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Practising Arithmetic Using Educational Video Games with an Interpersonal Computer

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ABSTRACT

Studies show the positive effects that video games can have on student performance and attitude towards learning. In the past few years, strategies have been generated to optimize the use of technological resources with the aim of facilitating widespread adoption of technology in the classroom. Given its low acquisition and maintenance costs, the interpersonal computer allows individual interaction and simultaneous learning with large groups of students. The purpose of this work was to compare arithmetical knowledge acquired by third-grade students through the use of game-based activities and non-game-based activities using an interpersonal computer, with knowledge acquired through the use of traditional paper-and-pencil activities, and to analyze their impact in various socio-cultural contexts. To do this, a quasi-experimental study was conducted with 271 students in three different countries (Brazil, Chile, and Costa Rica), in both rural and urban schools. A set of educational games for practising arithmetic was developed and tested in six schools within these three countries. Results show that there were no significant differences (ANCOVA) in the learning acquired from game-based vs. non-game-based activities. However, both showed a significant difference when compared with the traditional method. Additionally, both groups using the interpersonal computer showed higher levels of student interest than the traditional method group, and these technological methods were seen to be especially effective in increasing learning among weaker students.

Keywords

Cross-cultural projects, Intelligent tutoring systems, Shared display, Interpersonal computer, Arithmetic practice, Educational games

Introduction

Playing is, above all, a learning experience (Rosas, Nussbaum, Cumsille, Marianov, Correa, Flores et al., 2003). The use of computer games favors the development of complex thinking skills related to problem solving (Shih, Shih, Shih, Su, & Chuang, 2010), strategic planning (McFarlane, Sparrowhawk, & Heald, 2002), and self-regulated learning (Mayo, 2009). Computer games can also support different learning styles (Connolly & Stansfield, 2007), since speed and level of difficulty can be adjusted according to the player (Alcoholado, Nussbaum, Tagle, Gomez, Denardin, Susaeta et al., 2012).

In the past few years, parallel to the development of educational video games, strategies to optimize the use of technological resources have been developed with the goal of facilitating wide-scale adoption of technology in classrooms. In particular, the interpersonal computer stands out because of its low acquisition and maintenance costs (Kaplan, DoLenh, Bachour, Kao, Gault, & Dillenbourg, 2009). With an interpersonal computer, multiple users located in the same space share one output device, like a computer screen, but each user has their own input device that they use to interact simultaneously with the virtual world.

The interpersonal computer is very attractive for schools in developing countries, where computational infrastructure is an entry barrier (Trucano, 2010). Cost is a key element in the widespread adoption of technology in classrooms, which is the main reason why the interpersonal computer is such an attractive proposal: it centralizes resources by minimizing the amount of equipment and technical support required.

The use of multiple inputs has been studied by a number of researchers who have sought to demonstrate its effects on peers working with a single screen (Paek, Agrawala, Basu, Drucker, Kristjansson, Logan et al., 2004). The interpersonal computer bolsters the learning process when teacher and student are in the same physical space, since the technology does not just capture student attention and motivate them, but also significantly mediates the construction of concepts (Smith, Gentry, & Blake, 2012). The results show that children controlling their own input devices in a situation with shared screens are more active and therefore demonstrate less boredom and fewer disruptive attitudes (Infante, Weitz, Reyes, Nussbaum, Gómez, & Radovic, 2010). A fundamental aspect that favors interactivity among the students, and particularly their level of motivation, is the fact that the activity makes each of the students work with their own objects; each student controls their own input device, which forces them to participate and become protagonists of their own learning (Infante, Hidalgo, Nussbaum, Alarcón, & Gottlieb, 2009). When teaching arithmetic, Alcoholado et al. (2012) show that engaging in interactive practice on interpersonal computers facilitates learning more than using the traditional paper and pencil method. This suggests that this technology not only has economic advantages, but is also an effective educational tool.

Consistent with the above, and understanding the potentialities of using video games in the teaching-learning process, our first research question is: Within individual pedagogical activities in which arithmetic is practised using an interpersonal computer, what is the added value of a game in terms of student knowledge gained when compared with the same non-game-based activities and traditional paper-and-pencil activities?

On the other hand, according to Zaharias and Papargyris (2009), culture is a potentially important factor in deciding performance and user satisfaction with video games. Culture is also one of the factors that influence user preferences, according to Ramli, Zin, and Ashaari (2011). How to play and how to solve a video game challenge are activities commonly influenced by a player's background and environment (Fang & Zhao, 2010), which are in turn considered cultural values (Schumann, 2009). Thus emerges our second research question: Is culture a factor that influences learning and/or student interest when interacting with game-based activities on the interpersonal computer?

In the following section, we present a video game that makes use of an interpersonal computer to practise basic mathematics and study its performance compared to a non-game-based activity in three different cultural contexts. The experimental design is presented in Section 4, the results obtained in Section 5, closing with conclusions.

Game-based pedagogical mathematics activities for the interpersonal computer

Interpersonal-computer structure

Each student is assigned a cell on a shared screen (Figure 1), where they work individually, with no possibility of leaving the assigned cell. Through data persistence the system stores a record of each stage that a student completes. This allows each student to work at their own pace over various sessions. To facilitate the process of identification, each student is assigned a unique symbol, which appears on the screen (Alcoholado et al., 2012).

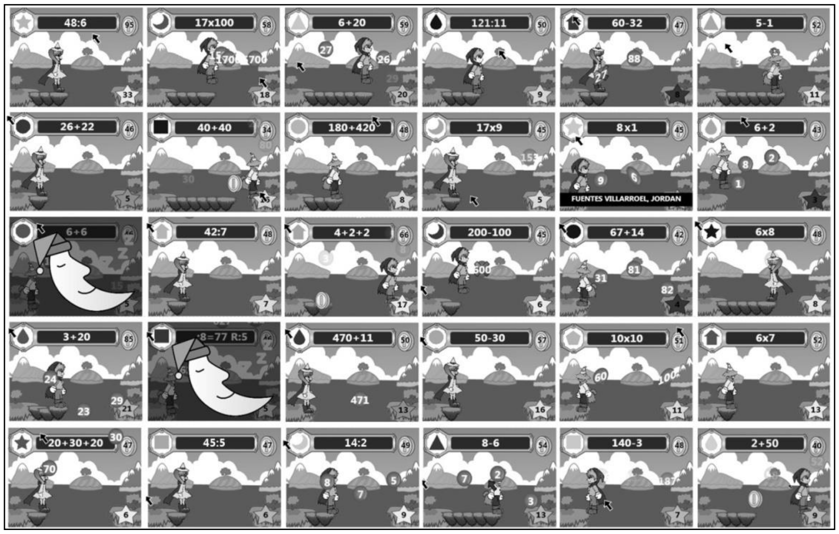


Figure 1. Shared screen

Considering that teacher mediation is essential, the system provides instant feedback of the state of each student via the same shared screen, which allows the teacher to identify which students need help and how they are doing. The teacher can support a specific student by moving his cursor freely across the screen to the workspace of said student. When the symbol identifying that student is chosen, it will show the student's name. This enables the teacher to interact with the student, either by using their cursor to guide the student on their individual screen or by working face-to-face with the student to help with the detected problem. It is the teacher's responsibility to review the student's incorrect responses.

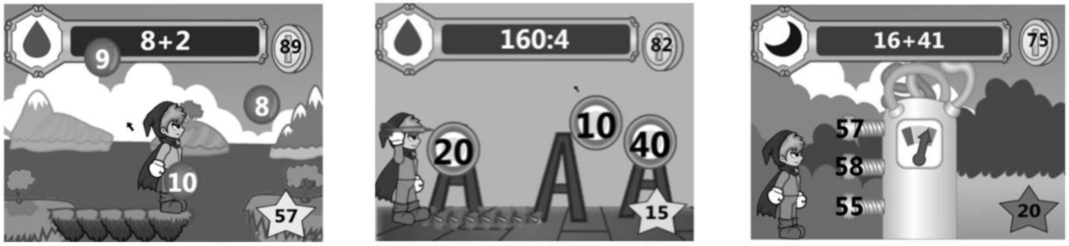
Game-based pedagogical design

The video game, designed to help students practise arithmetic, shows the student exercises according to their rate of progress. Given that its goal is to reinforce the student's mathematical knowledge and skills, this video game was designed to fulfill the characteristics of a test educational game (Li, 2012). It occupies a rule-based system: 18 for addition, 18 for subtraction, 13 for multiplication, and 16 for division (Alcoholado et al., 2012). The order of these rules follows the sequence defined by the Chilean (Mineduc, 2009), Brazilian (MEC, 1997), and Costa Rican (MEP, 2005) curricular frameworks, respectively. The number of exercises assigned for each rule depends on the skill level of each student. In order to move on from a concept, that is, a rule, the student must successfully solve at least ten consecutive exercises or eight exercises out of at least fifteen, with the last three exercises being correct (Alcoholado et al., 2012).

According to Sweetser and Johnson (2004), a video game's narrative is important in attracting players to the game and keeping them immersed, since it provides the players with a plot and background and makes them feel like part of the story. The game's narrative, used as much to develop the story (Qin, Rau, & Salvendy, 2009) as to solve problems, can be divided in two parts:

- Story—At the beginning of the activity, the teacher presents the story and general objective to the students (in a magical country a wizard stole their magical rocks, burying them deep in the ocean and forming small islands; the challenge is to explore the different islands with the goal of finding the stolen magic rocks and re-establishing geographic order.)

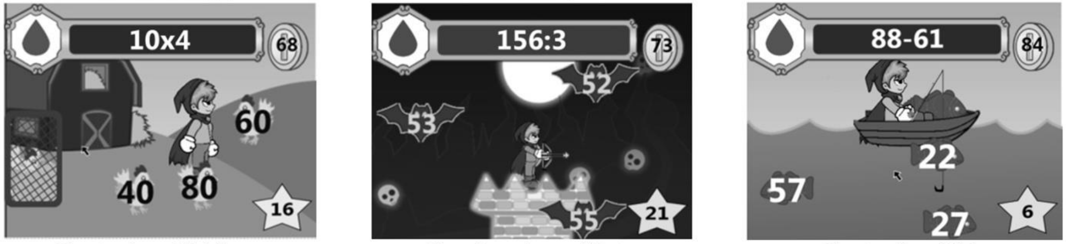
- Specific objectives—The objectives of the game should be transmitted clearly and directly to the player (Pagulayan, Keeker, Wixon, Romero, & Fuller, 2003). As the students explore the islands, they encounter various challenges represented by six different games related to the main story (Figure 2).



Building Bridges: (the avatar moves forward by adding pieces onto the bridge)

Pirate Ship (the targets in movement have to be correctly selected)

Dam (maintain the dam's pressure indicator in the green)



Capturing Chickens

Scaring Away Bats

Capturing Fish

Figure 2. Pedagogical Activities

Each individual's game space is composed of seven elements (Figure 3):

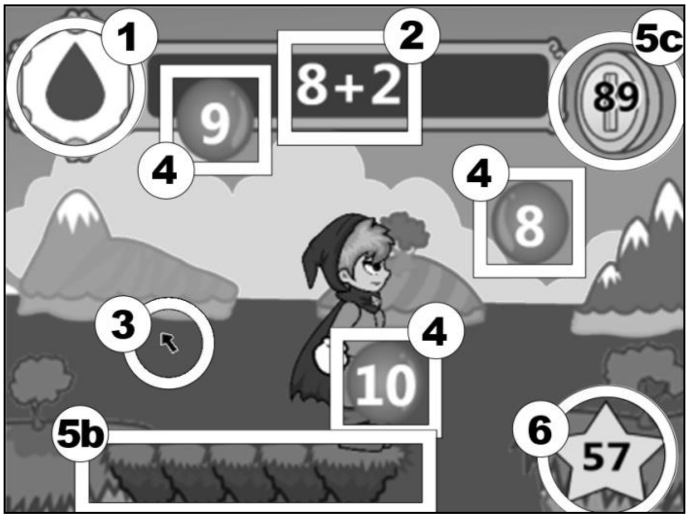


Figure 3. Individual game space

- Identification: Each player is assigned a unique colored symbol to identify them.
- Equation: Area displaying the mathematical equation that the student must complete.
- Player's pointer: Represents each child's cursor, which can only move within its own cell.
- Mechanics of the games: The goal of the game is for the child to choose the correct answer from a set of alternatives. For example, in Figure 3, the child had to choose the correct answer, 10, for the stated problem: 8 + 2. By maintaining the same simple mechanics for all of the games, we ensured that students needed only minimal skills to be able to play.
- Game rewards:

  Immediate results reward

  Players should always be able to see their results and their progress in the game with immediate access to all information regarding each player's actions. (Fu, Su, & Yu, 2009). This is achieved by using three animations that indicate when an exercise is answered successfully (Figure 4a), when a level of the game is completed successfully (Figure 4b), or when an exercise is answered incorrectly (Figure 4c). In this last case, the question can be re-submitted until the student responds correctly.

  Immediate progress reward

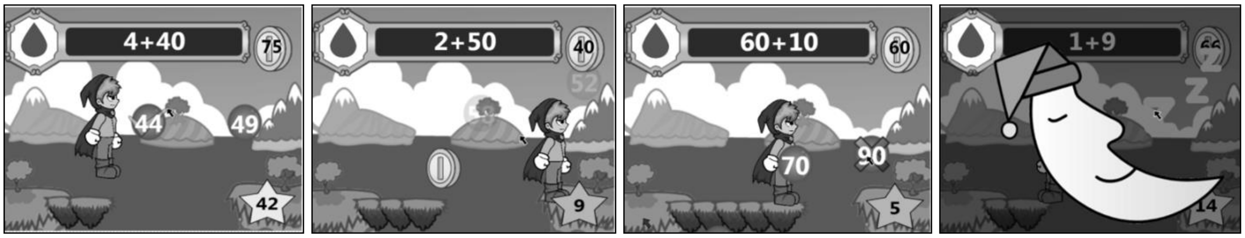
  To improve their mastery of the game, feedback is given to represent the child's progress (Federoff, 2002; Fu, Su, & Yu, 2009). After each player's action, the game displays a positive or negative reward so that the player can observe their own progress and see how close they are to reaching the goal (Fu, Su, & Yu, 2009). For example, in Figure 3, progress in the game is indicated by increasing or decreasing pieces of the bridge in relation to whether the player answered correctly or incorrectly. In Figure 2, "Capturing Fish," the fish either jump into the boat (correct answer) or fall out of the boat (incorrect answer). The level ends when the student accumulates seven pieces of the bridge in the first example or catches seven fish in the second example.

  Accumulated reward

  The total rewards earned in each session are awarded for each correct answer (coins) and for each completed level in the game (medals). For example, in Figure 3, 89 coins have already been accumulated.

- Pedagogical feedback: Information mainly for the teacher. Represents the number of questions answered in the session, with colors indicating achievement: green indicates 66.6% or more correct answers, yellow indicates 33.3%–66.6% correct answers, and red indicates 33.3% or less correct answers.
- Alert: In the case of a child who does not take part in the activity, that is, is inactive for more than 120 seconds, a sleep symbol is displayed in their cell (Figure 4d).

At the beginning of the first session, each student chooses their avatar, i.e., their character for the game, which, according to Anneta (2010), allows the players to identify themselves as individual members of the community of game-players. There are three types of avatars available: male, female, and animal (Figure 5), all drawn in the style of a children’s cartoon. This style was chosen following a study of 45 school children from the same grade level as the students in this project. Findings showed that 90% of children preferred the cartoon style to a more realistic one, while 80% preferred a more child-like aesthetic to an adolescent one.



(a) (b) (c) (d)

Figure 4(a) Positive feedback, (b) Game progress feedback, (c) Negative Feedback, and (d) Inactivity

Figure 5. Avatars

Considering the reduced size of each cell, and taking into account the suggestions made by Federoff (2002), the interface was developed to be as simple and unobtrusive as possible to facilitate use of the video game and reduce unnecessary cognitive processing (Pilke, 2004). The more intuitive the video game-player interaction is, the greater the possibility that “flow” will exist.

A video game is adequate when it creates flow, which allows a child to maintain interest in the game (Csikszentmihalyi, 1990; Annetta, 2010). An educational video game should strike a balance between fun and educational value (Prensky, 2003). The teacher is in charge of regulating the game-based dimension, since the child progresses through the different levels based on the teacher’s observations of the student’s needs, while the pedagogical requirements are regulated by the previously established system of rules. In order to do so, the teacher must decide which of the secondary narratives (i.e., the various games) to choose and when.

Non-game-based pedagogical activity for practising arithmetic using the interpersonal computer

The non-game-based individual interactive pedagogical activity using the interpersonal computer (Figure 6) allows up to 49 students in the classroom to work at their own pace, simultaneously, using a PC, a projector, and one mouse per child. Both the game-based and non-game-based activities were designed for practising arithmetic; both generate activities in line with the progress of each student by using the same intelligent tutoring system (Alcoholado et al., 2012). Each of the non-game-based applications’ individual spaces consists of six elements (Figure 7):

- Equation: Area showing the mathematical equation that the student must complete.

- Answer construction: The child must assemble each digit by increasing or decreasing the indicated number.
- Player's pointer: Represents each child's cursor, which can only move within their own cell.
- Identification: A unique colored symbol is assigned to every player. This serves two purposes: identifying the student's work area, and serving as a button with which to confirm the final answer.
- Individual answer feedback: Once a student has confirmed their answer, feedback appears in the middle of their cell. There are three types of feedback: correct answer (Figure 6, column 2, row 4), incorrect answer (Figure 6, column 1, row 2), and medals that correspond to the completion of the level and appear once the last question in the level is correctly answered (Figure 6, column 3, row 5).
- Alert: If a student's mouse remains motionless for 60 seconds, a symbol denoting inactivity appears (Figure 6, column 2, row 1). If this continues for more than 120 seconds, the cell's background turns the same color as the symbol (Figure 6, column 2, row 3).

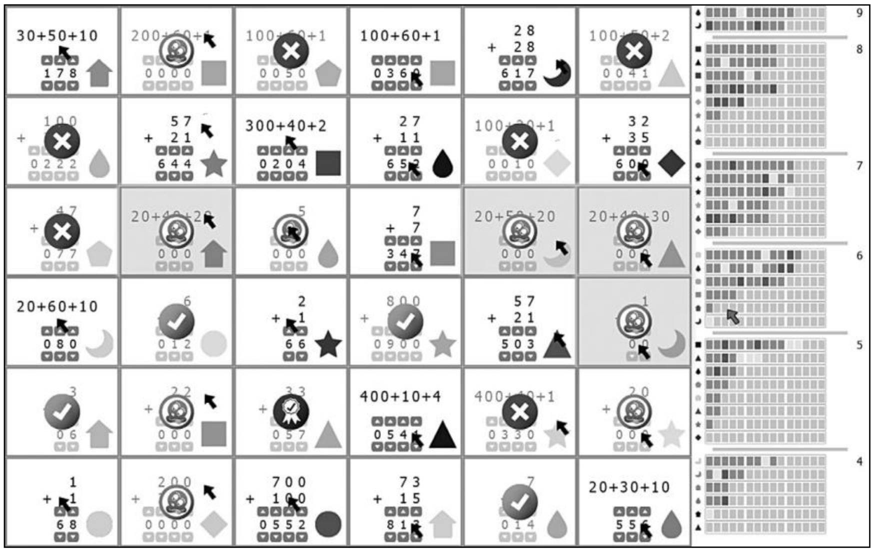


Figure 6. Shared screen from the non-game-based application

As with the gamed-based version, this application uses data persistence to store the point reached by each student once their respective session draws to a close. This allows each student to work at their own pace throughout the different sessions. The status of each student is also visible, (Figure 6, last column in the right) enabling the teacher to mediate either individually or across the entire group, as they deem necessary.

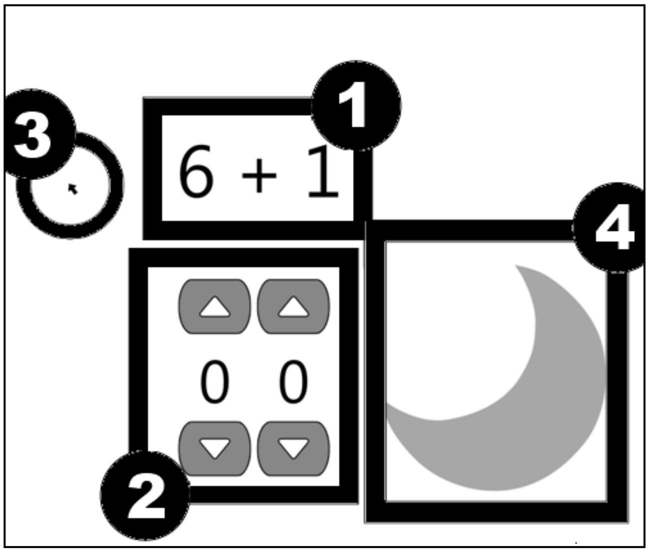


Figure 7. Individual space from the non-game-based application

Experimental design

We designed a quasi-experimental study about teaching arithmetic to third-grade students in order to answer our research questions. Three types of groups were created, one per class, based on the type of technology used to practise arithmetic, as seen in Table 2. The first group used the game-based version (Figure 3), the second group used the non-game-based version (Figure 7), and the third group used the traditional method (with paper exercises). Because not all of the participating schools had three third-grade classes, the game-based version was prioritized over the non-game-based version and the latter over the traditional method.

In order to respond to our second research question, regarding the influence culture has on knowledge acquisition and student interest in a technology-mediated learning process, we must first note that we are operating under the UNESCO definition (2001): "Culture should be regarded as the set of distinctive spiritual, material, intellectual and emotional features of society or a social group, and that it encompasses, in addition to art and literature, lifestyles, ways of living together, value systems, traditions and beliefs." From this broad definition, we have identified two characteristics that affect the interaction between a social group and mediating technology: 1) socioeconomic and rural/urban context and 2) exposure to technology.

In regards to socioeconomic context, three Latin American cities were selected for the study: Santiago, Chile; Guaratinguetá, Brazil; and San Ramón, Costa Rica. In each of these cities, both a rural and an urban school were selected. However, this was not possible in Brazil, since in the rural location there were no schools with at least two third-grade classes representative of the region. Table 2 indicates the class characteristics of all participating groups. These countries were selected based on their varying experiences with the aforementioned characteristics (ECLA, 2010; ITU, 2013).

Table 1 illustrates how the participating schools from rural areas stand out for their prevalence of agricultural labor, whereas the urban areas mainly depend on service industry jobs. There were computer laboratories in all the urban locations (and in the rural Chilean school), but only enjoyed frequent use in the cases of Chile and Brazil. In this context, we considered the existence of computer labs an indicator of the pervasiveness of technology. However, the technology required for the experiment was provided by the authors. As sampling bias can affect the quality of an experiment's results, care was taken that each of the six participating schools fell within the average range for national educational quality.

Table 1. School and location data

	Chile		Brazil		Costa Rica	
	Rural	Urban	Rural	Urban	Rural	Urban
# of students in the school	600	1690	120	495	400	645
# of classes at the school	18	47	6	16	16	26
Computer laboratory	Yes	Yes	No	Yes	No	Yes
Frequency of computer laboratory use (per week)	1	1	-	2	-	-
Professional profile	Farmworkers	Workers and housewives	Farmworkers	Service industry workers	Farmworkers	Housewives and service industry workers

For every school, a total of eight sessions of approximately 45 minutes each were conducted, distributed over time according to the school's availability (between three and six weeks). The study was broken into eight experimental sessions in order to approximate the context in which students practise arithmetic; in the participating schools most students have close to eight arithmetic practice sessions in a one-month period. In all the participating classes, a pre-test was applied at the beginning of the experimental study. This consisted of an individual evaluation of each student's previous knowledge of mathematics, for a maximum of 45 minutes. This evaluation contained 45 addition, subtraction, multiplication, and division exercises designed to identify the third-graders' skills (Alcoholado et al., 2012). At the end of the eight sessions, a post-test was conducted with the same instrument and under the same conditions. In order to ensure the reliability of these (pre- and post-test) instruments, they were analyzed for each of the participating classes according to the Cronbach's alpha criteria, Table 3. According to Bland and Altman (1997), a value of higher than 0.6 for Cronbach's alpha indicates that the applied test is acceptable for classifying students, based on the content delivered. Furthermore, these instruments were carefully reviewed by each of the teachers whose classes participated, so as to confirm both the validity of the pedagogic content and its effectiveness in terms of measuring knowledge acquired.

Table 2. Class characteristics

	Chile					Brazil				Costa Rica			
	Rural		Urban			Rural	Urban			Rural	Urban		
Type	Game-based	Non-game-based	Traditional method	Game-based	Non-game-based	Game-based	Traditional method	game-based	Non-game-based	Game-based	Traditional method	Game-based	Non-game-based
Students in the class	36	32	32	35	36	22	27	19	23	28	23	24	25
Participating students	28 (15, 13)	25 (12, 13)	25 (18, 7)	25 (14, 11)	22 (10, 12)	19 (10, 9)	18 (10, 8)	17 (9, 8)	16 (7, 9)	17 (8, 9)	20 (9, 11)	18 (10, 8)	21 (12, 8)
Hyperactive student ratio	0.08	0.06	0.09	0.06	0.08	0.09	0.11	0.21	0.13	0.04	0.09	0.08	0.12
Mean student attendance	7.26	6.6	-	6.76	7.55	6.85	-	6.74	6.81	6.39	-	6.17	6.05

The participants, both girls and boys (indicated in the second row of Table 2, with the number of girls being the first number in the pair), were taken from third-grade classes and ranged in age from eight to ten years old. The discrepancy between the number of students in each class and the number of students that participated (in the experiment) was caused by the way "participant" was defined; only those students who took the two assessments (pre and post) were considered participants.

This experiment also took into account the presence of hyperactive students, classified as such by their respective teachers. These students stand out from the rest of their classmates based on their high activity levels within the classroom. The hyperactive student number in Table 2 indicates the hyperactive student/total student ratio in each course. This information is relevant to the study because hyperactivity can influence the behavior of the rest of the class and lead to disruptions.

To ensure that the intervention was similar for all the students, we calculated the mean student attendance (Table 2), which corresponds to the average number of sessions attended by the students in each class. This value was obtained from the data recorded by the system during each session. The difference between the minimum and maximum number of sessions attended by the students in each of the groups was not significant.

The longest the experiment lasted was six weeks, in the rural Chilean school, because of the number of national holidays during the experimental period. The shortest time was three weeks, which occurred in the urban Costa Rican school, due to the restrictions imposed by the school that hurried the conclusion of school activities. In the rural Costa Rican school, from the fifth session onwards, a significant number of students did not attend the activities due to the start of the coffee-harvesting season. This made it impossible to apply the post-test, which impeded the non-game-based experiment from being fully concluded. Interestingly, however, at the same rural school in Costa Rica where the non-game-based experiment was cancelled, it was possible to carry out the game-based experiment in conditions similar to the urban Costa Rican school. The staff from all the classes indicated that in general, attendance was above average compared to a regular day.

Quantitative and qualitative data collection for this study was done in three different ways: through paper instruments (pre-test, post-test, and questionnaires); through information regarding work the students completed in both technology groups, which was stored by the system; and finally, through in-person observations of the students' behavior and interactions. This was handled by three observers in each country, who used the same observation guideline during all the sessions. Additionally, all activities were taped to later validate the observed results. All of the data was then processed using a spreadsheet.

Results

Quantitative results

At the end of the experimental study, a comparative analysis was conducted with the data collected by the instruments described above. The results of the pre- and post-test are shown in Table 3, together with the *t*-test and the increment between groups (Δ% group). The latter corresponds to average student progress for each group, calculated to evaluate the difference between the pre- and post-test results.

For all samples, the applied pre-tests obtained a Cronbach's alpha greater than 0.74, except for the rural Brazilian group, which only reached 0.52 and was therefore removed from the sample.

Table 3. Pre-test and post-test results

Country	Location	Type	t-Test	Pre-test		Post-test		Δ% Group	Cronbach's alpha
				$\bar{x}$	s	$\bar{x}$	s		
Chile	Rural	Game-based	< 0.001	26.70	6.85	30.26	8.23	13%	0.91
		Non-game-based	< 0.00001	28.24	9.58	31.68	9.91	12%	0.92
	Urban	Traditional method	< 0.001	12.35	5.99	14.39	6.38	17%	0.88
		Game-based	< 0.0001	13.64	5.31	16.36	4.67	20%	0.74
		Non-game-based	< 0.0001	11.09	5.14	13.95	4.80	26%	0.85
Brazil	Urban	Traditional method	< 0.001	29.83	9.68	33.78	8.54	13%	0.94
		Game-based	< 0.001	23.06	9.48	27.06	9.70	17%	0.93
		Non-game-based	< 0.001	28.19	9.64	32.63	9.24	16%	0.93
Costa Rica	Rural	Game-based	< 0.0001	18.94	5.68	23.71	5.11	25%	0.79
	Urban	Traditional method	< 0.00001	19.15	8.98	22.25	8.28	16%	0.93
		Game-based	< 0.001	17.06	8.56	20.50	8.74	20%	0.91
		Non-game-based	< 0.001	19.67	5.64	23.62	7.40	20%	0.78

Statistical significance was measured for each group by the *t*-test, which found significant results between the pre- and post-tests, as shown in Table 3. A one-way analysis of covariance (ANCOVA) was undertaken to compare the effectiveness of the various types of work groups (game-based, non-game-based, and traditional method). This analysis indicated a significant difference between the three groups ($F = 3.292$, $p < .038$). Upon analyzing the ANCOVAS of the paired off groups in Table 4, we observed a significant difference between the game-based and traditional method groups and the non-game-based and traditional method groups, but found no significant difference between the game-based and non-game-based groups. In Table 4, we indicate in parentheses the sample size, degrees of freedom, effect size, and the differences between the adjusted averages obtained from the paired-off groups' ANCOVAS, in cases of significant difference. We conclude that both technologies had a similar impact, with a significant difference arising in the traditional method group in terms of the student knowledge acquired.

Table 4. ANCOVA analysis of the three paired-off groups

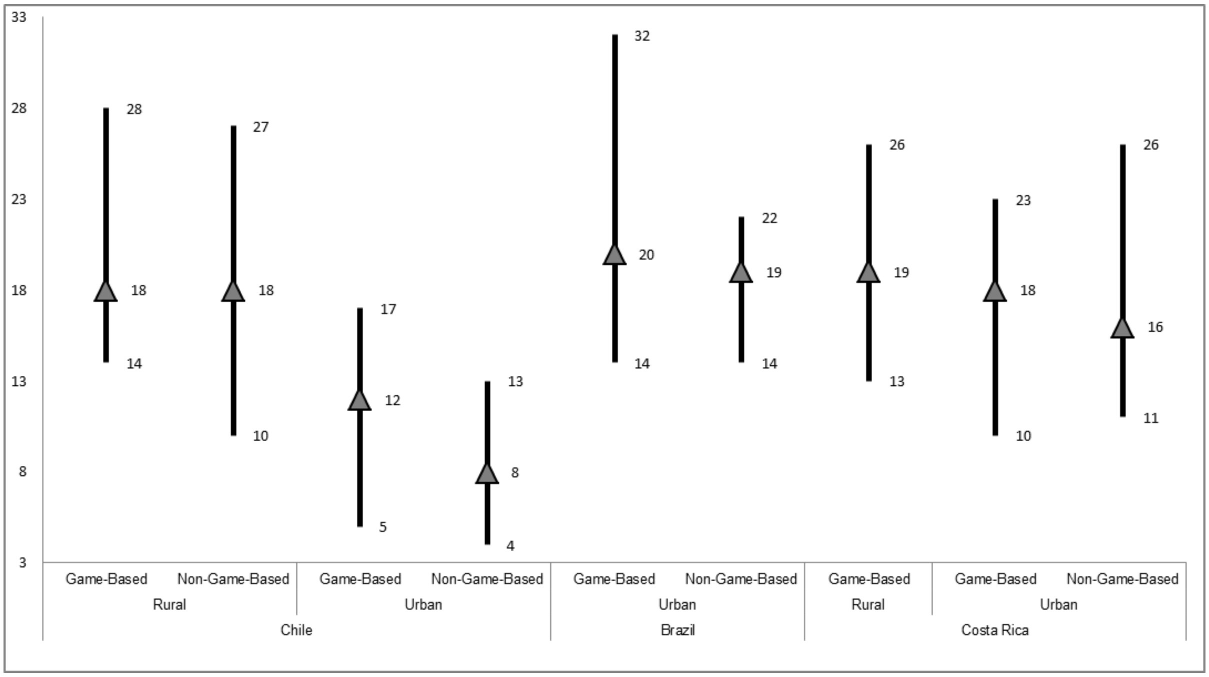
Group	Non-game-based	Traditional method
Game-based	$F = 0.968$, $p < .326$ (191, 189, -, -)	$F = 3.865$, $p < .048$ (170, 167, 0.22 small, 3.185)
Non-game-based	-	$F = 6.723$, $p < .010$ (147, 144, 0.30 small, 4.887)

Given that there was not a significant difference between the two technology groups, we aimed to analyze the learning impact based on previous knowledge. To do so, students from both experimental groups (game-based and non-game-based) were separated according to whether their performance in the pre-test placed them in the top or bottom half of their group, thus resulting in two groups: top-half and bottom-half. A one-way analysis of covariance (ANCOVA) indicated a significant difference between these groups ($F = 6.150$, $p < .014$). By analyzing the difference between the two groups' adjusted pre- and post-test averages, we observed a difference of 7.813 points in favor of the bottom-half group over the top-half group, when compared to the average progress of both. As such, we conclude that the learning impact was significantly greater among students who were initially in the less knowledgeable half of the group.

Finally, the impact of the technological resource's effectiveness regarding knowledge acquired in each one of the studied countries (Brazil, Chile, and Costa Rica) was investigated as a way of measuring cultural differences. A one-way analysis of covariance (ANCOVA) indicated a significant difference between the three countries ($F = 6.251$, $p < .002$). This result has been repeated to analyze the ANCOVA of the three countries paired off against each other (Brazil/Chile $F = 4.961$, $p < .027$; Brazil/Costa Rica $F = 4.019$, $p < .048$; Chile/Costa Rica $F = 7.603$, $p < .006$). The differences between the adjusted ANCOVA averages of three paired-off countries indicate that the impact of student knowledge acquired was greater for children in Brazil, followed by Costa Rica, and finally Chile (Brazil/Chile—7.144; Brazil/Costa Rica—1.249; Costa Rica/Chile—5.894). It should be noted that these findings are coherent with the average difference between each country's pre- and post-test, Table 3.

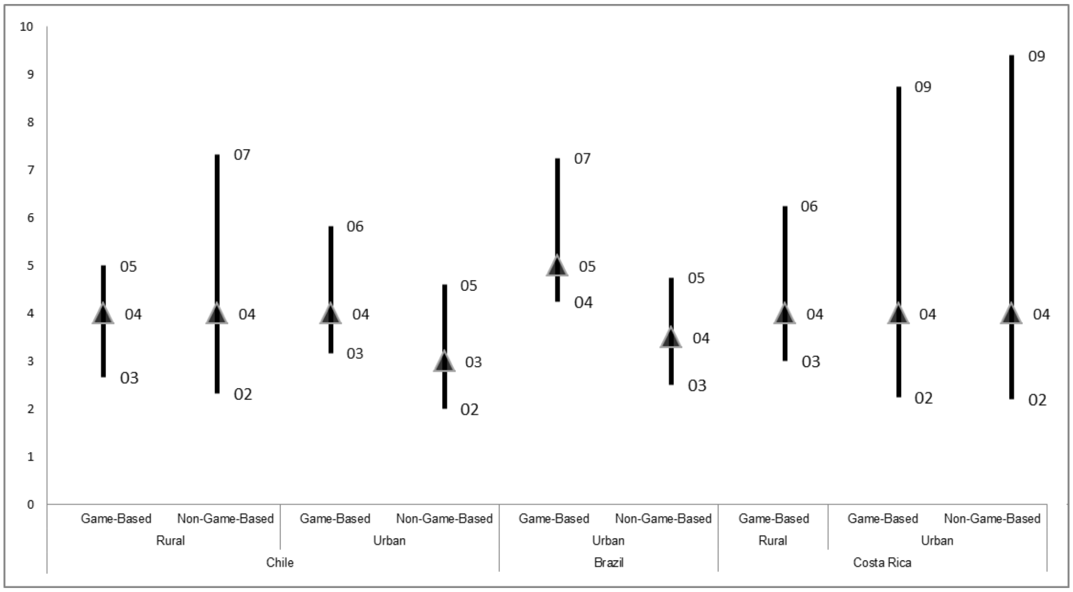
In all three countries, the technological groups (game-based and non-game-based) consistently obtained better results than the traditional method groups. For all the technological groups, the pre-test results had a –0.85 correlation with the final results (Table 3, Δ% group); the lower the scores obtained on the pre-test (Table 3, pre-test) by the group, the higher their scores post-test, which indicates that the application was more effective for the weaker groups.

Graph 1 illustrates each child's progress by the end of the experience, measured in pedagogical rules (Y axis), for each one of the schools studied (X axis). Three values are indicated for each school: the greatest is the average of the 25% of those students who, at the end of the experiment, had made the most progress in the number of pedagogical rules, while the lowest corresponds to the average of the 25% of students who made the least progress in the pedagogical rules. The value located between the previous two values (next to a triangle) corresponds to the median of this group. As the results in Table 3 illustrate, the medians of the game-based and non-game-based classes of comparable pairs are similar. Looking at the totality of the medians, there exists a correlation of 0.77 with the pre-test; the higher the pre-test score, the greater the class median.



Graph 1. Distribution of pedagogical progress levels during the entire experiment

The time required to learn how to use each pedagogical activity, whether game-based or non-game-based, is calculated by the number of arithmetical operations successfully applied per session, and is directly related to the number of pedagogical rules undertaken per session. Graph 2 shows the progress at the end of the first session, measured in pedagogical rules (Y axis), for each one of the participating educational institutions (X axis). The format of the graph used is the same as Graph 1. We observed that, in comparative contexts, that is, between urban school classes or rural school classes within the same country, the students using the game-based application progressed in the lower to medium range, which is similar to those using the non-game-based application. The exceptions being urban Brazil, which presented the greatest difference between the experimental groups' pre-tests, and urban Chile, which presented the lowest pre-test scores. The case of Brazil can be explained by the differences observed in the pre-test, whereas in Chile it could be due to the differences observed in the exposure to technology (see Table 5) as much as it is to the low pre-test scores when compared to all the other classes. We conclude that the time required to learn how to use both technologies was similar. Therefore, the necessary required abilities were similar to both technologies under study. However, this time period is also related to the arithmetic and technological ability of the children. It should be noted that of the 45 minutes available in the first game-based session, approximately ten of these were used to introduce the game-based narrative, which decreased the time available for practising arithmetic activities and, therefore, negatively affecting students' progress.



Graph 2. Distribution of pedagogical progress levels during the first session

Qualitative results

A questionnaire composed of four questions was given at the beginning of the activity to evaluate the prevalence and use of technology between the different countries and schools, Table 5 first four questions. This test was validated previously by applying it to 85 students at two Chilean schools (one urban and one rural), with the goal of defining the necessary set of questions and possible answers needed to classify the students.

Table 5. Exposure to technology and interest in the activity

	Chile				Brazil		Costa Rica		
	Rural		Urban		Urban		Rural	Urban	
Questions	Game-based	Non-game-based	Game-based	Non-game-based	Game-based	Non-game-based	Game-based	Game-based	Non-game-based
Was the first time you played a video game before you were six years of age?	45%	48%	55%	65%	52%	59%	41%	48%	44%
Do you play video games at least six times a week?	66%	69%	72%	75%	65%	73%	44%	47%	53%
Do you have a computer at home?	44%	35%	67%	75%	73%	71%	33%	57%	56%
Do you have an Internet	32%	36%	60%	66%	61%	53%	37%	23%	25%

connection at home?									
Did time pass quickly while I was playing?	85%	88%	68%	50%	67%	65%	80%	82%	75%
Did I forget I was in class while playing?	82%	78%	76%	64%	65%	61%	76%	86%	82%
Do I want to keep playing?	94%	92%	88%	60%	97%	85%	99%	98%	85%
Did I have a good time while I was playing?	95%	92%	89%	76%	98%	87%	99%	97%	92%
Is it fun to play?	82%	75%	81%	76%	71%	67%	94%	89%	82%

It can be observed that at least 41% of the students had their first experience with video games before they were six years of age, and that, except for Costa Rica, at least 65% of the students use this technology six times or more per week. Costa Rica presented the lowest values in all the indicators, and the rural locations presented a lower prevalence of computers.

A second questionnaire applied at the end of the experience studied student interest in the activity (Table 5, last four questions). We can see that the classes with the game-based activities had a higher level of interest when compared to non-game-based classes, for all the locations. There exists a –0.87 correlation between the exposure to the technology questionnaire results and the results from the student interest questionnaire. This shows that the less exposure a group had to technology, the more interested they were in the activity. Additionally, the observers noted an important difference in the reactions of students with greater and lesser exposure to technology. While the former reacted normally, the latter showed greater astonishment. When considered alongside the previous results, this suggests that the more accustomed students are with technology, the more demanding they will be.

In order to measure social interactions, the following student behaviors during each experience were quantified and registered: disruptive behavior; proactive responses to received feedback; lack of understanding of the activity; cooperation/assistance among peers, and satisfaction at having participated in the activity. The first four behaviors were registered the moment they occurred, while the last one (satisfaction) was recorded at the end of each session. Table 6 shows the average number of observations registered per child, and the children’s most representative quotes for each of the defined student behaviors.

Taking into account how cultural differences can influence perspective, the observers in each of the three countries were trained to maintain standardized observation criteria by analyzing various initial test videos. These videos showed children in Chile and defined which aspects of behavior to observe and their corresponding rubrics. The person in charge of these trainings also acted as a supervisor during the observations, and was present in all the activities in each of the three countries.

Table 6. Observed social behaviors (average occurrence per child in the experiment).

Observed behavior	Chile				Brazil		Costa Rica		
	R GB	R NGB	U GB	U NGB	U GB	U NGB	R GB	U GB	U NGB
Disruptive behavior: intentional interruption of the flow of their own activity or that of their peers.	3.9	6.4	3.1	8.8	6.3	3.5	10.0	6.7	11.1
	Examples: “Teacher, can I go to the bathroom?” “Teacher, I don’t want to play anymore.” “Aren’t there any other games?” Bothers or talks to classmates.								
Proactive response to receiving feedback: the student’s positive and spontaneous expression immediately after receiving the system’s feedback.	13.7	8.8	18.7	11.5	18.4	9.8	58.5	57.7	54.7
	Game-based examples: “I finished the bridge!” “I won three coins!” “I have N chickens.” Non-game-based examples: “I've earned N medals.” “I have all green scores.”								
Confusion regarding the activity: doubt	1.7	3.8	1.4	3.0	9.3	13.9	5.7	1.5	3.5
	Examples:								

expressed in a loud voice when presented with a pedagogical task.	“Teacher, how much is X + Y?” “Teacher, how do you do this?” “I don't know how to add this.”								
Peer cooperation/assistance: peer communication with the goal of helping or asking for help with a pedagogical task.	4.1	3.2	9.9	6.8	5.5	3.6	2.1	1.8	1.2
	Examples: A student teaches another how to answer a question. A student demonstrates a different way to answer a question. “That's not how you do it . . . Look, . . .” A student gives an answer to another student. “Put 54! 54!” Game-based examples: “Who is the red star?”								
Observed behavior	Chile				Brazil		Costa Rica		
	R GB	R NGB	U GB	U NGB	U GB	U NGB	R GB	U GB	U NGB
Satisfaction at participating in the activity: student’s positive and spontaneous expression immediately after finishing the session.	46.8	34.8	35.2	21.3	35.9	30.7	75.6	71.4	63.0
	Game-based examples: “Teacher, look! I got the green star!” “In this stage, I earned N medals!” Non-game-based examples: “In this stage I earned N medals.”								

The teachers commented that the children tended to be very concentrated on their own personal space, presenting lower levels of disruption than in traditional classes. In addition, comparing Table 2 and 6, we observed that the groups with the game-based activity had the lowest average occurrence of disruptive behaviors in each of the countries—except in the Brazilian urban school, which had a higher ratio of hyperactive students. We also observed a greater number of proactive responses to the feedback received in the game-based classes. Using feedback as a narrative element enabled the students to become more involved in the pedagogic activities. In the game-based activities there were also fewer expressions of confusion because students were more immersed in the activity. It is worth noting that in Brazil there was a greater number of expressions of confusion, but considering that the median in the pedagogic rules completed by each student was greater, the children were exposed to more complex activities that required greater student-teacher interaction. Correspondingly, there is more frequent cooperation/assistance among peers in the game-based activities. The cooperation/assistance among peers has a 0.78 correlation with the questionnaire about exposure to technology. That is, the more familiar students are with technology, the greater their tendency to cooperate. In accordance with the above and with the correlation obtained between exposure to technology and interest in the activity (Table 5), a correlation of –0.87 resulted between exposure to technology and degree of satisfaction with the activity.

Conclusions

Our first research question asked: Within individual pedagogical activities in which arithmetic is practised using an interpersonal computer, what is the added value of the game in terms of student knowledge gained when compared with the same non-game-based activities and the traditional paper and pencil activities? In this paper we have proved: 1) that there was no significant difference between the final results of the game-based and non-game-based systems. This shows that the game’s narrative and graphics did not impact learning when compared with the technology used in the other technological activity. 2) The game-based activity did, however, distinguish itself by capturing greater student interest, which led to greater involvement in the activity. 3) The traditional method group, with no technology, was shown to produce consistently inferior acquired knowledge results when compared to the technological groups. This was principally due to the fact that the technological systems could provide immediate and individualized feedback for each student. 4) In terms of knowledge acquired, the technological systems proved to be more beneficial for the students who were considered weakest at the beginning of the experiment.

Our second research question asked: Is culture a factor that influences learning and/or student interest when interacting with game-based activities on the interpersonal computer? Regarding acquired student knowledge, we were able to observe a significant difference between countries. Such difference may be explained by the different technology appropriation and usage levels in the respective school contexts, factors that correspond to the degree of fluidity that the students have as they interact with the application. Only in Chile did we observe children quickly familiarizing themselves with the game's narrative and, without being prompted, expressing excitement when completing the different stages. In Costa Rica, the number of student interjections regarding "Proactive responses to received feedback" and "Satisfaction of participating in the activity" was greater, but the intensity of the commentaries received was greater in Chile. This led us to conclude that children with less exposure to the game and technology achieved greater immersion; however, involvement is greater when the narrative is closer to the socio-cultural context of the child. Through the observations, we also noted that children from the game-based groups in Costa Rica, after finishing each of their sessions, asked each other about how far they had got in the game and ranked one another. This shows that in Costa Rica, the two game-based groups (rural and urban) transcended the narrative and naturally created an environment of healthy competition. We leave as an open question how a greater level of competitiveness among children could improve the results in the various cultural contexts. It should be noted that it was not possible to analyze the game-based component's added value by country due to the small sample size in each country.

Our results cannot be generalized; the samples were neither random nor representative of their countries. We leave as future work to develop a year-long randomized representative study to observe if this greater involvement translates into improved learning.

In the non-game-based version, the children had to construct the answers digit by digit, while the game-based version used multiple-choice. This led to a significant increase in students using trial and error. We leave as future work the development of game-based activities where the answers are not multiple-choice, to observe whether or not immersion is maintained and learning improved. An objective that was not fulfilled was the disconnection of students from their surroundings, whereby players become less conscious of their reality and of themselves (Fu, Su, & Yu, 2009). The interpersonal computer limits the game's mechanics (due to the low-pixel count that corresponds to each child and the lack of sound) and, therefore, more studies are needed to determine ways of creating more engaging activities for this platform.

The level of involvement and commitment of the children in the game-based groups after taking the post-test (on paper) was lower than the non-game-based group. One possible cause is the change of work environment, from video game to paper work. We leave as future work discerning how to evaluate the video game group with video games to observe if this improves their post-test. However, at the same time it is necessary to observe if these children are capable of transferring what they have learned to other mediums, such as paper.

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