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Problem solving and collaboration using mobile serious games

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A B S T R A C T

This paper presents the results obtained with the implementation of a series of learning activities based on Mobile Serious Games (MSGs) for the development of problem solving and collaborative skills in Chilean 8th grade students. Three MSGs were developed and played by teams of four students in order to solve problems collaboratively. A quasi-experimental design was used. The data shows that the experimental group achieved a higher perception of their own collaboration skills and a higher score in the plan execution dimension of the problem solving cycle than did the non-equivalent control group, revealing that MSG-based learning activities may contribute to such learning improvements. This challenges future research to identify under which conditions learning activities based on mobile serious games can promote the development of higher order skills.

1. Introduction

Several authors have pointed out the potential benefits of the use of mobile devices for educational purposes (Csete, Wong, & Vogel, 2004; Vahey, Tatar, & Roschelle, 2007). These devices allow for learning everywhere; when walking, in the street, on the bus, in the school, or even on the subway (Salinas & Sánchez, 2006), creating the potential for a new phase in the evolution of technology-enhanced learning, marked by the continuity of learning experiences across different environments (Chan et al., 2006). Mobile devices can also help students make on-site decisions assisted by basic information processing (Syvanen, Beale, Sharples, Ahonen, & Lonsdale, 2005). The focus of several of these projects is on the way these devices are integrated into a school context in which there are already operational working practices of teachers and students, available resources, learning objectives and representations regarding education and technology (Roschelle, 2003).

The possibility of using games in which the main purpose is learning, known as serious games (Stone, 2005), opens up enormous opportunities to connect education to the daily life experiences of learners and their learning styles (Proserpio & Viola, 2007; Vahey et al., 2007). This, in turn, could increase their motivation for and commitment to learning (Bokyeong, Hyungsung, & Youngkyun, 2009; Johnson, Johnson, & Holubec, 1994; Lim, Nonis, & Hedberg, 2006). Several studies have been done in order to analyze the impact that serious games have on learning processes, and in particular on the development of social, collaborative and problem solving skills (Klopfer & Yoon, 2005), as well as on areas within the school curriculum such as language, science and mathematics (Mayo, 2007). Serious games have the potential to allow the student to interact with both the machines and with other students, providing an incentive for and facilitating collaboration and participation in learning activities (Csete et al., 2004).

Through the use of mobile devices, serious games become independent of the spaces previously determined for their use. Mobile Serious Games (MSGs) combine the possibility for the user to be able to play as he moves throughout different real-world places (Stone, 2005), taking advantage of the user's playing style, the speed of his movements, times, changes in the environment, acceleration, and the manipulation of objects, among many other things (Thomas, Schott, & Kambouri, 2004). Schwabe and Göth (2005) present a study that involves the use of MSGs, in which they found that the participants were able to immerse themselves into a mixed reality that augments physical and social environment. These authors believe that the success of MSGs is based mainly on the degree to which they motivate students. Another MSG, presented by Facer et al. (2004), takes advantage of the user's interaction with his surroundings and collaboration between the players in order to achieve an experience with high levels of participation in and motivation for learning.

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Razumnyy (2005) proposes that when interacting with MSGs, learning takes place more easily and effectively, due to the conditions provided by such games. However, Gros (2007) reveals that critical studies point out that merely incorporating serious games, does not contribute to learning. Such studies highlight that other fundamental conditions are required for learning to take place, such as the teacher's familiarity with technology or embedding the game within a learning methodology that provides it with context and meaning.

Regarding science education, many concepts are difficult to understand for students of primary education. This may be due to the high degree of complexity and the level of abstraction of such concepts as well as the students' limited experience (Flick & Bell, 2000). In response to this, the use of technology can make significant contributions to the teaching of science and biology in particular (Akpan, 2001; Flick & Bell, 2000). Diverse authors demonstrated that the students' difficulty of understanding scientific concepts can be confronted using serious games. For example, Greenfield (1996) shows that serious games can contribute to two very important goals of science learning: to develop learning through observation and hypothesis testing, and scientific simulations. Barab et al. (2009) point out in their study that the contextualization that serious games can provide for the learning of scientific phenomena can contribute to considerable improvements in science learning. In particular, the use of MSGs in this context allows users to interact playfully in non-static locations for science learning purposes (Williams, Jones, Fleuriot, & Wood, 2005).

In the same way, one of the high order cognitive abilities that serious games can contribute to is developing problem solving skills (Klopfer & Yoon, 2005). Kelly et al. (2007) propose a model for describing problem-solving games that can be used for educational purposes. In the model, reflection is vital in order to understand the process of the game and to define strategies. When performed in groups working as a team, problem solving is strengthened as a learning activity (O'Neil, Chuang, & Chung, 2004). According to these authors collaborative problem solving is defined as activities that involve interactions among a group of individuals that can be divided into two components: collaboration and problem solving. For a problem solving process to be collaborative, the learners must work as a team to develop roles for each member that relate well with and complement each other in search of a common goal. For this to happen, the objectives that each team member pursues individually should be closely related to the others' objectives, and each team member should only be able to reach his own objectives entirely if the rest of the team also achieves theirs (Johnson et al., 1994).

Some researchers have studied variables that influence problem solving and collaboration, such as the social background of the students. For the majority of countries included in the PISA 2003 study on problem solving, for example, the students' social backgrounds did have a significant effect (OECD, 2004). Other studies have found differences in the degree of problem solving abilities by gender (Pol, Harskamp, & Suhre, 2008) and differences in collaborative learning by the gender, status and culture of the groups involved (Resta & Laferrière, 2007).

This paper presents the results obtained with the implementation of a series of MSG-based learning activities for the development of problem solving and collaboration skills in Chilean 8th grade students. Preliminary results were studied in a previous paper (Sánchez, Mendoza, & Salinas, 2009). The hypothesis of this study is that learning activities based on mobile serious games can contribute to the development of problem solving and collaboration skills, and to the improvement of primary school learners' motivation for learning and perceptions of science. To test the working hypothesis, three MSGs were developed (Evolution, Museum and BuinZoo) and a series of MSG-based learning activities were designed. The activities and MSGs are related with the "Evolution of Species" content from the science curriculum for 8th grade Chilean education. In order to identify the contexts in which the learning activities make a much clearer contribution to learning, the paper analyzes results for problem solving and collaboration skills in schools with differing socioeconomic status.

2. Methodology

2.1. Mobile serious games

To design the MSGs, we have consolidated 4 primary focuses: 1. The existence and pertinence of mobile serious games (MSGs) that stems from the routine character of the use of mobile technology and the impact that videogames have on education (serious games) (Barab et al., 2009; Razumnyy, 2005; Stone, 2005); 2. The difficulty that learners face with learning and studying science concepts (Flick & Bell, 2000), in this case, concepts related to the evolution of species; 3. The context generated by a learning environment in which the integration to any degree of technology cannot be isolated, but rather must be accompanied by a methodology in accordance with its use (Gros, 2007; Prensky, 2001); 4. The need to support the development of higher order skills such as problem solving and collaboration (Johnson et al., 1994; Kelly et al., 2007).

2.1.1. Evolution

MSG Evolution (Fig. 1) was designed and developed for use in Classmate mobile devices, using sophisticated 3D graphics, where the design of some elements such as time, actions, logic and resources was aligned with the real-time strategy commercial games, since this type of games is potentially a tool for developing problem solving skills (Prensky, 2006).

The game consists of four environments, each related to one animal class (fishes, amphibians, reptiles and birds), and each class has three species: *light*, *medium, and heavy*. Each environment is divided into sectors, which simulate the habitat of each species. In each environment the players start playing with one unit (consists of 50 individuals) of *light* species, while the system controls several units of three species (*light*, *medium, and heavy*) which are distributed throughout the environment. The system-controlled units act as enemies of the species that control the player. The goal of the game is to develop and maintain the various animal species that exist in each environment. In order to achieve this goal, the players must perform a variety of actions: select and move the units within the environment, reproduce, evolve, feed, and flee from enemy units or attack them. The player-controlled units of *light* species are the only ones that can evolve to other species (*medium* and *heavy*) within the same animal class, which can occur when the player moves his units to sectors ("habitat") of the other species. In this case, evolution can only occur under certain conditions of number of individuals and satiety of player-controlled units. Once the process of evolution occurs and the player-controlled units species evolves (e.g. from *light* to *medium*), the player gets units of the other species present in the environment. If the player does not apply appropriate actions to maintain their units, they will die of starvation, will die due to lack of oxygen, or in extreme cases lose all individuals resulting in the extinction of species (Note: The game attempts to represent the process of biological evolution that occurs in nature. Therefore, teachers are the ones who must make the necessary explanations so that students do not produce misconceptions about evolution.).

Fig. 1. MSG Evolution screenshot. 1) Game screen, 2) information about number of individuals and saciety of the selected unit, 3) information about the species of the selected unit, 4) buttons (See the sectors corresponding to each species in the minimap, Pause, Stop, respectively), and 5) minimap.

The game has extra characteristics oriented toward providing incentives for player motivation. Specifically, these characteristics are: 1. Enemy patrols, which consist of system-controlled units (enemy units) that move through predefined sectors, waiting for the player-controlled units to come close in order to attack them. If the player decides to flee from the enemy units, after a certain predefined distance these stop the attack. 2. Action points, which consist of each action that the user performs with his species has a predefined number of points associated to it, which are added to or subtracted from the total score, according to the action performed. 3. Diversity score, which consists of a score assigned according to a value obtained from an equation used to measure diversity (Shannon–Wiener index). The Shannon–Wiener index takes into account the number of species and the evenness of the species in the community (in the case of this game, the community is equivalent to species present in each environment). In this way, the player is given more points when he has a high index, and is given fewer points if having a low index.

2.1.2. BuinZoo & museum

MSGs BuinZoo (Fig. 2a) and Museum (Fig. 2b) are trivia games for Classmate mobile devices that guide the visit to a zoo and a museum respectively, and which allow to work concepts related to curricular content “Evolution of species”.

At the beginning the game presents a mission, which corresponds to a problem that the students have to resolve on site that they are visiting: the zoo, called BuinZoo, and the National Museum of Natural History, both in Santiago, Chile. In the visit to the museum, the problem consisted of explaining how fossilization takes place and how this process relates to the evolution of species. In the visit to the zoo, the problem consisted of explaining the morphological, physiological and/or behavioral adaptations that three of the species at the zoo had experienced throughout their evolution. After presenting the mission, the game displays a set of multiple-choice questions, with 5 alternatives each, which are based on information available at the zoo and the museum, as well as direct observation of animals in the case of zoo. The questions are divided into individual and group questions. In the first case, the students must answer the question individually. When the student answers correctly, the game provides more information about the answer and a clue for answering the group question. In the case of group questions, the instructions indicate to students that they have to get together with their group in order to discuss and choose the correct alternative, because each group member has a clue to answer the question. Individual and group questions are organized into “activities” and each “activity” has a specific number of individual questions and one group question. The activities have a limited time frame to accomplish, once the time limit is up, the game moves on to the next activity. The time frame for each activity is allocated in proportion to the duration of the visit (short, regular or extended: 60, 90 or 120 min, respectively), which must be selected by the students when they enter the game according to the teacher’s instructions. Once the students answer all game questions, the game displays a notification to remind them that should make a multimedia presentation that summarizes the lessons they have learned from the visit and respond the problem posed at the beginning of the game.

2.2. Sample

The sample was made up of 10 eighth-grade classes from 5 different schools, with two eighth-grade classes from each school. It was an intentional sample, meaning that the participating schools were selected according to certain criteria that were pertinent to the research, and not by statistical representivity. These criteria were based on student achievement in science, and socioeconomic status of the school. As such, schools that were above or below the national average score obtained on a national standardized science test (called SIMCE) taken by 8th grade students in 2004 were chosen; as well as those that were above or below the national average in an index of social vulnerability of the school-aged population, assigned to every school by a government agency. In this way, two types of schools were obtained: one type of schools with a high average science score and a low degree of socioeconomic vulnerability, made up of two schools and 146 students in total (including both the control and experimental groups), and another type of schools with a low average science score and a high degree of socioeconomic vulnerability, made up of three schools and 227 students. This selection was made considering the close relationship between academic achievement and socioeconomic status of students.

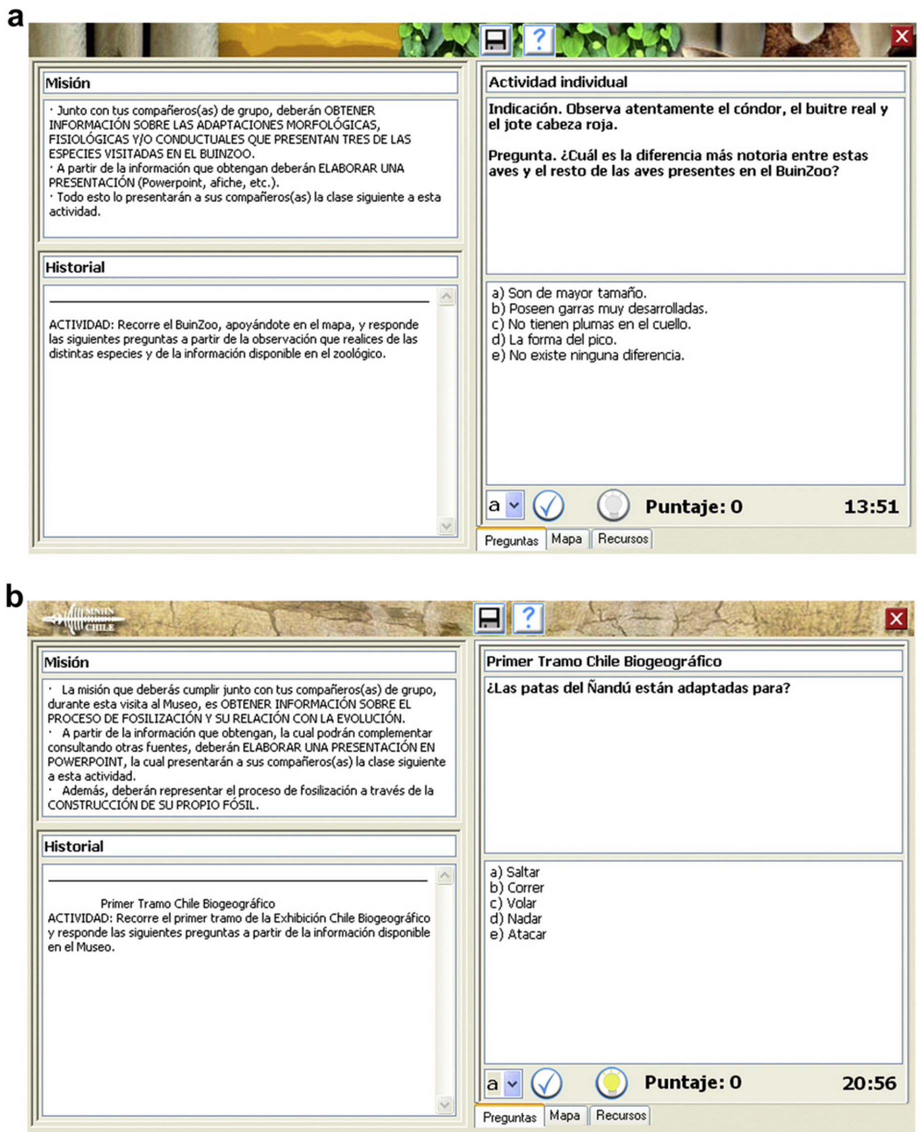

Fig. 2. a) MSG BuinZoo, and b) MSG Museum screenshots. Main text in the Fig. 2a: Indication. Carefully observe the condor, king vulture and the red-headed vulture. Question. What is the most notorious difference between these birds and other birds in the BuinZoo? a) Are larger. b) Have well developed claws. c) Have no feathers on the neck. d) Beak shape. e) There is no difference. Main text in the Fig. 2b: Ostrich legs are adapted for? a) Jump, b) Run, c) Fly, d) Swim, e) Attack.

2.3. Research design

As we worked with classes, the students could not be assigned randomly to the control/experimental groups. Therefore, a quasi-experimental research design was applied, a non-equivalent control group design. In this case, measurements were taken only afterward to avoid changes in the subjects from exposure to the instruments which affect the internal validity of research (Campbell & Stanley, 1963; Shadish, Cook, & Campbell, 2002). We selected schools that have two eighth-grade sections that were taught by the same teacher. One section, the experimental group, had classes with learning activities based on MSGs. The other section, the non-equivalent control group, had traditional classes, without field trips, and did not use the MSGs or mobile devices used by students from the experimental group. Both groups participated in the data collection activities.

The experimental variable corresponds to the MSG-based learning activities in which the experimental group participated. These activities were developed in 23 sessions distributed in a three-month period of time. The activities involved were: a) *activities out-of-school context*, made up of two *field trips*, one to BuinZoo and another to the National Museum of Natural History, that were supported by the MSGs BuinZoo (1 session) and Museum (1 session) respectively, and *systematization activities* (4 sessions), in which the students organized the information collected in field trips; b) *game sessions* (5 sessions, once a week), in which the students used the MSG Evolution; and c) *research activities* (12 sessions), in which students researched a specific topic, developed a final product and made a presentation.

2.4. Research instruments

The instruments used were: 1. A structured, self-applied survey, 2. A scale for the perception of problem solving skills, and 3. A scale for the perception of collaborative skills.

The survey was used to collect information on the participating students' perceptions of the project and collect data to evaluate the impact of the intervention. This instrument contains 77 closed questions organized in four dimensions: characterization of students, computer management, learning conditions and evaluation of various project areas.

The scale for the perception of problem solving skills, made up of 14 items, included four dimensions which correspond to the four steps suggested by Polya (1957) to solve a problem: understanding the problem, strategy design, strategy execution and the evaluation of the strategies utilized. Some of the statements included in the scale, for which students had to state their level of agreement, were "Before solving a problem, I identify the information that I have available", "To solve a problem, I organize my ideas in different ways in order to find the best solution", "While I perform a task I am reviewing the steps I am taking in order to know if I am doing it well", and "I constantly evaluate my performance when I solve a problem".

The scale for the perception of collaborative work, made up of 25 items, included five dimensions: leadership, work responsibility, work objectives, role of the tutor and willingness to work in a group. These dimensions were selected based on the central ideas that were found in Johnson et al. (1994), Driscoll and Vergara (1997), and Sánchez (2001). Some of the statements included in the scale were "In group assignments I do not believe that it is necessary for one member to direct the rest", "When a member of my group does not understand something, I make sure to explain it to him", "When working in a group, I like to know all my classmate's opinions in order to have varying points of view", "When we work in a group, it is not necessary for the teacher to be supervising our work all the time", and "I prefer to work with other classmates to do school work".

The problem solving and collaboration scales were designed as a Likert-type scale of 5 points, in which the students must indicate their perception of the skill cited in the statement from "strongly agree" to "strongly disagree". Each answer was matched to a score scale from 5 to 1 respectively. Both scales were validated through their application to a group of students from schools with similar characteristics to the participants in the project. The Cronbach's Alpha reliability index for the problem solving scale was 0.88, while for the collaborative skills scale it was 0.82.

2.5. Procedure

2.5.1. Intervention in the classroom

Classroom intervention was carried out in two stages: 1. First stage, which included MSG-based learning activities out-of-school context (field trips) and work activities performed in the classroom; 2. Second stage, which included MSG-based learning activities in-school context, and work activities performed in the classroom. All activities were carried out by students working in 4-member groups, which were permanent throughout the entire study.

In the first stage of classroom intervention, the students visited a museum and three weeks later, a zoo (Fig. 3). Before each visit, the teachers gave an introductory class in which they worked on content related to the visit. In the introductory class for the visit to the museum, the teachers worked with the students on the theories of the origin of life on Earth. In the introductory class for the visit to the zoo, the teachers worked with the students on the concepts of adaptation and evolution. These topics are part of the science curriculum that the teachers must work on with their students. During the visits to the museum and the zoo, the students used the MSGs Museum and BuinZoo, respectively, which guided their visit. The class after each visit, the students had to present a product that summarized the lessons they had learned from the visit (Fig. 3). After the visit to the museum, the students handed in a model that represented the process of fossilization and

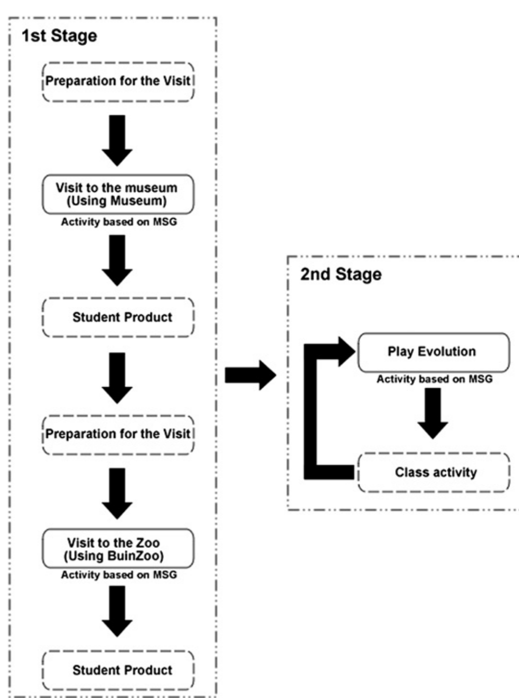

Fig. 3. Diagram of the stages developed during the classroom intervention.

made a multimedia presentation in which they explained the process of fossilization and the importance of fossils for studying the evolution of species. After the visit to the zoo, the students made a multimedia presentation through which they explained and exemplified the way in which the species had adapted to their environment.

In the second stage of classroom intervention, the students played with the MSG Evolution and worked in research activities (Fig. 3). Once a week for five weeks, the students performed MSG-based activities in-school context, either in the classroom or in any other space that the teachers allowed, which lasted approximately 90 min each. As the MSG Evolution is structured in four environments, students must play in groups of 4 and so each team member interacts with a different environment every week. Thus, after four game sessions all team members have interacted with the four environments. In this way, the actions that each team member takes in a specific environment will affect the results achieved by the player to interact with that environment the next game session and the team as a whole. During all the game sessions each team had to work collaboratively in order to solve the problem in the game: to develop and maintain the various animal species that exist in each environment. For this each team member had to carry out a mission in the environment in which he had to interact: know the environment, feed and reproduce their units, and keep biodiversity. These missions were related with the contents worked in the research activities. In each team each member had a specific role (leader, coordinator, moderator and annotator), which should accomplish according to the activities to be carried out. In each game session, each team, with the participation of all members, had to perform the following activities collaboratively: read the mission to fulfill in the game, read and begin to complete a worksheet, play and interact with the MSG to fulfill the mission, and finish to complete the worksheet. Each team member had to participate in the activities according to the role played. The worksheet was based on the four stages of the problem solving process according to Polya (1957): understanding the problem, defining a strategy, implementing and evaluating it. To complete this worksheet all team members had to discuss about the problem (mission) they had to solve, the strategy to solve it and how to implement it in the game, and had to evaluate the strategy that each one of them implemented in the game. Thus, the teams had to review the strategy they had followed in previous session and modify it if necessary before starting to play. Then they should implement the strategy in the game, and at finish playing they should re-evaluate the strategy used. Thus, all the decisions that are made regarding to the game must be discussed, debated, and worked on together in order to solve collaboratively the problem posed in the game. All this work had to be supervised by the teacher, who must organize students into teams, work with each team to make sure they were working according to the worksheet and resolve any doubts they may have. In the final game session, the students participated in a competition among all the teams in the class, in which each team played as in the previous game sessions, but now applying all the knowledge acquired during the development of missions. The team that obtained the highest score was the winner, and had to explain the strategy they used to the entire class.

Between each game session the students worked in two research activities that allowed them to systematize, complement and deepen their learning of contents worked with the MSG Evolution. Each research activity lasted three sessions. In the first two sessions the students had to carry out research on a particular topics (adaptation and biodiversity; evolution and natural selection) using different sources of information (Internet, books, library, etc.), and produced a final product (multimedia presentation, research report or poster), whereas in the third session, the students presented the finished product.

2.5.2. Data collection

Once the classroom intervention had been completed, data were collected through the application of the instruments explained above. The survey and scales were administered simultaneously to all the students in both the experimental and non-equivalent control groups in each school. Although the instruments were self-applied, a researcher was always available to answer students' questions and collect the surveys once they were completed. Only one session was necessary to apply the instruments.

Once the data had been collected, the surveys were reviewed in their entirety and digitalized into an electronic spreadsheet. At the same time, a SPSS database was created in order to analyze the data. Data was analyzed using descriptive statistics (frequencies, means, and percentages) and statistical analyses (such as Chi-square, MANOVA, two-way ANOVA). To test the hypothesis, a 0.05 level of significance was chosen.

3. Results

After having completed the project, a higher percentage of the students in the experimental group expressed the opinion that science class was entertaining (45%) and exciting (21%) than did the students from the non-equivalent control group (38% and 16% respectively), while a higher percentage of the students in the non-equivalent control group expressed the opinion that science class was boring (7%) and necessary (39%) than did the students from the experimental group (4% and 31% respectively) (Fig. 4). Although a higher percentage of students who participated in the project has a favorable opinion of science classes, there is no association between the variables 'motivation for learning' and 'participation in the project' [χ^2 (3) $= 4.648$; $p = 0.199$].

Although almost the same percentage of the students from the experimental and non-equivalent control groups strongly disagree stating that, "the sciences represent a subject that only few people can understand" (20% in both groups), in the experimental group a higher percentage of students disagree with this statement (47%) than in the non-equivalent control group (40%) (Fig. 5). On the other hand, a higher percentage of the students in the non-equivalent control group agree with this statement (32%) and strongly agree (8%) than did the students from the experimental group (28% and 5% respectively) (Fig. 5). Although a higher percentage of students who participated in the project disagrees with this statement, there is no association between the variables 'perceptions of science' and 'participation in the project' [χ^2 (3) $= 2.507$; $p = 0.474$].

The students who participated in the MSG-based learning activities especially valued the activities out-of-school context (field trips) and the fun character of the experience. On a scale of scores from 1 to 7, the students graded the visit to the zoo with an average of 6.4 points, and the visit to the museum with an average of 6.3 points.

To study the overall effect of the factors type of school to which students belonged and participation in the study on the perception of students about their collaboration skills, a MANOVA was performed. The score obtained on the total scale and the five dimensions included in the scale was significantly affected by the type of school [Wilk's lambda $= 0.950$, $F(5,284) = 3.003$, $p = 0.0017$] and by participation in the study [Wilk's lambda $= 0.867$, F $(5,284) = 8.583$, $p < 0.001$]. In the individual analysis only the dimension "Role of tutor" was affected

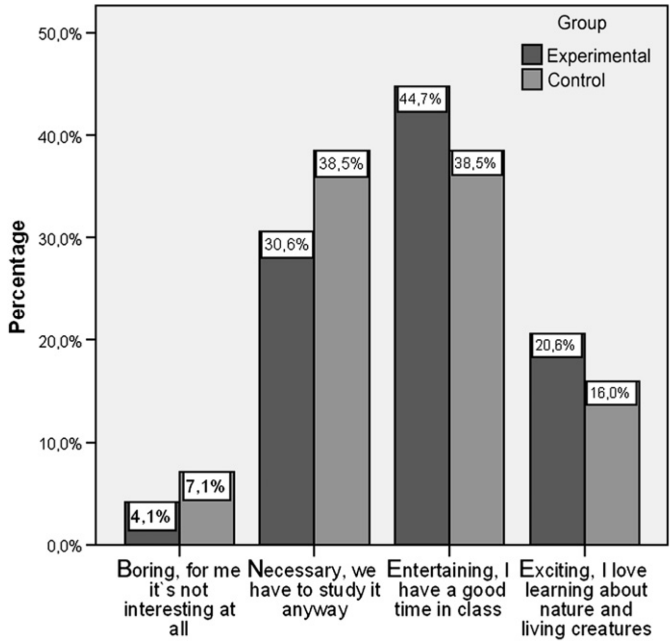

Fig. 4. Results of student opinions about the science class. Dark gray bars represent experimental group and light gray bars non-equivalent control group. Values represent the mean.

significantly by the type of school [$F\,(1{,}288) = 5.31$, $p = 0.0219$], where students belonging to the group of schools with low average science score and high socioeconomic vulnerability scored higher than students in the group with high average science score and low socioeconomic vulnerability. On the other hand, participation in the study had a significant effect both on the total scale [$F\,(1{,}288) = 4.09$, $p = 0.044$] and the dimensions "Leadership" [$F\,(1{,}288) = 6.896$, $p = 0.0009$], "Work responsibility" [$F\,(1{,}288) = 5.07$, $p = 0.025$], and "Work objective" [$F\,(1{,}288) = 19.25$, $p < 0.001$]. In all these cases students who participated in the study received scores higher than the students that did not participate, except in the dimension "Leadership" in which the trend reversed (Table 1).

To study the overall effect of the factors type of school to which students belonged and participation in the study on the perception of students about their problem solving skills a MANOVA was conducted. The score obtained on the total scale and the four dimensions included in the scale was not significantly affected by the type of school [Wilk's lambda = 0.993, $F\,(5{,}265) = 0.4$, $p = 0.8485$] or by participation in the study [Wilk's lambda = 0.979, $F\,(5{,}265) = 1.132$, $p = 0.3438$] nor the interaction between both factors [Wilk's

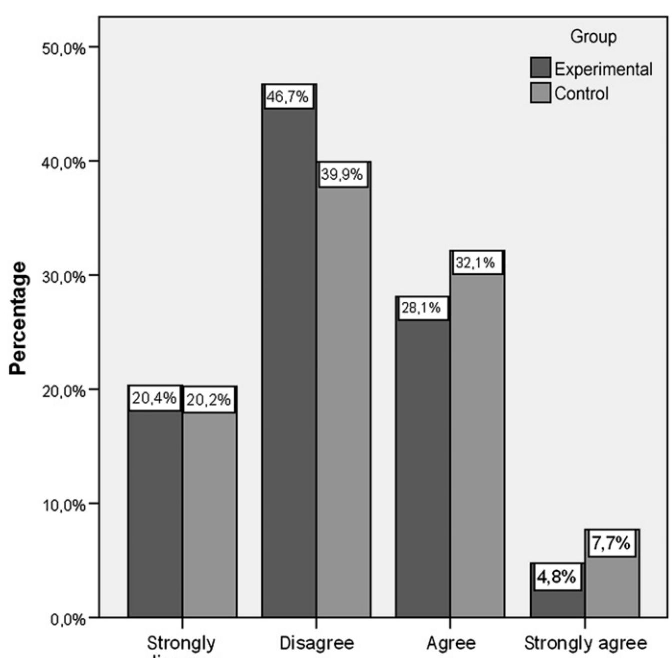

Fig. 5. Results of student opinions about the statement, "the sciences represent a subject that only few people can understand". Dark gray bars represent experimental group and light gray bars non-equivalent control group. Values represent the mean.

Table 1
Descriptive statistics of experimental and non-equivalent control group scores obtained on the five dimensions and total scale for the perception of collaborative work.

	n	Mean	SE
Leadership			
Experimental group	158	3.76	0.05
Non-equivalent control group	134	3.97	0.06
Work responsibility			
Experimental group	158	4.27	0.05
Non-equivalent control group	134	4.11	0.05
Work objectives			
Experimental group	158	4.22	0.05
Non-equivalent control group	134	3.90	0.05
Role of the tutor			
Experimental group	158	3.76	0.05
Non-equivalent control group	134	3.64	0.05
Willingness to work in a group			
Experimental group	158	3.26	0.05
Non-equivalent control group	134	3.13	0.06
Total scale			
Experimental group	158	3.86	0.03
Non-equivalent control group	134	3.75	0.04

lambda $= 0.964$, $F(5,265) = 1.959$, $p = 0.0851$]. In the individual analysis only the dimension "Implementation of the strategy" was affected significantly by participation in the study [$F(1,269) = 3.983$, $p = 0.047$], where students who participated in the study scored higher than their non-participating peers (Table 2).

4. Discussion

The results show that the methodology developed through the use of MSGs contributes to the development of collaboration skills. From the data we could ascertain that the group that participated in the experience, independently of the school's socioeconomic status and science scores of the students, expresses a better global perception of their collaboration skills than the students in the non-equivalent control group, as well as a better perception of the dimensions related to work responsibility and work objectives. In the case of leadership, the students of the non-equivalent control group indicated that for them the presence of a group member who regulated the work of the others was more necessary than in the experimental group. The reason for this is that although the non-equivalent control group had a group member designated as leader, the tasks were shared out among all team members.

In the case of problem solving skills, although the experimental group always performed better than the non-equivalent control group, we only found statistically significant differences in favor of the experimental group regarding the students' perception of their own capacities for plan execution, independently of the school' socioeconomic status and science scores of the students. In this case, the students indicated that they examined the details more and were more careful in making sure that the steps they made were correct.

In addition to the collaboration and problem solving results, the students that participated in the experience had a better opinion about science class and a more familiarized perception of science than the non-participating students, although in neither case had there been association between the variables. This complements the results of other studies on the potential of the use of mobile devices for learning (Facer et al., 2004), the contribution that mobile technology and videogames make to science learning (Barab et al., 2009; Chan et al., 2006), and the importance of contextualizing scientific phenomena so that they are better understood by students (Barab & Dede, 2007; Barab et al., 2009).

In summary, the data obtained shows that the intervention has had an impact on collaboration and problem solving skills among the students that participated in the study. This results show that MSG-based learning activities contribute to the development of skills, as shown by Klopfer and Yoon (2005) and Csete et al. (2004).

Table 2
Descriptive statistics of experimental and non-equivalent control group scores obtained on the four dimensions and total scale for the perception of problem solving skills.

	n	Mean	SE
Understanding the problem			
Experimental group	140	3.93	0.06
Non-equivalent control group	133	3.85	0.06
Strategy design			
Experimental group	140	3.92	0.07
Non-equivalent control group	133	3.80	0.07
Strategy execution			
Experimental group	140	3.95	0.06
Non-equivalent control group	133	3.77	0.06
Evaluation of the strategies			
Experimental group	140	3.82	0.07
Non-equivalent control group	133	3.76	0.07
Total scale			
Experimental group	140	3.90	0.06
Non-equivalent control group	133	3.80	0.06

5. Conclusions

This paper presents the results obtained after the implementation of a series of MSG-based learning activities for the development of problem solving and collaborative skills in Chilean 8th grade students. The research hypothesis that was tested during the study is that MSG-based learning activities can contribute to the development of problem solving and collaboration skills, the improvement of perceptions of science, and increasing the motivation for learning among primary education students.

Integrating games into education is not easy to achieve. There is an attempt to integrate mobile devices and serious games on an ad-hoc learning methodology to develop and improve problem solving and collaboration skills. These skills belong to the 21st-century skills (Rotherham & Willimgham, 2009). Therefore, developing and evaluating a methodology to improve these skills is a very important contribution to educational systems. The fact that the study did not have a major impact on skills on both collaboration skills and problem solving skills could be interpreted in light of the kinds of skills being measured. In effect, it is possible to consider that the lapse of time required to develop one such skill or another could be different (Garton, 2004). A three-month lasting project such as that described here contributes to the development of these skills, but a much longer, systematic intervention may be required to obtain results on the set of dimensions that make up these skills. This should be explored more fully in future studies in order to produce an impact in all the dimensions analyzed.

Our work has been guided by an interest in developing learning activities to include MSGs with a logic that is closely matched to the most attractive games on the market, integrating it with learning contents. Developing games for learning opens up new possibilities for understanding how teaching and learning practices are mediated by technology and under what conditions those practices actually improve learning. We believe it is necessary to continue the study of MSGs. One line of future work could be to measure student learning to investigate whether the use of MSGs improves learning. Another line of future work for the study should be to improve some characteristics of the three MSGs to tailor more to the students' mental models and to the learning environments which allowed taking advantage of new places outside the classroom (like other kind of museums, historical places, some historical neighborhood or buildings into the city, etc.), for curricular purposes.

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