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Does Educational Games Enhance Mathematics Performance in Sixth-Grade Elementary School Students?

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Abstract

This study aimed to determine whether educational games improve mathematics performance in elementary school students. Volunteers were 47 Costa Rican students from a public school, who were assigned to an experimental (EXP: educational games) or a control (CTRL: traditional class) group. Twenty games were created and nine experienced teachers provided expert judge validity assessed by Kendall's concordance coefficient (W). The EXP group completed 20 sessions (8 weeks) of 10-min games and following every game, students provided feedback. Before and after the treatment, students completed an official sixth-grade mathematics test. Two-way mixed ANOVA (assessments: pre-test, post-test by groups: EXP, CTRL) showed a significant main assessment effect. The W for teachers' feedback allowed to use the games indoors, and student's opinion following the games was considered 'very good'. In conclusion, 20 educational games failed to improve mathematics academic performance in sixth-grade students; however, students enjoyed the games and there was a trend to improve performance compared to a CTRL group.

Keywords: educational games; classroom; methods; exercise; mathematics test

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Introduction

A high academic performance in traditional core education subjects, including mathematics, is a concern in our modern society. However, the means to achieve the highest potential in students is not always correct. For instance, in some countries, curricular changes in schools include partial or total replacement of physical activity (PA) time to increase the number of lessons in core subjects in an attempt to improve academic performance (Kober & Rentner, 2011; Kohl et al., 2013). However, reducing the amount of PA may lead to impaired academic performance (Howie & Pate, 2012; Kubesch et al., 2009).

Another problem faced in the classroom is the perceived lack of motivation, attention, stress, and anxiety that students have for subjects, especially mathematics (Caviola et al., 2017; Luttenberger et al., 2018), a phenomena described as 'math phobia' (Brown et al., 1989). To change student's perceptions about math, teachers must implement new creative or renewed strategies during the educational process; for instance, educational games (EdGa), also known as academic games (Bragg, 2012; Giannakos, 2013). EdGa imply movement, thinking, enjoyment, decision making, and immediate feedback (Green & Seitz, 2015; Howie et al., 2014, 2015; Howie & Pate, 2012). These features could improve self-esteem, curiosity, motivation, engagement, and passion for studying. Besides EdGa, there is another strategy called 'game-based learning' (GBL) with the same purpose benefits; however, it relies sometimes on expensive technology unavailable in all societies (Setyaningrum et al., 2018).

Electronic devices such as computers, cellular telephones, and video games have turned into the most frequently used GBL method in the classroom. Nevertheless, the findings regarding their effectiveness aimed at improving academic performance are inconclusive (Fokides, 2018; Green & Seitz, 2015; Mahmoudi et al., 2015; Ritzhaupt et al., 2011; Setyaningrum et al., 2018). Thus, the biggest concern is not only whether technology is a reliable learning aid, but also if traditional educational materials (e.g., card decks, dices, table games) combined with PA (e.g., jumping, lunges, coordination) may provide benefits in core subjects like math in elementary school students. The evidence suggests a positive association between PA and cognitive tasks such as attentional focus, executive function, short-term memory, long-term memory, selective attention, learning effectiveness, activate participation, and academic performance (Bartholomew & Jowers, 2011; Chaddock et al., 2012; Donnelly & Lambourne, 2011; Have et al., 2018; Howie et al., 2015; Petri & von Wangenheim, 2016; Silveira & Villalba, 2018; Soga et al., 2015). Based on the evidence, it is hypothesized that academic performance would be enhanced if students are given more time and space for PA in the classroom.

A constraint for teachers when decide to implement new creative activities inside the classroom is time availability. For instance, time determines how much attention a topic receives or how much practice students will have for the test. One of the advantages of EdGa is that these can be used during classroom breaks. Indeed, 10- to 20-min of exposure to EdGa have shown to enhance academic performance (Hillman et al., 2009; Howie et al., 2014). For instance, Howie et al. (2015), reported that 10- and 20-min EdGa improved math performance in 9 to 12 yr. old children compared to a 5-min intervention. Also, Janssen et al. (2014), found that 60-min of regular classes followed by 15-min of moderate or vigorous intensity PA inside the classroom elicited higher attention scores compared to a control group (seated classroom lesson) and a passive break condition (listening to a story) in 10 to 11 yr. old children. Therefore, this hypothesis has been consistently reported in the studies by Alanazi (2020), Block et al. (2018), Grieco et al. (2009), Kubesch et al. (2009) and Mahar et al. (2006).

Abundant evidence studying the effects of EdGa on math performance have focused on topics such as math scores assessed on a computer (McNaughten & Gabbard, 1993), counting, number identification, and numerical magnitude (Ramani & Siegler, 2008), logic-mathematical thinking (Kamii & Rummelsburg, 2008), decimal fractions (Roche, 2010), math proficiency and motivation (Chang et al., 2015; Kebritchi et al., 2010), math fluency (Howie et al., 2015), attention, speed, learning, and stability (Chizary & Farhangi, 2017; Fokides, 2018; Mahmoudi et al., 2015), 90-sec math test (Block et al., 2018), line estimation, calculation fluency, and math competence (Vanbecelaere et al., 2020). Yet, there is scarce evidence on the effects of EdGa on real class math exams; for instance, Phillips et al. (2015), used 20-min of aerobic PA intervention in 14 to 15 yr. old students and found improvements between 11% to 22% on a math performance test assessed 30-min after the intervention.

Experimental educational studies performed in laboratory settings allow controlling several variables; for instance, noise control from classmates, public transportation, break times, etc.; however, those conditions are a threat to the external validity of these studies. Thus, researchers interested in evaluating a realistic effect of an intervention must perform the experiment in the actual class. Therefore, the purpose of this study was to determine whether EdGa used as a teaching aid for math classes would enhance the academic performance in elementary-school students. The hypothesis that lead our work was that EdGa would enhance math performance compared to a regular teaching methodology.

Material and Methods

Participants: Volunteers were 47 sixth grade students (Age = 11.7 ± 0.8 yr.) from a public school in Costa Rica. The students were randomly assigned to an experimental (EXP: EdGa math classes, n = 24, males = 11, females 13) and a control (CTRL: regular math classes, n = 23, males = 11, females = 12) group. Also, a nine-member expert judge panel of female teachers (41-45 yr. = 3, 46-50 yr. = 1, 51-55 yr. = 5) established content validity of the EdGa. An informed consent was obtained from the institution principal, teachers, students and parents to voluntarily participate in the study. The study protocol followed the ethical the principles set forth by the Declaration of Helsinki.

Instruments: Twenty math EdGa were submitted for validation; each game had the following features: name, objective, content, materials, activity description, exercise time, rules, variants, diagram, and materials (if needed). The game topics were chosen according to the contents taught for the first math exam on the third term: area of the circle, regular polygons, percentages, and the rule of three (Supplementary file). The EdGa were appraised by teachers considered experts judges before these were performed in the classroom. For the validity process each expert judge received one copy of the game and was asked to rate it using a 5-point Likert scale (1= poor, 2 = regular, 3 = good, and 4 = very good, 5 = excellent) designed by the study authors. The instrument consisted of 13 items: 1) The name is appropriate for the type of activity that will be developed; 2) The objective is related to the topic taught, contents, and participants; 3) Materials are specified; 4) The description is detailed, precise, straightforward and allows any teacher to use it; 5) Teacher and student roles are specified; 6) Present activities for evaluation or self-evaluation; 7) The time assigned for the activities is sufficient; 8) Rules for students and teachers are specified; 9) The game diagram is clear and understandable; 10) One or two variants for the game are mentioned; 11) The game level is appropriate for the student’s age; 12) The game can be performed indoors; and 13) The methodology agrees with pedagogical approaches.

After receiving feedback from the teachers, a classification of each game was made based on the total points: ≥60 (very good), 50-59.9 (good), 40-49.9 (regular, need adjustments), 30-39.9 (poor), and less than 39.9 (deficient). The games with scores between 65 and 50 pts. could be implemented in the classroom, the games between 40-49.9 pts. needed adjustments that must be considered to solve and submit them again for a second judge review. Finally, the games with scores <39.9 pts. were discarded. This methodological approach has been suggested before (Kerlinger & Lee, 2002). Another validation method was computed for these games, which is described in the statistical analysis section.

The students completed a brief questionnaire designed to determine their opinion about the EdGa based on six criteria: 1) Clear and precise instructions, 2) Appropriate materials, 3) The game was motivating and helped on my learning, 4) The game was consistent with the topic covered in class, 5) The game allowed my active participation on class, and 6) I understood the game. The maximum score achievable was 6 pts., which allowed to compute a total mean score per game and to build opinion categories: 5 to 6 (very good), 3 to 4 (regular), and <3 (bad) .

Procedures: After parents and children signed the informed consent, the next step was to coordinate with the teacher, the day and time to perform the EdGa. During each intervention, the students received 30-min of a math content, followed by 10 min of one EdGa. The game topic order was: 1) area of a circle, 2) regular polygons, 3) percentages, and 4) the rule of three. Then, other 40-min math class continued. After each game was finished, the students score them. The CTRL group only received regular math classes. The treatment lasted 8 weeks and the last day the students completed an official sixth-grade math test. The test assessed the topics implemented with the EdGa.

Statistical analysis: A two-way mixed ANOVA (assessments: pre-test, post-test by groups: EXP, CTRL) was calculated to compare academic performance on math. The Kendall's concordance coefficient (W) was used as a measure of consistency for the expert judge validation and for the students' assessment. In addition, the analysis was selected given the ordinal nature of the data, small teacher sample, small number of observations, few numbers of question for validation, and low variability in the answers registered. The W lies between 0 (complete disagreement) and 1 (complete agreement) (Kendall & Smith, 1939; Monge, 2020; Salkind, 2010). The goal of this analysis is to keep the null hypothesis (i.e., a concordance between observers). Statistical significance was set at $p \leq 0.05$, and data were analyzed using the Statistical Package for Social Sciences Software (SPSS, v. 24, IBM, Armonk, NY).

Results

ANOVA showed significant differences between pre-test and post-test in the EXP (CI95%: -26.6, -6.3; p= 0.002; η^2= 0.194) and the CTRL (CI95%: -23.6, -3.3; p= 0.010; η^2= 0.140) groups on math performance (Figure 1). No significant differences were found in either pre-test (CI95%: -6.0, 13.0; p= 0.465; η^2= 0.012) or post-test (CI95%: -2.4, 15.2; p= 0.148; η^2= 0.047) in the EXP and CTRL group. No significant percentage change was found between EXP (16.41 ± 24.47) and CTRL (13.48 ± 23.86; CI95%: -11.4, 17.3; p= 0.682) groups.

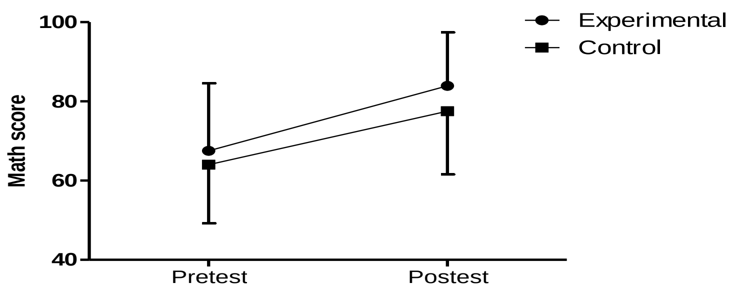

Figure 1. Comparison between groups on the math score test after 20 sessions with educational games.

The grading results for the 20 EdGa evaluated by the nine teachers (experts judges) and the 24 students using the questions from the instruments section is shown in table 1. From the teacher's perspective, all the games scored above 60 pts., classifying them as 'very good' games, with similar opinions from the students. The W coefficient showed that 12 out of 20 games (60%) showed evidence of concordance among evaluators. This means that almost all chose a value of 5 (very good) on the corresponding items to validate the EdGa. When no consistency was found it was due that one or two teachers chose 4 (good) and in very few opportunities 3 (regular). None of the games received a bad concordance evaluation (Table 2).

Table 1. Categorization on each game based on its mean by the teachers.

	Teachers		**Students**	
Game name	**Score**	**Category**	**Score**	**Category**
Dwarves and giants circumferential	62.5 ± 4.30	Very good	5.71 ± 0.55	Very good
Crazy ball	63. 2 ± 4.08	Very good	5.88 ± 0.45	Very good
Wild math	62.0 ± 4.64	Very good	5.88 ± 0. 34	Very good
Square-numerical memory	64.6 ± 1.27	Very good	5.88 ± 0.34	Very good
Puzzle with movement	64.1 ± 2.85	Very good	5.88 ± 0.45	Very good
Math activation	62.4 ± 5.48	Very good	6.00 ± 0.00	Very good
Polygons Bingo	63.5 ± 4.09	Very good	5.88 ± 0.34	Very good
Ingenious hangman game	64.8 ± 0.63	Very good	5.96 ± 0.20	Very good
Craziest number search	62.8 ± 3.91	Very good	5.96 ± 0.20	Very good
The Winning Ball	63.7 ± 2.75	Very good	6.00 ± 0.00	Very good
				continue
Discovering the hidden phrase	63.7 ± 4.11	Very good	6.00 ± 0.00	Very good
The watch with the rare numbers	62.7 ± 4.69	Very good	6.00 ± 0.00	Very good
I challenged you-I challenged you	64.5 ± 1.27	Very good	5.88 ± 0.45	Very good
The Magic Drawing	64.5 ± 1.58	Very good	6.00 ± 0.00	Very good
Throw the Rings	64.6 ± 1.27	Very good	5.79 ± 0.41	Very good
The colors are in charge	62.6 ± 5.08	Very good	6.00 ± 0.00	Very good
Find out where 'Pedro de los Palotes' was	64.4 ± 1.90	Very good	5.92 ± 0.28	Very good
Crazy scientific	64.5 ± 1.27	Very good	6.00 ± 0.00	Very good

Duel of the percentages	63.9 ± 2. 85	Very good	5.88 ± 0.45	Very good
Broken telephone	64.0 ± 3.16	Very good	6.00 ± 0.00	Very good

Values are mean ± standard deviation.

Regarding the students, the mean per game was above 5 that represents a ‘very good’ opinion (Table 1). To support this point, the Kendall’s W showed 80% (n=16) of concordance in the opinion obtained from the students, which qualifies them as ‘very good’ games. The lack of consistency for the 4 games were because some students chose a 4 (good) or 3 (regular).

Table 2. Kendall's Coefficient of Concordance (W) for each game for teachers and students

	Teachers		**Students**	
Game name	**Kendall’s W**	**p ≤**	**Kendall’s W**	**p ≤**
Dwarves and giants circumferential	0.31	0.001	0.18	0.333
Crazy ball	0.18	0.018	0.27	0.030
				continue
Wild math	0.41		0.001	0.16
Square-numerical memory	Perfect agreement		0.15	0.579
Puzzle with movement	Perfect agreement		0.27	0.030
Math activation	0.31	0.000	0.17	0.462
Polygons Bingo	0.08	0.433	0.16	0.542
Ingenious hangman game	Perfect agreement		0.17	0.462
Craziest number search	0.41	0.001	0.17	0.462
The Winning Ball	0.54	0.001	Perfect agreement	
Discovering the hidden phrase	Perfect agreement		Perfect agreement	
The watch with the rare numbers	0.18	0.018	0.33	0.003
I challenged you-I challenged you	0.08	0.433	0.17	0.462
The Magic Drawing	Perfect agreement		Perfect agreement	
Throw the Rings	Perfect agreement		0.18	0.366
The colors are in charge	0.31	0.001	Perfect agreement	
Find out where ‘Pedro de los Palotes’ was	Perfect agreement		0.16	0.520

Crazy scientific	0.08	0.433	Perfect agreement	
Duel of the percentages	0.15	0.420	0.27	0.030
Broken telephone	Perfect agreement		Perfect agreement	

Discussion

This study focused on the implementation of EdGa as a strategy to improve academic math performance in children between 11 and 12 yr. Although both groups increased the scores significantly from pre-test to post-test and no significant interaction effect was found. This study also showed that technology is not the only pedagogical approach to carry on benefits in teaching and learning process; pencil and paper methods could also be implemented.

Have et al. (2018) analyzed the effect of PA a math class in 450 children (7.2 ± 0.3 yr.) that were randomly divided into a CTRL and EXP groups. The EXP group received 6 math sessions of 45 min (at least 15 min of PA) per week for 9 months; the CTRL group received regular classes. Following the intervention, the EXP outperformed the CTRL group on a math skill test. Similarly, Mahmoudi et al. (2015), used a video game for math learning on first grade secondary school students and found that twice a week for ten session of 45 min improved speed and attention on math calculations. The lack of consistency in the results between those studies and the present one could be explained by the total amount of time that treatment lasted or by the game intervention inside the class.

Kubesch et al. (2009), analyzed the effect of PA in cognitive variables related with academic performance. Participants from 13 to 14 yr. old ran the Berlin Marathon virtually for 5-min or 30-min inside the classroom as a break. The results showed that 30-min rather than 5-min increased scores in cognitive variables such as inhibition, working memory, and cognitive flexibility, which suggest a dose-response pattern. These variables have also been directly associated with academic performance (Cortés Pascual et al., 2019; de Greeff et al., 2018). Therefore, more studies will be necessary to reach robust conclusions on whether games like those developed in our study could elicit significant math academic performance. Future experimental studies should consider using the same games and adjust the intervention length and the amount of weekly contact time to confirm the improvement trend found the EXP group.

The EdGa on a break during a math class brings an original, creative, enjoyable, interesting, emotionally stimulating, and different strategy for elementary school children (Bravo et al., 2013) because this strategy has been related with increased attention, concentration, academic behaviors, and academic achievement (Ahamed et al., 2007; Dishman et al., 2006). Why does EdGa have this effect? If we compare regular classes where teacher lectures and students take note or solve problems in their books against a class where games are used and at the same time not only emphasize math topics, but also give an opportunity enrich the learning environment (e.g., freedom to interact with the teacher, new topics, have fun, stop boredom), the answer is clear (Selvi & Öztürk Çoşan, 2018; Su et al., 2014). This was demonstrated in our study based on the positive opinions of the students over the games performed in the classroom. The games could be used at the beginning or ending of each topic to review, reinforce, and assess the progress; however, more solid, and consistent evidence is needed.

Other physical variables that have been tested and demonstrated an association with academic performance are the number of weekly PA classes and the exercise intensity (Ardoy et al., 2014; Carlson et al., 2008). Neither the number of weekly classes nor the intensity were considered in the present study.

There were some limitations in the present study. Pilot testing with the games was not performed. This might have allowed students to become familiar with the class dynamics. Assessment of psychophysiological (e.g., heart rate, anxiety, motivation), socioeconomic (incomes, home), and nutritional variables would have been necessary to help us explore potential mechanisms explaining the results. The validation process of the games must be improved, trying to get more feedbacks from teachers from different schools (private and public) and with that, perform more powerful statistical analysis like Cronbach's alpha, structural equation modeling, among others.

This study demonstrated that students who play pencil and paper games with an emphasis on math do not worsen their academic performance, on the contrary, their scores improve from pre- to post-test and possibly their opinion to this topic also changed positively. Technology is not the only resource who can keep students inside the classrooms, a combination of movement and educational options is another valid option to consider for teachers in elementary schools.

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Data Availability Statement: The datasets generated and analyzed during the current study are not publicly available but will be provided by the corresponding author on reasonable request.

Supplementary Materials*:* The 20 educational games are in Spanish and English language with their corresponding name, objective, content, materials, activity description, exercise time, rules, variants, diagram, and supplements. All of them are available as an open educational resource in OSF platform (available at: https://drive.google.com/drive/folders/1Yo56pBQExotRBrnmc29IA_Xy9nMxlhST?usp=sharing) and can be used by anyone.

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