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Effects of gamification on critical thinking in elementary school students

Efectos de la gamificación en el pensamiento crítico de estudiantes de Educación General Básica

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ABSTRACT

The objective was to analyze the effectiveness of gamification in the development of critical thinking in students of Basic General Education in the subject of mathematics. A quantitative, descriptive and comparative approach was used, based on a pre-experimental design (pre-test/post-test). The population included 74 students from the Abdón Calderón Educational Unit. A Critical Thinking Assessment questionnaire (23 items; α: 0.81) was applied. It contemplated the dimensions of interpretation, analysis, evaluation, inference, explanatory capacity and self-regulation. The gamification strategy had a playful and collaborative approach and included 10 face-to-face sessions, with durations ranging from 2 to 3 academic hours. The descriptive analysis included measures of frequencies and percentages by levels. For comparison, the non-parametric Wilcoxon Test (Wilcoxon-T) comparison test was used (H1: pretest < posttest; e.g. value < 0.05). Gamification had a significant impact on strengthening critical thinking. The findings demonstrate a considerable increase in skills at the level of dimensions and variable. The high skill levels of this type of thinking were significantly increased (Posttest > Pretest; e.g. value < 0.05). Evidence suggests that gamification, when carefully designed and implemented, has the potential to have a positive impact on the development of critical thinking skills. Comparisons between the pre-test and the post-test have shown significant improvements. The field of study also faces several challenges, including context dependence, measurement problems, and the need for careful design to avoid potential factors such as distraction or overemphasis on extrinsic motivation. There is also a need for longitudinal studies and to specify the ethical implications.

Keywords: Pre-experimental designs in education, Mathematics education, Gamification, Critical thinking

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RESUMEN

El objetivo fue analizar la efectividad de la gamificación en el desarrollo del pensamiento crítico en estudiantes de Educación General Básica en la asignatura de matemáticas. Se partió de un enfoque cuantitativo, descriptivo y comparativo, basado en un diseño preexperimental (pretest/posttest). La población incluyó 74 estudiantes de la Unidad Educativa Abdón Calderón. Se aplicó un cuestionario de Evaluación de Pensamiento Crítico (23 ítems; α: 0.81), Contempló las dimensiones de interpretación, el análisis, la evaluación, la inferencia, la capacidad de explicación y la autorregulación. La estrategia de gamificación tuvo un enfoque lúdico y colaborativo y contempló 10 sesiones presenciales, con duraciones que oscilaron entre 2 y 3 horas académicas. El análisis descriptivo contempló medidas de frecuencias y porcentajes por niveles. Para la comparación se utilizó la prueba no paramétrica de comparación Test de Wilcoxon (Wilcoxon-T) (H1: pretest < postest; p.valor < 0.05). La gamificación tuvo un impacto significativo en el fortalecimiento del pensamiento crítico. Los hallazgos demuestran un aumento considerable en las habilidades a nivel de las dimensiones y la variable. Los niveles altos de habilidades de este tipo de pensamiento se incrementaron significativamente (Postest > Pretest; p.valor < 0.05). La evidencia sugiere que la gamificación, cuando se diseña e implementa cuidadosamente, tiene el potencial de tener un impacto positivo en el desarrollo de habilidades de pensamiento crítico. Las comparaciones entre el pretest y el postest han demostrado mejoras significativas. El campo de estudio también enfrenta varios desafíos, incluidos la dependencia del contexto, los problemas de medición, y la necesidad de un diseño cuidadoso para evitar posibles factores como la distracción o el énfasis excesivo en la motivación extrínseca. También existe necesidad de estudios longitudinales y precisar las implicaciones éticas.

Palabras claves: Diseños preexperimentales en educación, Educación matemática, Gamificación, Pensamiento crítico.

INTRODUCTION

In the rapidly evolving landscape of education, much attention has been paid to innovative approaches to improving learning outcomes (Oliveira et al., 2021; Reyes et al., 2020, 2023, 2024). Among these, gamification has become a powerful tool to engage students and potentially foster critical thinking skills (Ruíz-Chávez & Terrones-Marreros, 2023).

Gamification has been conceived as the application of game design elements and game principles in non-playful contexts (Deterding et al., 2011; Yang et al., 2020; Ruíz-Chávez & Terrones-Marreros, 2023), and has been increasingly adopted in educational settings. Its potential to motivate learners, increase engagement, and improve learning outcomes has been widely recognized (Xi & Hamari, J2019). At the same time, the development of critical thinking skills remains a crucial goal in education, as these skills are essential for success in the

twenty-first century workplace and for an informed citizenry (Salazar Aguirre & Cabrera, 2020).

In the literature, it has been reported that the concepts of gamification and critical thinking have been addressed. When examining the influence of gamification on critical thinking, it has been found that studies tend to be undertaken based on correlations between gamified learning experiences and critical thinking outcomes, with those that have also employed pre-test/post-test comparisons to measure the impact of gamification interventions on critical thinking skills (Dichev and Dicheva, 2017; Sailer & Homner, 2020). Gamification in education refers to the integration of game elements and mechanics into learning environments to improve motivation, engagement, and learning outcomes (Deterding et al., 2011; Yang et al., 2020; Ruíz-Chávez & Terrones-Marreros, 2023). These elements can include points, badges, leaderboards, challenges, rewards, and narratives, among others (Cózar-Gutiérrez & Sáez-López, 2016). The underlying principle is to harness the motivational power of games to make learning more enjoyable and effective (Jagušt et al., 2018; Gómez-Carrasco et al., 2020).

Research has shown that gamification can have positive effects on several aspects of learning (Dwyer et al., 2014). For example, a meta-analysis by Sailer & Homner (2020) found that gamification in education had small but significant positive effects on cognitive, motivational, and behavioral learning outcomes. The authors noted that the effectiveness of gamification depends on several factors, including context, specific game elements used, and learning domain.

Sailer & Homner (2020) conducted a systematic review of gamification research and reported that gamification was most commonly applied in computer science and information technology courses, although it is also possible to find them in experimental sciences and language learning courses. Toda et al. (2019) highlight that gamification generates positive results in terms of student participation, motivation, and academic performance. However, it is important to note that the effectiveness of gamification is not fully accepted. Some studies have reported neutral or variable results, emphasizing the need for careful design and implementation of gamified learning experiences (Dichev & Dicheva, 2017).

Critical thinking is a complex cognitive skill that involves the ability to analyze, evaluate, and synthesize information to form reasoned judgments and solve problems (Liu et al., 2014; Ruíz-Chávez & Terrones-Marreros, 2023). It encompasses a series of subskills, such as interpretation, analysis, evaluation, inference, explanation, and self-regulation (Ruíz-Chávez & Terrones-Marreros, 2023).

The importance of critical thinking in education and beyond cannot be overstated. In an era characterized by information overload and rapid technological change, it has been reported that the ability to think critically is essential to achieving academic success (Liu et al., 2014). Critical thinking skills are crucial for academic performance across disciplines, as they allow students to engage deeply with course material and develop sophisticated understanding (Liu et al., 2014), not forgetting that it is a topic that involves school ethics (Kim & Werbach, 2016). It has

also been pointed out that it serves for job preparation, being a desirable skill for employers and critical thinking is also valued in terms of having an informed and civic citizenry (Aguilar Vargas et al., 2020).

And it has become a relevant factor for lifelong learning, because it favors the ability to think critically and continuous adaptation in a rapidly changing world (Dwyer et al., 2014). Given its importance in promoting critical thinking skills, it has been present in the intentions of education at all levels. However, developing these skills can be challenging, and educators are continually looking for effective methods to promote critical thinking in their students. This paper shows the results of the application of a gamification strategy to develop critical thinking in tenth grade students of Basic General Education in Ecuador. It was assumed that an appropriate strategy could increase the levels of this skill in young schoolchildren.

METHODOLOGY

The research is quantitative and comparative, proposed under a pre-experimental design (pre-test / post-test). A total of 74 students in the tenth year of Basic General Education from an Educational Unit in Quito, who were studying mathematics, were consulted. A survey was used, and the instrument was the Critical Thinking Evaluation Questionnaire by Palma et al. (2021) (23 items; α: 0.76), and whose pilot test (30 subjects) yielded a α: 0.81. It contemplated the dimensions of interpretation, analysis, evaluation, inference, the ability to explain and self-regulation.

The gamification strategy included 10 face-to-face sessions, with durations ranging from 2 to 3 academic hours. This initiative had a playful and collaborative approach. First, a pre-test was carried out that served as a baseline and diagnosis, followed by the implementation of the strategy over 4 weeks, to then proceed to its assessment by means of a Posttest, using the same questionnaire. The levels of both tests were calculated as proposed by Palma et al. (2021). The descriptive analysis included measures of frequencies and percentages by levels. For comparison, the non-parametric Wilcoxon Test (Wilcoxon-T) comparison test was used (H1: pretest < posttest; e.g. value < 0.05).

RESULTS

Strategy Description

The gamification strategy implemented in this research was developed with the purpose of investigating and stimulating the development of students' critical thinking in the subject of mathematics. The strategy involved pedagogical activities that incorporated playful aspects, considering challenges, rewards and competitive activities, with the intention of making the teaching of curricular content more attractive and promoting a participatory and active learning environment.

In the implementation process, it covered 10 sessions, where different games and activities were applied, designed to be able to approach mathematics concepts in a creative way, allowing students to participate individually and collaboratively in solving problems.

The activities were adapted to the cognitive level of the students and a progressive degree of difficulty was assumed, in order to promote analytical thinking and logical reasoning.

Pedagogical techniques were used that encouraged students to question and reflect on the information, as well as the transfer of the knowledge acquired to different contexts. Gamification aspects, such as challenges and rewards, and the use of scores, were incorporated in a way that stimulated student participation and engagement in the learning process, contributing to the development of skills such as decision-making and critical and interpretive analysis, respecting their own pace (self-regulation). A pre-test and a post-test were carried out to evaluate the effects of gamification on the development of students' critical thinking.

Comparison between the Pretest and the Posttest

Table 1 presents the data concerning the *interpretation dimension*. It was observed that, during the pre-test, 15% of the young people showed a high level, while the intermediate level contemplated 31%; the prevailing level being low, with 54%. In the post-test, the metrics varied, registering a change in the percentage structure.

There was evidence of a change in the high level, going from 15% to 51%, and in the low level, which went from 54% to 15%. The W-T showed that there was a significant difference (e.g. value 0.032 < 0.05); and that therefore the application of the strategy generated a change in the levels.

Table 1

Comparison: interpretation dimension.

Dimension	Levels	Pre-test		% Acum.	Postest		% Acum.	Wilcoxon-T (W-T)
		N	%		N	%		
Interpretation	High	11	15	15	40	51	51	**0.032***
	Middle	23	31	46	18	34	85	
	Low	40	54	100	16	15	100	
	Total	74	100		74	100		

Nota: * p ≤ 0.05; ** p ≤ 0.01.

Table 2 shows the data from the *analysis dimension*. It could be seen that, in the pre-test, 14% of the students exhibited a high level, while the medium level contemplated 32%; the low-level prevailing, with 54%. Post-test metrics varied, with a percentage improvement recorded.

The high level went from 14% to 52%, and at the low level, it went from 54% to 20%. The W-T showed a significant difference (p.value 0.025 < 0.05); and that therefore the strategy and its application generated the expected effect.

Table 2

Comparison: analysis dimension.

Dimension	Levels	Pretest		% Now.	Postest		% Now.	Wilcoxon-T (W-T)
		N	%		N	%		
Analysis	High	10	14	14	39	42	42	**0.025***
	Middle	24	32	46	19	38	80	
	Low	40	54	100	16	20	100	
	Total	74	100		74	100		

Nota: * p ≤ 0.05; ** p ≤ 0.01.

Table 3 shows the metrics of the *evaluation dimension*. The pre-test showed that only 18% of the students exhibited a high level of evaluation, in contrast to the low level (44%). It can be seen that 83% had a medium or low level. These metrics changed after the strategy was implemented. In the post-test results, the high level rose to 44% and the medium level went from 34% to 49%. The low level only reflected 7%. The W-T again showed that the strategy and its application generated the desired effect (e.g. value 0.035 < 0.05).

Table 3
Comparison: evaluation dimension.

Dimension	Levels	Pretest		% Now.	Postest		% Now.	Wilcoxon-T (W-T)
		N	%		N	%		
Evaluation	High	13	18	18	34	44	44	**0.035***
	Middle	25	34	51	21	49	93	
	Low	36	49	100	19	7	100	
	Total	74	100		74	100		

Nota: * p ≤ 0.05; ** p ≤ 0.01.

Table 4 shows the metrics for the *inference dimension*. The pre-test showed that the high level (18%) went to 38%, after the application. The low level ranged from 50% to 20% on Posttest. This is reflected in the W-T (e.g. value 0.041 < 0.05), demonstrating the effect of the application.

Table 4
Comparison: inference dimension.

Dimension	Levels	Pretest		% Now.	Postest		% Now.	Wilcoxon-T (W-T)
		N	%		N	%		
Inference	High	15	20	20	33	38	38	**0.041***
	Middle	22	30	50	24	42	80	
	Low	37	50	100	17	20	100	
	Total	74	100		74	100		

Nota: * p ≤ 0.05; ** p ≤ 0.01.

Table 5 shows the results of the *explanation dimension*. Percentage-wise, positive variations were observed between the pre-test and the post-test. The most relevant variation focuses on the high level (18% vs 51%).

The low level ranged from the initial 45% to 7% on Posttest. This is also reflected in the W-T (p.value 0.01 < 0.05), exhibiting a significant relationship.

Table 5

Comparison: explanation dimension.

Dimension	Levels	Pretest		% Now.	Postest		% Now.	Wilcoxon-T (W-T)
		N	%		N	%		
Explanation	High	15	20	20	41	51	51	**0.01****
	Middle	26	35	55	22	42	93	
	Low	33	45	100	11	7	100	
	Total	74	100		74	100		

Nota: * p ≤ 0.05; ** p ≤ 0.01.

The results of Table 6 summarize what was observed for the *self-regulation dimension*. Percentage-wise, positive changes were also observed between the pre-test and the post-test. The variation that stands out the most is focused on the high level (14% vs 33%). The low level varied from the initial 46% to 16% in the Postest, with the favorable change being evident. The W-T (e.g. value 0.039 < 0.05), exhibits a significant relationship that validates the application of the gamification strategy.

Table 6

Comparison: self-regulation dimension.

Dimension	Levels	Pretest		% Now.	Postest		% Now.	Wilcoxon-T (W-T)
		N	%		N	%		
Self-regulation	High	10	14	14	31	33	33	**0.039****
	Middle	30	41	54	21	51	84	
	Low	34	46	100	22	16	100	
	Total	74	100		74	100		

Nota: * p ≤ 0.05; ** p ≤ 0.01.

Table 7 summarizes what is reflected in the dimensions. It can be seen that critical thinking was increased from the gamification strategy. The high level reflects the favorable effect (16% vs 46%), and a reverse change was seen at the low level (46% vs 19%). This was demonstrated with the W-T (p.value 0.014 < 0.05). In this sense, the usefulness of the strategy is demonstrated at the level of dimensions and variables.

Table 7
Comparison: variable – Critical thinking.

Variables	Levels	Pretest		% Now.	Postest		% Now.	Wilcoxon-T (W-T)
		N	%		N	%		
Critical thinking	High	12	16	16	38	46	46	**0.014***
	Middle	28	38	54	14	35	81	
	Low	34	46	100	22	19	100	
	Total	74	100		74	100		

Nota: * p ≤ 0.05; ** p ≤ 0.01.

Discussion of results

The discussion of the results reveals that gamification, as a pedagogical strategy, had a significant impact on strengthening critical thinking in students. The findings demonstrate a considerable increase in critical thinking skills. Holguín et al. (2020) point out that many teachers do not use gamification effectively due to a lack of training and resources. However, after the implementation of gamification, there was a significant increase in students' ability to analyze and organize information, so its use is recommended, in agreement with Cotes et al. (2023).

Another relevant aspect is the improvement in the students' ability to evaluate information on the topics addressed, as demonstrated in the post-test. This reflects the importance of gamification in the development of evaluation and analysis skills, as proposed by López et al. (2022), who consider that critical thinking is essential to discern the validity of information.

The results also showed that students improved their ability to apply the information received and analyze mathematical concepts through gamification, which confirms the one pointed out by Encalada (2021), that gamification facilitates the understanding and retention of concepts. This strategy provided students with opportunities to apply their knowledge in a practical and real way.

The findings are consistent with what has been reported in pre-test/post-test studies, such as that of Cózar-Gutiérrez and Sáez-López (2016), whose results showed a significant improvement in critical thinking scores in the experimental group ($p < 0.001$), while the control group showed no significant changes. This is also in line with what was pointed out by Gündüz et al. (2020), who found a significant increase in critical thinking scores in the experimental group ($p < 0.001$), compared to no significant change in the control group.

The findings are similar to those highlighted by Jagušt et al. (2018) with primary school students in Croatia, where their results have significant effects on problem-solving skills for students who used the gamified application ($p < 0.001$), especially for students who had lower performance.

A study by Yang et al. (2020) in China also reports concurrent results with significant improvements in the level of critical thinking ($p < 0.001$) after the gamified pedagogical intervention.

It also coincides with the findings of Holguín García et al. (2020), who also reported that gamification generated favorable effects in the teaching of mathematics. Such pre-test/post-test studies endorse the results obtained here and validate the thesis of the positive effects of gamification on critical thinking skills explored in various thematic areas and educational contexts.

CONCLUSIONS

From this evaluation, it was possible to identify a significant increase in the use of skills such as interpretation, analysis, evaluation, mathematical and cognitive inference, the ability to explain and self-regulation, which confirms the effectiveness of gamification as a pedagogical tool to strengthen critical thinking.

Evidence suggests that gamification, when carefully designed and implemented, has the potential to have a positive impact on the development of critical thinking skills across various educational levels and subject areas. Comparisons between the pre-test and the post-test have shown significant improvements in critical thinking skills after gamification interventions in various educational settings, something that is confirmed by this work.

However, the field of study also faces several challenges, including context dependence, measurement issues, and the need for careful design to avoid potential pitfalls such as distraction or overemphasis on extrinsic motivation. These challenges point to important directions for future research, including the need for longitudinal studies, research of diverse contexts and populations, the development of design principles, and consideration of ethical implications.

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