Research Article

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Evaluating the Educational Impact of 3D-Printed Toys in Elementary Settings: A Mixed-Methods Study

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Abstract

This study explores the impact of integrating the use of disruptive technologies on 3D-printed toys within elementary education through a mixed-methods approach, combining an experimental design with qualitative interviews. Focusing on the potential of disruptive technologies to innovate educational practices, we divided participants into control and experimental groups, the latter engaging with the 3D-printed educational toys. Despite the innovative application of 3D printing technology in educational settings, our findings reveal no significant differences in the learning outcomes between the two groups. Therefore, this research contributes to the literature on educational innovation, suggesting that the mere introduction of novel technologies, such as 3D printing, may not be sufficient to enhance learning effectiveness. Regarding practical implications, the study is aimed at scholars, teachers, and educational managers, to underscore the necessity of a critical assessment of educational tools and calls for further investigation into how technology integrates into pedagogical frameworks to truly benefit elementary education.

Keywords: *Educational innovation; Game-based learning; Disruptive technologies; Learning effectiveness*

1. Introduction

The teaching of history aims to strengthen our identity and allows to connect the students with their social environment, providing a deep understanding of human life (Van Straaten et al., 2018). History also helps to consolidate the national identity and citizenship skills in the students (Barghi et al., 2017). However, in the current educational model, history courses are static and focused on the memorization of facts and data (Mokhsin et al., 2019), implying a loss of interest and motivation in the students (Van Straaten et al., 2018).

Regarding motivation, students often describe their experiences with history in negative terms (Johansen, 2014). The competency-based approach to learning has recently become popular (Toktamysov et al., 2021), which includes research and historical thinking that emphasizes the role of the learner in the construction of knowledge (Moseikina et al., 2022). Recent studies focused on analyzing the effectiveness of playful pedagogical tools such as robots (Gupta & Jain, 2021; Chou et al., 2011), technology toys (Kara et al., 2013; Gao et al., 2020) or digital games in educational settings (Li et

al., 2019; Mayer & Johnson, 2010; Lin et al., 2018). However, in environments of poverty and reduced technological progress, it is necessary to develop educational tools that adapt to their maturity characteristics and learning styles (Manrique et al., 2011).

Teaching history may have several limitations. In traditional methods, learning is centered on repeating the ideas from other people (Moseikina et al., 2022). Students are prone to memorize historical data without an actual understanding of the content, getting a loss of interest and an increasing aversion to learning history (Lin et al., 2018). Another restriction is the fact that each course is taught in an isolated manner, despite that in real-world settings, disciplines are interconnected among each other based on projects (Spelt et al., 2009; MacLeod & van der Veen, 2020). Moreover, there is a scarcity of innovative tools in the local context.

We describe in this project the application of a 3D-printed toy as a learning tool in elementary education, specifically in the course of History. The implicit challenge by developing this tool is to help students to understand their role as individuals on a society. Therefore, this paper will analyze the impact of the use of a learning toy as a tool for motivation and performance in elementary education.

This study is important because it sheds light on how technology startups in Latin America expand internationally. It helps fill a gap in our understanding of international entrepreneurship in the region, which could be useful for both public and private decision-makers. By providing insights into successful market entry strategies, this knowledge can support economic growth and maximize the impact of entrepreneurship throughout Latin America.

2. Literature Review

2.1 Games in childhood development

Games are defined as the impulse of experiences through the realization of activities and behaviors motivated by oneself at one's own discretion and will. It is a very open activity whose objective can be achieved in different ways, all satisfying and enjoyable, and is characterized by high degrees of freedom in its realization and content (Gielen, 2009). Games have always been a part of human life (Tahmores, 2011) and has been considered of paramount importance for the learning and development of the infant (Yilmaz, 2016; Hinske et al., 2008). Children play for pleasure, satisfying their primary needs and developing creative and intellectual skills. Through games, children shape the symbols that mediate between the person and the reality that surrounds them (Cvijanović & Mojić, 2018). The child shows his imagination and finds an opportunity to express his creative feelings when playing. Joyful, mobile, and visually appealing play reduces stress, promoting a sense of progress (Tahmores, 2011). Games also help children socialize and prepares them for effective social communication and for entering the adult world. Games also contribute to the physical and mental development of children and provide safe spaces for experimentation and interaction with the environment (Tahmores, 2011). Therefore, there is a positive relationship between games and children's learning (Yilmaz, 2016). Hence, playing games in educative settings is getting more acceptance (Khaleel et al., 2016). The interaction with toys and other gaming artifacts is important for the child development (Kara et al., 2013) because it supports their cognitive processes (Yilmaz, 2016), shaping the experiences, stimulating the imagination and supporting the continuous experimentation (Kara et al., 2012; Kara et al., 2013; Klemenovic, 2014). Toys can be useful tools in school, and especially in elementary education have an enormous potential to enhance the learning process (Yelland, 1999). A learning environment based on toys can provide physical experiences for the children (Yilmaz, 2016) where kids are able to test their skills according to the learning objectives (Kara et al., 2013).

2.2 Game-based learning

The game-based learning approach has played an important role in the different levels of education (Li et al., 2019), with physical or digital toys in educational settings to achieve a learning objective (Martinez-Hita et al., 2021). This methodology promotes the creative thinking, the interaction among peers and facilitates cooperation and the active participation of the students in their learning process (Parra-González et al., 2021). It also helps to develop skills like teamwork, listening, self-learning and information synthesis (Murillo-Zamorano et al., 2021). Game-based learning approach can make the cognitive process more fun and more effective, by focusing on the student experience (Moseikina et al., 2022).

School teachers believe that game-based learning is a good instructional method and can improve students' learning motivation (Lin et al., 2018). However, the risk of using games in educational settings is that their entertainment functions may distract the learner from the academic content (Mayer & Johnson, 2010). Hence, to ensure the effectiveness of student learning, game times should be adjusted to the adequate time for reading classes, and the game must be related to the course content. Appropriate game stages and obstacles are important, as well as modes of content presentation (Lin et al., 2018). There are several types and educational styles of game-based learning (Qian & Clark, 2016) which aim to provide learners with content to actively manage their studies (Moseikina et al., 2022) and create the need for the formation of certain learning objectives that contribute to personal awareness of intrinsic and extrinsic motivation (Kalogiannakis et al., 2021), i.e. all aim to achieve strong interaction and motivate the learner (Tsai et al., 2016).

Motivation is a physiological process that influences in persistence, direction and energy linked to behavior (Moos & Marroquin, 2010) and it is understood as a set of impulses that keep a person with a determined conduct (Deci & Ryan, 2000; Pintrich, 2004). These impulses can come such internally as externally from a individual. From this sort of motivations, impulses can be classified as autonomous and as controlled. The first ones refer to behaviors explained by personal factors meanwhile the second ones refer to conducts explained by environmental factors that can influence authoritatively to provoke a determined behavior (Deci & Ryan, 2000). Autonomous motivation has the largest potential to keep a personal interest in people, which carries positive consequences such cognitively as affectively when they behave as players in game context. Game potential in education enhancement lies in motivation that can come from students (Malone, 1981) due to, motivational power of games is in the initial impulse, potentiation and holding of an activity with a given goal (Mayer & Johnson, 2010). Also, related to motivation must be remarked the sentiment of competitiveness that a person experiences in the activities that performs. So, to assure that students perform optimally it is necessary to strengthen levels of motivation, what can be achieved generating a conscious state of immersion with a generalized approach, envelopment and joy that positively influences in behaviors associated to learning process and academic performance (Shi et al., 2014).

2.3 History teaching and learning

History course, is important because students can build a personal identity, see themselves as a part of society, and contribute to general understanding of human existence (Van Straaten et al., 2018; Moseikina et al., 2022). Additionally, develops and propels common sense, consciousness, and wisdom (Berg, 2019). However, several problems emerge from teaching this course because traditional methodology pursues the repetition of ideas either exposed by a teacher or that can be found in books. So, learning is reduced to reproduce the way of thinking of other people (Moseikina et al., 2022). Besides, contents such as historical figures, dates, places, and events are obtained through memorizing, making the obtaining of new knowledge to depend strongly on it (Lin et al., 2018). This is not aligned to current teaching methods used in other matters which impacts negatively in academic performance (Alshikhabobakr et al., 2020). To increase learning effectiveness, students must develop capabilities to acquire knowledge autonomously. This way, they could be

increasingly interested in a determined field, So, it emerges a more active participation during classes (Moseikina et al., 2022). For these reasons, research in History education propose a change in teaching to develop and to promote historical thinking in students. Implementation of active methodologies in the Subject of History can influence positively in the development of skills, increase of interest in contents and the development of historical thinking.

Contemporary history teaching and learning approaches include historical thinking and historical research which emphasize the role of students in the development of historical knowledge (Moseikina et al., 2022) that it composed by the handling of methods to do research in History and goes beyond of memorizing. It is the combination of descriptive concepts such as dates, figures, and events, along with the analysis of causes and consequences, handling of information sources, consideration of different perspectives and developments of events. To achieve teaching goals in History course, the implementation of active methodologies is not enough. Teachers must handle theoretical knowledge in the construction of historical thinking and to know how to choose methods and strategies properly for its development (Rodriguez-Medina et al., 2020) acting as a catalyst of these changes (Voet & De Wever, 2017).

Regarding the role of teachers in History teaching, cognitive revolution has criticized traditional teaching of History course, based on learning, and memorizing of events, for not accomplishing engagement of students with high level thinking (Voet & De Wever, 2017). With the development of new educational technologies, the training of teachers must assume new roles, to rebuild teaching strategies, and to promote new approaches (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2011), the role of teachers has changed from a lecturer to a coach (Lin et al., 2018). Likewise, reforms must be oriented to establish the learning context in a new teaching system, integrating new technologies with a renewed teaching methodology and to develop a socially active environment, promoting cooperation and teamwork.

2.4 Educational innovations

Lester et al. (2014) used as an input the centered in storytelling learning and the solving of problems to create the digital game "Crystal Island: Uncharted Discovery". It was used in Natural Sciences courses for elementary schools. The research showed that learning of sciences and the capability of solving problems by the students had an enhancement, and the game environment enhanced participation of students and their motivation to learn.

Martínez-Hita et al. (2021) researched about the impact in academic performance in children of a educational project about a historical thinking based game applied to elementary level in Murcia, Spain. The main objective of the research was to check if the learning of History had an improvement in children right after the implementation of this new methodology. It was shown that there was a significant improvement in meeting learning objectives. The project had an almost experimental approach, with an experimental and a control groups, there were such ad hoc as post hoc tracking, and sampling involved 44 students from fourth grade in elementary school, whose ages were between 9 and 10.

Yilmaz (2016) studied the use of Education Magical Toys (EMT) with augmented reality in children from 5 to 6 years old. The general objective was to determine, cognitive achievements and behavioral patterns and the grade of interaction among children while they played with the toys. Results showed that children and teachers enjoyed interacting by using toys. However, there was not a different cognitive performance from the one obtained from the case without the use of toys. So, they concluded that learning must not be based only on interactions using toys, but the process must be managed by a teacher.

Kewalramani et al. (2021) researched about the use of toy robots with AI interfaces in Preschool education to develop literacy. The research pursued to understand how AI based toys, guided by a teacher, help to develop literacy by exploration in the infant. Results showed that children collaborated creatively, and the activity promoted exploring skills: creative, emotional, and

collaborative. The research used mixed methods with not probabilistic sampling and 21 children with ages between 4 and 5 years were involved, along with 3 teachers from Preschool education.

Lin et al. (2018) researched about the use of digital jigsaws in the teaching of History course, in a fifth-grade school from elementary level in Taiwan. The research pursued to evaluate the impact of the game "Govern Formosa" in the learning, measuring effectiveness and motivation. It was shown that learning and knowledge levels of the students had a significant improvement. Also, it was found that the game increased motivation and the interest from infants in the treated topics. The approach was almost experimental, applying question forms for ad hoc and post hoc purposes, with a not probabilistic sampling including 27 students.

The research by Navarro et al. (2019) describes the process of design and validation of the educational videogame called "1821: La lucha por la independencia", which seeked to boost the teaching of the Peruvian Independence History, It was verified that the dynamic of the game helped the treatment of the related topics from a different approach to the one based on memorizing, along with being amusing. It was used a qualitative approach almost experimental. Using individual interviews and question forms containing open and closed questions once the experience was applied. Sampling was composed by 7 College students with ages between 17 and 19 years.

Alshikhabobakr et al. (2020) explored the use of designs and animations in the Alice program to boost the learning of topics not contained in STEM disciplines. It was pursued to evaluate effectiveness in the enhancement of learning and the increase of interest in the History course. The obtained results, in terms of learning, were positive but not very significant or neutral. However, from the qualitative approach, it was seen an increase of motivation to learn more about History. The used approach was mixed almost experimental, and the sampling involved 64 elementary students, 27 from seventh grade and 37 from ninth grade.

3. Methodology

The main objective of this research was to study the learning outcomes in elementary school students. The project used game-based learning as the teaching method. Therefore, the intervention was developed by performing lessons about Peruvian History and measuring the outcome from 4 groups were compared: 2 control groups (A) using traditional methodology (without games) and 2 experimental groups (B) where a mix of traditional and new methodologies were applied.

3.1 Data collection

Data was collected from with four groups of students from an elementary school in Lima (Peru). Regarding to ethical issues, informed consent was approved by the institution. The instrument is a standard test to track academic performance, designed for the evaluation of learning standards established in the elementary level national curricula program in first and second grades in elementary level. The mentioned performance test is composed of 11 questions, and it was validated by a panel of experts.

3.2 Sample selection criteria

Selection of groups and their members was performed by convenience, according to the accessibility to the subjects involved in the research (Hernández et al., 2014). Therefore, members stood on their class groups, without any changes in the composition of original groups. The four groups were composed by 35 students in control group 1, 22 students in control group 2, 23 students in experimental group 1 and 22 students in experimental group 2. The total universe in the research was 92 students with ages belonging to 6-8 years range.

3.3 Data collection procedure

The research was executed according to CIPP model: context, input, process, and product (Stufflebeam, 2000; Aziz et al., 2018). Before the intervention program application in class, the context was evaluated to find needs and to identify problems that could come across and could require urgent solution. The performed analysis showed that there was a lack of tools that could support the establishing of specific situations and active methodologies in teaching Peruvian History, in the first years of elementary level.

Therefore, the authors designed an assemblable toy whose parts were manufactured with 3D printing, which is based on historical images of an Inca emperor named Manco Capac. One of the characteristics of this toy is that it can be assembled on a potato (*solanum tuberosum*), where the potato acts as the trunk of a human being. When the assembly of the toy is finished, the shape of the artifact is like an Inca emperor. The name of the toy is "Manco Papac", alluding to the use of the potato, which is a root vegetable original from Peru. In Figure 1 we show the 14 parts of the toy, including the potato as the human trunk. Then in Figure 2 we present a scheme of the toy after being assembled.

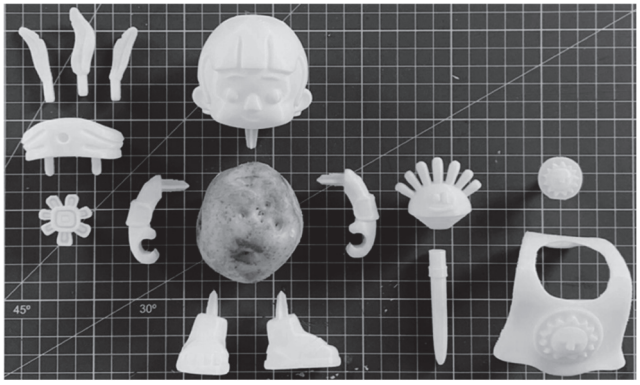

Figure 1. Manco Papac (the toy) and its parts

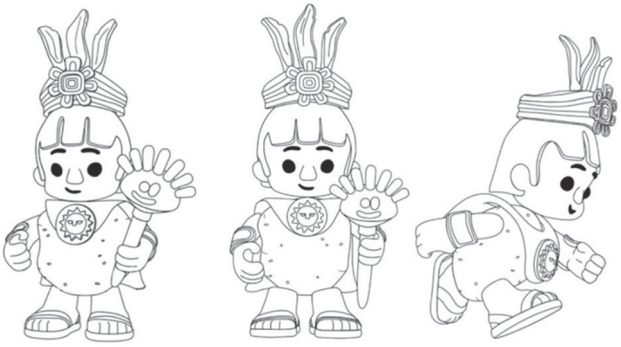

Figure 2. Manco Papac fully assembled

Later, the toy was delivered to teachers to implement a game-based learning activity in experimental group, for the personal social curricula area according to the national program for 1st and 2nd grades. The activity consisted of the collaborative construction of the Manco Capac character, where

students had to experiment with different fruits or vegetables (potato, lucuma and tomato) to determine which would be the best option to be used as the character's base. Subsequently, they assembled the character in a pose that represented a scene from 'The Legend of Manco Capac and Mama Ocllo', presenting their creation to the class and justifying their choice of base and scene represented. This activity served as an integration for several curricular areas (art and culture, science and technology, communication, etc.) by developing multiple transversal competencies like the identity building, developing autonomously through their motor skills, interacting through their socio-motor skills, as other skills. Regarding the control group, they followed a traditional book-based methodology.

The post-hoc test was performed to both groups, to assess the learning of the students and the program intervention as a while. In the post-hoc test, learning was assessed with a scale from 0 (lower score) to 10 (higher score).

To ensure the validity of the results, training was conducted for the teachers involved, where all teachers receive the same training on how the session was to be delivered and teachers in the experimental group received training on how to use the toy in their lessons. In addition, detailed and standardized guidelines were developed for the implementation of the activities, minimizing variability in teaching. Finally, the researchers were present at the sessions to ensure that teachers followed the guidelines and did not introduce bias.

Regarding the control of previous exposure to toys with similar characteristics, an exhaustive review on the existence of artistic assembly toys inspired by Peruvian contexts was carried out without finding relevant background in this topic. Therefore, classrooms were selected and conditioned with similar characteristics for the different groups, e.g., size, available resources, etc. The activities were carried out in the first hours of the day and a detailed backlog of any external variables that could influence the results was also kept.

4. Results

4.1 Descriptive statistics

The descriptive statistics give a comprehensive overview of the distribution of scores within each group. Table 1 shows that both groups appear to have similar central tendencies (mean and median) and spread (standard deviation).

Table 1. Test scores for each group

	Group A	Group B
Observations	45	47
Mean	8.83	8.66
Median	9.00	9.00
Standard Deviation	1.48	1.43
Minimum Value	3.6	4.3
Maximum Value	10.0	10.0

As shown in Figure 3, though both groups have results that seem to be similar, the main differences can be found in the presence of outliers in the control group, where three students obtained lower scores than the lower boundary. To preserve the integrity of the database, we chose to maintain these outliers in the reported results.

4.2 Analysis of Variance

To analyze the differences between the group score distributions, we can use the ANOVA test to compare both groups performance. One key assumption for the ANOVA test is that the data must be normally distributed within each group. Therefore, we used the Shapiro-Wilk test to check for the normality of the data for each group. If the data is not normally distributed, we might consider using the Kruskal-Wallis test, which is a non-parametric alternative to ANOVA. Thus, to check for the normality of the data for each group we performed the Shapiro-Wilk test. The test results are as shown in Table 2.

Group	p-value
A	2.59×10^{-7}
B	3.36×10^{-5}

Table 2. Shapiro-Wilk test results

As both *p*-values are lower than the significance level of 0.05, we rejected the null hypothesis of the Shapiro-Wilk test, which stated that the data follows a normal distribution. Therefore, we have strong evidence to reject the null hypothesis, indicating that the scores do not follow a normal distribution for either group. As the data is not normally distributed for either group, we performed the Kruskal-Wallis test, which is a non-parametric alternative to ANOVA. The *p*-value for the Kruskal-Wallis test is 0.4851. As the *p*-value is less than the significance level (0.05), we fail to reject the null hypothesis. This suggests that there isn't a statistically significant difference in scores between Group A and Group B based on the data provided. Hence, based on the Kruskal-Wallis test, we demonstrate there is not enough evidence to suggest that the two groups have different score distributions.

After the quantitative stage of research, we moved to a qualitative approach, integrating our study within a mixed methods framework. While quantitative analysis gave us a broad overview of numerical patterns, we need to understand the underlying complexity in these figures to uncover the deeper motivations and perceptions regarding the use of an innovative tool.

Peruvian History is taught using historical narrations as teaching methodology, and the most used tools are videos, tales, and images. The main difficulties to teach History of Peru are the lack of interest/motivation, and the lack of resources and tools. However, once is got the attention from students, they show to be amazed, surprised, interested, and curious. The preferred strategy to teach the course of History of Perú is the historical storytelling for children.

The experimental group showed enthusiasm, joy, emotion, interest, and motivation:

> *"They were excited, very happy to be able to play and to ensemble the toy". (R. P., personal interview, November 09, 2023)*

> *(The toy) "caused them a lot of joy and enthusiasm because they were going to build something, they knew they had a challenge, and that was also very encouraging for them. Very nice stuff!". (G. F., personal interview, November 07, 2023)*

Meanwhile, the members of the control group showed curiosity and respect as well. The most surprising attitude from experimental group was neatness during the challenge, while control group showed curiosity and attention. Regarding the process application, members from the experimental group were more willing to organize themselves and to collaborate with each other to do a presentation:

> *"They have been willing to work as a group as well. I thought that maybe there would have been more problems, some fights, but in this case, they were able to do it without difficulties, and it caught their*

attention". (R.P., personal interview, November 09, 2023)

Participants in the control group were holding expecting and curious during the entire intervention. In relation to conducts and attitudes that were seen using the toy, the experimental group showed teamwork, organization, ludic attitude, interest, and resilience:

"I think it has been an experience that has made them very happy, it made them feel respect, to be able to work well in a group, to be able to present their work, to not stop expressing themselves". (G. F., personal interview, November 07, 2023)

Meanwhile the control group showed enthusiasm, expectation, curiosity, and motivation. The skills that could be developed from the use of the toy in the experimental group were communication, construction of identity and construction of historical interpretation meanwhile in the control group was the same (except for communication) plus, reading of diverse kinds of texts written in their mother tongue and involved themselves in the quest of common goodness. A teacher from the experimental group agreed with the fact that the experience using a toy is way more significant and contributes to the remembrance of the treated topics:

"This activity was significant because they manipulate and because the experience, as it is pleasant, stays with them longer. They remember it, more associations can be made and better induction to the subject or greater availability for learning". (R. P., personal interview, November 09, 2023)

"They are creating their own knowledge through the assembly. It is not only that you are going to assemble it, at that moment there is much more that they can do and that many times the teacher does not decide". (G. F., personal interview, November 07, 2023)

5. Discussion and Conclusions

The obtained results impart deeper insights into the usefulness of toys as a tool, showing a relative significant utility in terms of assimilation of contents and enhancing communication skills to stimulate interactions among students and teachers along with active learning strategies that give a sense of purpose in a meaningful context unlike what usually happens with older procedures such are memorizing and repeating information that will be forgotten later.

However, it is important to state that the role played by educators in order to give proper context to games used as a mean to ease learning in classrooms, because of that it is shown that it impacts directly in the success of the describe instances, otherwise, there will be not added value if teachers are not able to manage accurately all the factors that affect a correct accomplishment of goals established by History curse curricula.

It is interesting to observe that, when a drill down analysis is executed, it is possible to conclude that a proper handling of new technologies applied to education field is highly required when it is needed to use toys in classrooms, for instance, when augmented reality games are devised and fluency is needed when time for educators arrive as managers of all aspects of a game to mainly guide students to perform successfully.

Along with a proficient use of new education technologies, it becomes necessary to handle properly soft skills to manage successfully key elements as motivation. Especially, when the target audience in classrooms are mostly elementary educations students that required intensive guidance in their learning processes due to maturity issues, and motivation plays a central role to get rid of some barriers that emerge when learning has an important of compulsory tasks that must be done to meet goals contained in education curricula.

Besides, the uses of toys it seems to be easy to replicate to that kind of courses when motivation seems to be a critical driver to propel meaningful learning, what shows an interesting path to follow further research to check impacts in other fields such as Natural Sciences.

Additionally, it comes to be an interesting opportunity to do further research in higher ages courses due to the proven utility that game-based learning shows in students, to make easier the absorption of new knowledge along with the respective of content retaining in mind unlike what mostly happens in memorizing based learning processes. Experiences like this can be found widely, for instance, the use of well-known Beer Game in College students to understand complexity in supply chain inventory management. This suggest that ages do not represent a barrier to use toys as tools to boost learning experiences, making knowledge obtaining a much more active process than it used to be.

Finally, it can be concluded that effectiveness from a qualitative perspective, complementing the quantitative one, that this approach through the use of toys constitutes an interesting alternative to help educational processes, in particular, in History courses, Also, is remarkable that using a mixed approach it is possible to do important findings that can be hidden when it is exclusively used whether quantitative or qualitative approach only. This tends to be meaningful in aspects like de description of the students' attitude towards leaning, something that cannot be obtained exclusively using a quantitative methodology.

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