99% confidence that the average number of correct answers in the evaluation increases after students are exposed to the game.

A post-hoc analysis was also carried out, obtaining a Cohen's *d* quantifier value of 1.58 indicating a large effect size. On the basis of this value, the sample size and the desired significance level (alpha = 0.01), we performed a power analysis to obtain the exact power value of the instrument. Thus, it was found that the instrument had a power of 99% (beta = 0.01) at a confidence level of 99% (alpha = 0.01).

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

The possibility of a gender effect was controlled for by dividing the sample and analyzing the male and female groups separately. The results for both revealed improvements, the average number of correct answers increasing from 5.57 to 10.36 for female students and 6.69 to 9.62 for male students. A *t* test showed that in both cases these findings were statistically significant (males: $p = 0.0044$; females: $p = 0.0001$). The difference between the respective improvements of the two gender groups was also tested, 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 factor we utilized the Pearson's correlation coefficient, which measures the linear relationship between two random quantitative variables. The test showed no significant correlation between the number of correct answers and previous experience with either technology (cell phone use: $r = -0.3$; computer use: $r = 0.12$) or video games (computer games: $r = 0.06$; console games: $r = 0.16$; cell phone games: $r = -0.03$).

5. Discussion and conclusions

The main contribution of this work is the validation of a proposed framework that can serve as a useful tool for designing video games and integrating them into the classroom. The framework provides a step-by-step design process for defining the elements of a game in

accordance with the educational and pedagogical needs as established by the user. The validation itself involved the design and integration of an actual game that was implemented via an experimental application in a real classroom context. The utilization of a CMPG model facilitated the integration process. An evaluation of the experiment demonstrated that in general terms the instructor could successfully use the game as a tool for teaching a particular and relatively complex subject to a group of students.

A number of more specific conclusions can be drawn regarding the game. The statistical analysis of the pre- and post-evaluation results validated its effectiveness for teaching electrostatics, but detailed comparison of the specific learning objective results also revealed its failure to effectively convey either the relationship between charge intensity and force (one of 6 learning objectives for the game) or how to perform vector addition of forces in two dimensions. Regarding the first of these, the failure may have been due to the absence of explicit moments in the game where the students must compare how different charge intensities affect the movement of the charges. As for vector addition of forces, the problem was the lack of explicit visualization of vectors in the game, which made it hard for the students to understand how the forces are summed. We plan to develop a second version of the game that includes explicit quests to explore the difference in force when charge intensity changes and integrates force vector visualizations. We expect it will do better at transmitting the concepts the game reported here proved unable to get across.

An analysis of the test results by student characteristics showed that there was no significant relationship between gender, previous computer use or previous game playing and pre-test/post-test improvement. These outcomes are significant because they contradict the general conception that games are only useful for male students with previous game experience. Additional evidence in the same direction was the excitement displayed by female students while they were playing (one female student even asked where she could download this game). A possible explanation of the game's success among female students is the social component. The collaboration required in some quests adds a social dynamic to the game that traditional challenge-based games lack.

The observations based on the video recordings of the experiment justify three additional conclusions. First, motivation was high during the entire gaming session, demonstrating that the students were engaged by the game and remained so right to the end. Second, the system can be learned rapidly. Indicators such as the number of errors in game actions and interface confusion dropped quickly after a few minutes of game-play, suggesting students were able to learn the game during the training quests and could use that knowledge in later quests. This rapid "learnability" also proves that it is possible to develop games which can be learned and used effectively in a single session. An as yet unanswered question, however, is how much training time teachers will need to master the tool and be able to provide adequate pedagogical support. Third, and finally, although various groups played the game independently, significant positive interaction took place between them.

The generally satisfactory results of the experiment suggest that although the concepts learned were contextualized in a fantasy-based game environment, students can transfer that knowledge to the task of answering questions on standard written tests. The possibility they would not be able to make such a transfer was one of our main concerns while developing the game, but the results furnish solid evidence to the contrary. We believe successful transfer was possible mainly because the guidance and explanation given by the teacher acted as a link between the fantasy world of the game and the real world of the test. Thus, if games are to be used as an educational tool, the teacher's knowledge of both the tool and the concepts is essential. In future work we intend to analyze this factor further.

Several other lines of research are suggested by the experiment reported here. First, considering the success of the framework and the game we have presented, a natural next step would be to compare the game's results with those of traditional classes and develop other games using the same process. A second area for exploration would be to use the same framework for developing more games but with a different pedagogical model and supporting technology. This would isolate the effects of the framework from the pedagogical model. Finally, other elements of the framework could be analyzed such as how differences in the story or the aesthetics of the game might affect the learning outcomes of different students.

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