ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2026, 11 (3): 599-611 doi: 10.28978/nesciences.263048

Interactive Gamified Instruction in Combinatorial Reasoning: Strengthening A Foundational Competency for Genetic Algorithms and Bioinformatic Sequence Enumeration

Alvaro Santiago Andrade-Yánez[1], Nora Esperanza Parra-Celi[2]*, Reinaldo Antonio Guerrero-Chirinos[3]

[1]Universidad Técnica Particular de Loja, UTPL, Ecuador. ORCID: https://orcid.org/0009-0007-6908-5558, E-mail: asandrade10@utpl.edu.ec

[2]Universidad Técnica Particular de Loja, UTPL, Ecuador. ORCID: https://orcid.org/0009-0003-8433-039, E-mail: neparra@utpl.edu.ec

[3]Universidad Técnica Particular de Loja, UTPL, Ecuador. ORCID: https://orcid.org/0000-0003-0499-7453, E-mail: raguerrero12@utpl.edu.ec

Abstract

Combinatorial reasoning is an essential mathematical competency used in the study of probability and in a wide range of applications, including calculating sequence variants in bioinformatics and computing for genetic algorithms, which search through a space of possible combinatorial solutions through selection, crossover, and mutation. This study sought to examine the use of "Gamification" as an educational tool to enhance students' learning of "Combinatorial Analysis" at the Eugenio Espejo Pre University Institute. A pre-experimental quantitative design was used, with 18 students as the empirical subjects who participated in the pedagogical intervention using gamified learning activities on permutations, variations, and combinations. Pretests and posttests were used to evaluate academic performance before and after the intervention and to assess students' perceptions of the gamification elements, along with a survey designed to measure students' motivation. The evaluation of the results indicated positive feedback on points, badges, and challenges, as well as instant feedback, and a clear increase in academic achievement. The Wilcoxon signed-rank test showed a statistically significant difference between the pre- and post-scores ($p < .001$), with an increase of +3.05 points. The effect size obtained using Rosenthal's r was .91, indicating a large-magnitude impact of the intervention. It concludes that the gamified teaching method, developed based on the course Genially, is a good alternative for reinforcing combinatorial thinking and students' motivation, a competency needed in the downward application of computational courses, which rely on students' imaginative power and systematic and enumerative counting abilities.

Keywords:
combinatorial reasoning; gamification; Genially; genetic algorithms; bioinformatics

Available Online: 01/09/2026

Introduction

Counting, ordering, and selecting items systematically is one of the more challenging skills within the mathematics

**Corresponding Author: Nora Esperanza Parra-Celi, E-mail: asandrade10@utpl.edu.ec*

learning outcomes for secondary and pre-university years of education, known as combinatorial reasoning. It is not only a subject that can be learned in class with probabilities, but also appears in many real-life situations! Computer science also uses genetic algorithms, which employ combinatorial thinking to encode candidate solutions as chromosomes and search over large numbers of permutations or subsets of these using selection, crossover, and mutation operators. The efficiency of this process requires knowing how many combinations or permutations of these chromosomes exist under these constraints. Similarly, problems in bioinformatics, such as counting nucleotide or amino acid sequences, enumerating k-mers, or evaluating candidate sequence alignments, are essentially combinatorial enumeration problems. Enhancing combinatorial reasoning at the pre-university level can thus be seen as developing a transferable competence applicable to higher-level applications in computation and biology, not only in mathematical classrooms but also beyond.

The present study was motivated by this premise and was developed within the framework of the prospective mathematical competencies that high school students acquire, with a particular focus on mathematical competencies linked to the concept of combinatorial analysis, one of the branches of mathematics that has as its object the methods for counting, ordering, and selecting elements. The notions of this branch are essential for the study of probability, and for this purpose it is called mathematical knowledge. The study began with a reflection on academic problems encountered when students tackle combinatorics problems in university admission tests. The academic difficulties students experienced when solving combinatorics problems were explained mainly by the academic preparation they developed during secondary education. Students' difficulties with combinatorics problems encountered during secondary education persist until they take the university admission test. The situation directly affects the transition to higher education for students who do not meet the same level expected in college and university entrance selections. Given the low quality and depth of preparation of young people at high school, a great portion of high school graduates end up at private pre-university centers to augment their previous education.

This competitive and academic pressure has led to a steady increase in demand for preparatory schools for university entrance in this country over the past few years. Eugenio Espejo Pre-University Institute, located in the city of Ibarra in the province of Imbabura, is a private educational institution that offers academic support to students lacking mathematical skills and preparatory courses for university entrance examinations. In these "leveling" courses, most students have been identified as having conceptual misunderstandings in combinatorial analysis problems, including issues with the order of elements and the misuse of formulas, both in problems involving order and in those without order. These weaknesses have already been reflected in test scores and also curb the ability to think logically, which is crucial for university-level studies. This is covered in the statistics and probability strand of the Ministry of Education's mathematics curriculum.

Historical data from the National Institute for Educational Evaluation (INEVAL) for the statistics and probability strand at the national level indicate the presence of this problem. In the Ser Bachiller examination, the percentage of correct answers for this strand was 37% (INEVAL, 2017) and no more than 54% (INEVAL, 2019) in 2014 and 2019, respectively. This suggests some improvement, but the results remained negative with respect to the cognitive skills developed in this area of mathematics. This period is chosen because, until these years, INEVAL published only results by thematic block; the examination has also been replaced by another one, and in 2022 it was no longer required as the only condition for admission to public universities. The only existing evaluation is the diagnostic criteria called Ser Estudiante, which has been used since the year 2013 and provides diagnostic thresholds for meeting or exceeding educational standards rather than percentages of correct responses by block. Although dated, they constitute a historical and diagnostic precedent because they show difficulties that recur each year in combinatorial analysis and persist in teaching practice to the present day, particularly in pre-university courses, where each year a large number of students aim to reinforce their knowledge prior to admission exams.

Nevertheless, this topic is relevant at the national level, yet little research examines in depth the learning difficulties arising from combinatorial analysis, leaving this an untouched aspect in the Ecuadorian educational research field. Given the situation, it was essential to draw on the theoretical knowledge and empirical evidence from the literature on the subject. In this context, several international studies were examined, in which researchers describe the same patterns of issues that students generally encounter in combinatorial analysis. A study by Fuentes and Roa (2014) was conducted with a first-year group of secondary students (54) from Granada, Spain. Likewise, Vázquez et al. (2014) found that many first-year Applied Mathematics students at the Autonomous University of Puebla (AUPEB), Mexico, had little understanding of the basic counting principle during the first semester of their probability course. They said they were unable to imagine the examples associated with the problems in those classes, so they considered the verbal problems as abstract mathematical statements.

In the context of first-year Computer Engineering students in Discrete Mathematics at the University of Informatics Sciences in Havana, Cuba, Quintana et al. (2020) also found that students had difficulties mainly with applying the combinatorial principle, selecting formulas, verifying steps, and linking problems to the real world. The studies collectively suggest that learning problems in combinatorial analysis are not uncommon across educational settings and levels but are a recurring pattern. This recurrence prompts the researcher to analyze some of the reasons that might be responsible for the issue. In the Ecuadorian context, one possible structural reason for the learning difficulties with the concept of Combinatorial Analysis has been identified: the curricular structure adopted by the Ministry of Education in Ecuador's mathematics curriculum. In particular, the content covering the statistics and probability strand appears in the last chapters of textbooks, which, in many cases, is unlikely to be developed to the proper level in time for the end of the school year (Alvarez et al., 2023). Then there is the fact that there is reduced mathematics instructional time per week, which may make it difficult to cover more complex content that requires more complicated reasoning and problem-solving steps.

One aspect of teaching combinatorics is that it tends to be presented as isolated examples and formulas to be plugged into and churned through, which does not allow for appreciation of the concepts being taught; therefore, students are not necessarily able to transfer and apply concepts to other situations. In such a context, it's necessary to rethink the curriculum and teaching methods in relation to technology-supported didactic resources. Both the use of digital tools and innovative pedagogical approaches have become fundamental to improving learning experiences, favoring conceptual understanding and promoting student involvement. In this sense, the problem that needs the most attention is the development of students' combinatorial thinking through activities derived from real problems and deep reflection, so as to prevent students from simply learning based on algorithms, which restricts students' abilities in mathematical competencies (Anzola, 2017; Lamanna et al., 2022).

Gamification is a new teaching technique that has been gaining traction in education to foster learning and active student engagement (Corchuelo, 2018). According to Robson et al. (2015), gamification need not be reduced to the superficial implementation of points or badges—rather, it concerns how game design mechanics, dynamics, and elements influence behavior in non-gaming environments and, consequently, motivation. By adding gamification elements, interest and engagement with class topics can be cultivated, as students' efforts can be acknowledged and rewards can be given, creating a dynamic learning environment with constant feedback (Jama & Cornejo, 2023). Gamifying learning, though, demands high-quality, engaging, and relevant teaching materials suited to the subject matter that can capture students' interest and deliver a stimulating learning experience that facilitates meaningful learning. Gamification approaches in the classroom have been embraced by the emergence of software and digital tools that amplify their value; Kahoot, Educaplay, ClassDojo, Quizizz, and Genially are some of the better-known tools used to enrich learning, adapt to different learning methods, provide immediate feedback, and personalize the learning process (Lanuza & Lanuza, 2020; Sánchez, 2019). In a similar vein, Toda et al. (2019) state that it is necessary to carefully classify and align the elements of a game with the learning targets, as these take on lower motivational value if there is no coherent articulation of their use.

Along with the emergence of technological platforms in the learning field over the last few years, not all of them fit the specific characteristics of certain subject areas (Aldalur, 2025). Thus, it is crucial to choose an appropriate tool, depending on the content domain. In fact, a subject that involves concrete learning material activities, such as activities in wider algebra, does not tend to create problems for young learners because there is more room for clear learning materials in the form of explanatory text, while a subject involving abstract learning material activities, such as combinatorial analysis, gives rise to conceptual difficulties if the presentation format used by teachers is not properly developed. In this context, Genially's digital tool emerges as a versatile resource that makes designing gamified experiences easier through interactive, visually captivating presentations. It is true that the number of devices available for access makes it a technological resource, both in face-to-face classrooms and in virtual environments (Ochoa & Moscoso, 2024). It is used as a learning tool for enjoyment and to develop a didactic sequence in combinatorial analysis that integrates images, texts, and interactive content to convey the concepts of combinatorial analysis clearly, combining academic rigor with play. It also enables the creation of templates with immediate feedback, a typical element of gamification, to support student autonomy and facilitate their learning through trial and error and repetition (Catalán & Pérez, 2020).

Against this backdrop, the principal aim of this research is to assess the effectiveness of gamification as an educational tool for enhancing students' learning of combinatorial analysis at the Eugenio Espejo Pre-University Institute (PEU), viewed as one of the first steps toward the ongoing improvement of a reasoning skill of greater generality for computational areas such as genetic algorithms and bioinformatics sequence enumeration.

In this regard, three objectives were set: (1) Identify the key elements of gamification as a teaching strategy for learning combinatorial analysis; (2) Design a teaching strategy based on activities that incorporate gamification in Genially; and (3) Assess the impact of implementing gamification as a teaching strategy on the learning of combinatorial analysis. The following working hypotheses are assumed: The null hypothesis (H0) is that using

Genially for learning combinatorial analysis does not improve student learning at the Eugenio Espejo Pre-University Institute; and the alternative hypothesis (Ha) is that using Genially for learning combinatorial analysis improves student learning at the Eugenio Espejo Pre-University Institute.

Materials and Methods

In developing the learning measurement instruments and techniques, this study adopted a quantitative approach to measure two variables: the independent variable, the game concept of gamification, and the dependent variable, learning in combinatorial analysis. These two variables facilitate the use of the systematic measurement instruments and techniques employed in the study, as shown in Table 1. This methodological approach has two features that set it apart: it yields numerical responses and allows the results to be analyzed statistically to elucidate relationships among the study variables, enabling precise and repeatable findings.

Table 1. Study Variables, Dimensions, Indicators, and Instruments

Variables	Dimensions	Indicators	Instrument
Independent: Gamification	Cognitive	Perception	Questionnaire with Likert scale
	Affective	Motivation	
	Behavioral	Participation	
Dependent: Learning of Combinatorial Analysis	Cognitive	Academic performance	Knowledge test

Note. Author's own elaboration based on the study's methodological design.

The present study used a pre-experimental longitudinal design involving a one-group pretest/posttest. This design is appropriate when participants cannot be randomly assigned and no comparison group is available, but changes can be observed after the group is intervened with and an intervention is applied (Chávez et al., 2020). A total of 18 young school leavers aged 18-19 were included in the study. Because the population was small, all available students were included without using a sampling technique; from a methodological perspective, however, this sampling approach is equivalent to a census (López & Fachelli, 2016). Information was gathered using two instruments. The independent variable (gamification) was measured with a questionnaire using a 5-point Likert scale (1 – strongly disagree; 5 – strongly agree). The instrument consists of 14 items distributed among the dimensions of perception (4 items), motivation (6 items), and participation (4 items), as shown in Table 1. It was applied before (pretest) and after (posttest) the pedagogical intervention. Both measurements were carried out to collect data on students' perceptions of the game elements to be used in the gamified activities. The pedagogical activities were designed on Genially, and the posttest was applied to assess whether attitudes changed after exposure to the gamified experience.

A few validated instruments were reviewed during the development of the questionnaire, and the GAMERTYPE questionnaire, developed by Prieto and Moreno (2024), which consists of 30 items, was used as a reference for the development of its relevant items. Its original approach was preserved but adapted for combinatorial analysis and Genially. Content validity was determined using expert judgment (judgments by 3 professors with research methodology experience regarding the relevance, pertinence, and clarity of the items). Both the pretest and posttest surveys demonstrated high internal consistency, with Cronbach's alpha values of .842 and .861, respectively, as shown in Table 2.

Table 2. Cronbach's Alpha Reliability Coefficients

	Cronbach's Alpha	N of items
Pretest	.842	14
Posttest	.861	14

Note. Author's own elaboration based on the results of the reliability analysis.

A second instrument, a knowledge test consisting of 10 multiple-choice exercises on combinatorial analysis, was administered before and after the intervention to assess the dependent variable (learning of combinatorial analysis) and to compare scores. Content validity was also assessed using expert judgment, with three mathematics teachers reading the items, completing the rubric, and rating them on a four-point scale (optimal [4], good [3], fair [2], and deficient [1]). After validation, the instrument was used as a diagnostic pretest and posttest to evaluate its effects on learning following the intervention. Inferential statistics were used to draw inferences from the pretest and posttest, specifically to determine whether there were any significant differences between the scores recorded on both tests. For this group of students assessed before and after the pedagogical intervention, the Wilcoxon signed-rank test, suitable for related samples, was used. The pedagogical intervention focused on using digital gamification via the Genially website to learn combinatorial analysis.
The theoretical content was explained using multimedia resources, complemented by gamified didactic sequences for solving combinatorics exercises, covering the three major concepts: permutations, variations, and combinations. The intervention comprised four 2-hour class sessions conducted in a collaborative work modality, with students working in pairs, to facilitate discussion of the solution strategies used, the exchange of ideas, and the construction of knowledge in the context of the gamified activities. Each session had a two-part design. In the first part, theory was taught using multimedia materials created in Genially, complemented by examples to guide students and help them better understand the concepts.
In the second session, students participated in a gamified didactic sequence consisting of successive challenges that alternated among gamification components, such as stories, challenges, points, badges, and instant feedback. If a student mistakenly picked an answer, the platform provided an explanation of the procedure or of a math concept required to solve the problem, allowing the student to correct the mistake and try again until the correct answer was found before proceeding to the next challenge. The first session used a Genially multimedia presentation to familiarize students with the basics of Combinatorial Analysis and the fundamental counting principles, followed by a didactic sequence in the form of an Escape Room set in a museum, which asked students to take part in a series of challenges to proceed through each room.
The second session covered simple permutations and permutations with repetition, followed by a gamified set of interactive exercises that provided immediate feedback. During the third session, simple variations and variations with repetition were discussed and illustrated through an interactive presentation and guided examples, after which a series of progressively more challenging variations was presented in context. The fourth session focused on combinations, including a theoretical presentation, application exercises, and a second escape room set on a spacecraft. All multimedia explanations and gamified sequences were hosted on the Genially platform. In the development of this study, these humanistic ethical principles were followed for educational research with human subjects.
Permission to use the data collection instruments and to implement the pedagogical intervention within the regular activities of the leveling course was requested from the authorities of the Eugenio Espejo Pre-University Institute. Before the questionnaire and knowledge test were administered, participants were briefed on the study's aim, the voluntary nature of their participation, and assurances that their responses would remain confidential. This procedure is based on the World Medical Association's Declaration of Helsinki. Although originally designed for biomedical research, its principles have extended to other areas involving human subjects, placing the welfare of the subject at the forefront rather than restricting consideration to the interests of science, and making informed consent an essential component of working with humans (Brítez Silvero, 2016). Likewise, Castro-Molina (2020) states that documents such as the Declaration of Helsinki, the Belmont Report, and the Oviedo Convention have consolidated common ethical principles, such as autonomy, beneficence, and justice, which are also relevant when research is conducted in educational environments involving populations being educated.
Participants' anonymity was ensured by coding the various parts of the questionnaire and the knowledge test, so that individual student data could not be traced back to the individuals during processing and analysis. Students were not evaluated for their participation, and withdrawal carried no repercussions. Lastly, scientific integrity was not violated in any way during data handling, neither during the pre-test nor during the post-test; and no conflicts of interest were mentioned by the researchers regarding the use of the website used for the intervention (Genially).

Table 3. Results of the Normality Test

	Statistic	df	Sig.
Difference (Pretest–Posttest)	0.816	18	.003

Note. Shapiro-Wilk test applied to the pretest–posttest score difference (df = degrees of freedom; Sig. = significance).

Results from the Wilcoxon test indicated statistically significant differences between pre- and post-test scores ($Z = -3.852$; $p < 0.001$), as shown in Table 4. Furthermore, the effect size, determined using Rosenthal's r coefficient, was .91, which represents a large effect and indicates that the students' academic performance improved significantly after the intervention.

Table 4. Comparison of Pretest and Posttest Scores Using the Wilcoxon Test

Variable	N	M Pretest	M Posttest	Z	p	r	Magnitude
Learning of combinatorial analysis	18	4.06	7.11	-3.852	<.001	.91	Large

Note. N = number of participants. M = mean. Z = Wilcoxon test statistic for related samples. p = asymptotic significance (two-tailed). r = Rosenthal effect-size coefficient ($r = Z/\sqrt{N}$). Formula and interpretation criteria follow Rosenthal and Rubin (2003): $r \approx .10$, small effect; $r \approx .30$, medium effect; $r \approx .50$, large effect.

The results here coincide with those of Jiménez et al. (2020), who developed an Escape Room in Genially and obtained an improvement of almost 2 points on the post-test, a difference that, in educational terms, is quite meaningful, corresponding to a 3.05-point increase. The gain may be linked to the characteristics of the Escape Room itself: the storyline and the high levels of adventure at every stage help keep individuals engaged by stimulating participation and motivating them. This blend of components in an Escape Room can significantly impact student motivation, according to Mosquera et al. (2024). The results from the pre-test and post-test survey indicated that most of the students accepted the gamification elements, which was evident from the post-test survey, supporting their results as shown in Figure 2, where 86.10% of the students responded that they accepted the element of gamification in high consumption, corresponding to the positive effect on motivation.

Academic motivation, as described by Picoita et al. (2025), is a combination of internal and external factors that affect students' motivation to study and, in turn, positively impact their academic success. Thus, it is not surprising that the improvement in the motivation indicator was likely one of the features associated with the design of the intervention that led to improved science performance at the posttest. The feedback provided at the end of every exercise in the Genially sequences could also have contributed to the improvement observed: immediate feedback after each answer provided information to students at the moment they made a mistake, allowing them to quickly recognize it and rework it with the help of the informational clues provided by the platform, rather than considering it later. This is consistent with the findings of Hadijah et al. (2022), who state that providing immediate feedback enables students to reduce errors by receiving feedback and guidance at the same time they make an error, helping them reprocess their thinking and adjust their strategy to grasp mathematical concepts; and Attali and Van Der Kleij (2017), who advise that immediate feedback is a learning aid because it allows students to see feedback, guidance, or improvement at the exact moment it is needed, before incorrect procedures are repeated.

This immediacy could have helped correct errors quickly, which may explain the better posttest results. Yet Almeida et al. (2022) indicate that the impact of digital gamification approaches (e.g., presenting points or badges in an escape room) on learners' engagement and subsequent examination outcomes remains unclear, as positive results may vary by age, educational level, and the context in which these approaches are applied. Other authors make the same point that digital gamification can be distracting for some learners, as missions and story settings may create distraction rather than engagement (Dichev & Dicheva, 2017). Differences between previous research and the current study may stem from the didactic approach used and the way gamification elements were applied in the learning process.

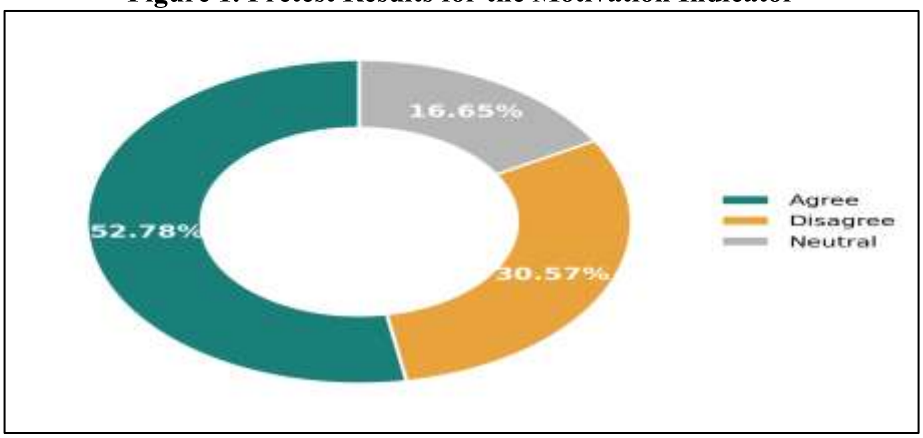
However, game elements, such as points, badges, challenges, and narratives, are not equally effective across all learning environments, as they depend on students' characteristics and implementation (as highlighted by Toda et al., 2019), meaning they alone do not yield equal positive effects. Much the same with the excessive and improper use of game, it can overwhelm and create monotony for students, and a well-designed implementation can easily encourage students to participate and engage in the learning process.

Excessive and ill-designed use of game elements can also cause boredom among students (Bai et al., 2020), whereas well-planned implementation can increase students' participation and engagement in learning. For this study, personal elements of gamification were incorporated through didactic sequences, with each challenge being a combinatorial-analysis problem and followed by instant feedback. The positive findings on academic improvement can thus be construed as merely the presence of game elements rather than as an extension of how these elements were embedded to support a teaching modality that aligned with the learning goals, in keeping with the model suggested by Robson et al. (2015) on the deliberate use of game mechanics and dynamics.

Results and Discussion

This section reports the findings from the pre- and post-questionnaires administered to students and their interpretation in light of the current literature. The independent variable, gamification, was evaluated using indicators of student motivation, perception, and collaborative participation, followed by results on academic performance. To assess the extent of motivation that gamification elements created in students, answers provided in the document, both before and after the pedagogical intervention, were analyzed, allowing detection of the level of interest in the various gamification elements that were inserted into the combinatorial-analysis learning activities. The findings from the baseline survey, conducted before the intervention, revealed that 52.78% of the students agreed to use the gamification components of points, missions, badges, and immediate feedback, while 30.57% disagreed and 16.65% were neutral (See Figure 1).

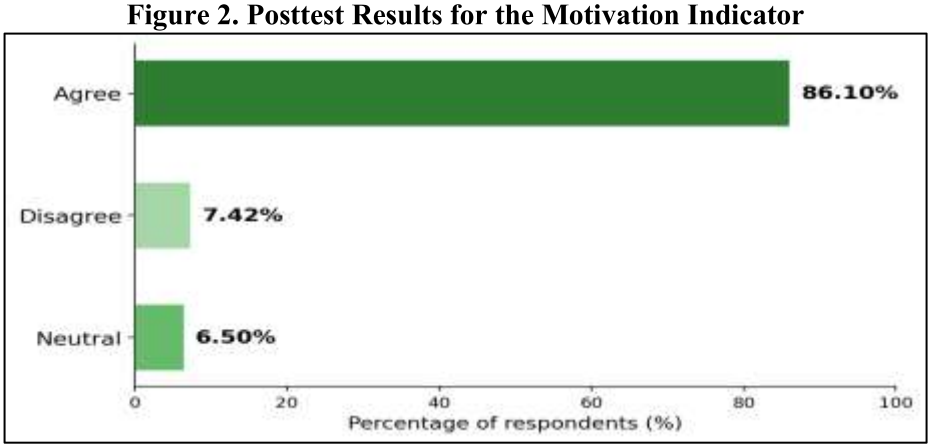
Figure 1. Pretest Results for the Motivation Indicator



Note. Author's own elaboration based on questionnaire data from the pretest (n = 18).

Figure 2 clearly shows that, after the pedagogical intervention, the majority of students (86.10%) agreed that game elements can be used in learning activities for combinatorial analysis, which is considered positive. 7.42% of students disagreed (negative), and 6.50% were neutral.

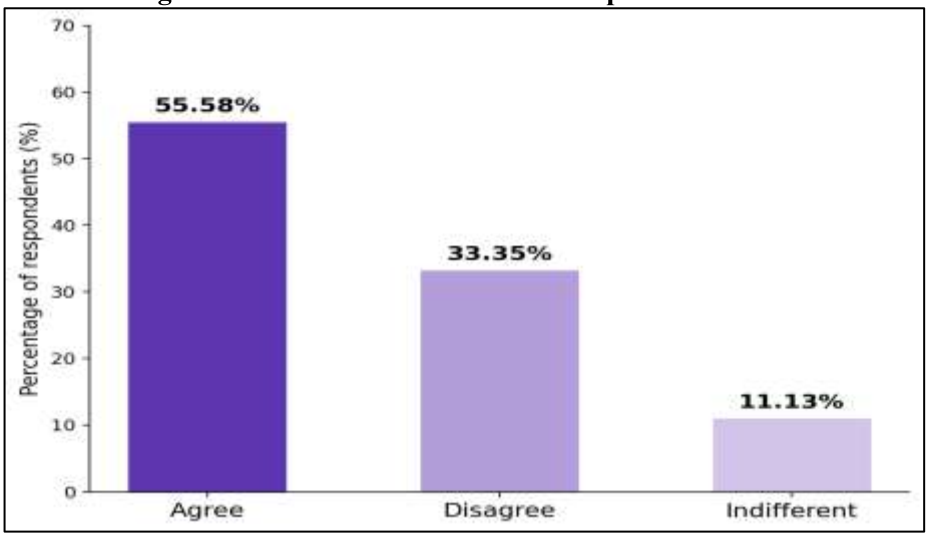
Figure 2. Posttest Results for the Motivation Indicator



Note. Author's own elaboration based on questionnaire data from the posttest (n = 18).

This rise in acceptance demonstrates how effective gamification is at enhancing student engagement and motivation. The results align with findings by Portier and Sanchiz (2024), which show that using gamification in the classroom leads to higher intrinsic and extrinsic motivation. Likewise, Alarcón et al. (2020) and Hakulinen and Auvinen (2014) found that points, badges, challenges, and immediate feedback in ICT-mediated gamified activities have positive effects on motivation and engagement. Correctly solved exercises with points, virtual badges, and feedback could therefore have served as positive reinforcement, prompting persistence and effort. However, a smaller number of students (7.42%) did not agree with this, which aligns with other research warning that gamification does not have an equal impact on students (Uz Bilgin & Gul, 2020). Pre- and post-student responses regarding perceptions of Genially as a support tool for learning combinatorial analysis were analyzed. The pre-test showed that 55.58% of students received positive scores on the Genially use dimension, 33.35% received negative scores, and 11.13% obtained a score of 0 (indifference), as shown in Figure 3.

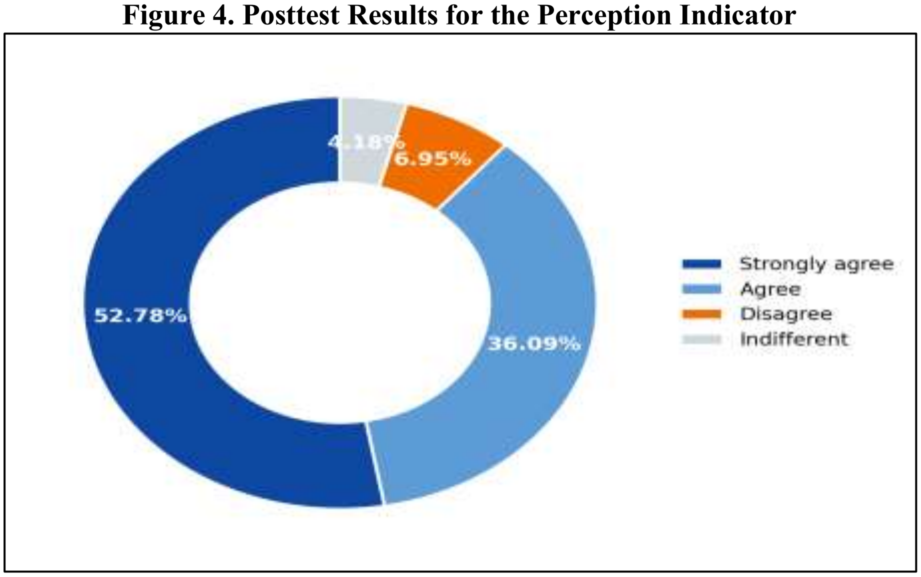
Figure 3. Pretest Results for the Perception Indicator



Note. Author's own elaboration based on questionnaire data from the pretest (n = 18).

However, 36.09% and 52.78% of the students stated that they agree and strongly agree, respectively, that Genially is a technological resource for learning about combinatorics, as shown in Figure 4. Only 6.95% disagreed, and 4.18% were undecided. The results indicate a positive assessment of the use of this technology platform in the learning process.

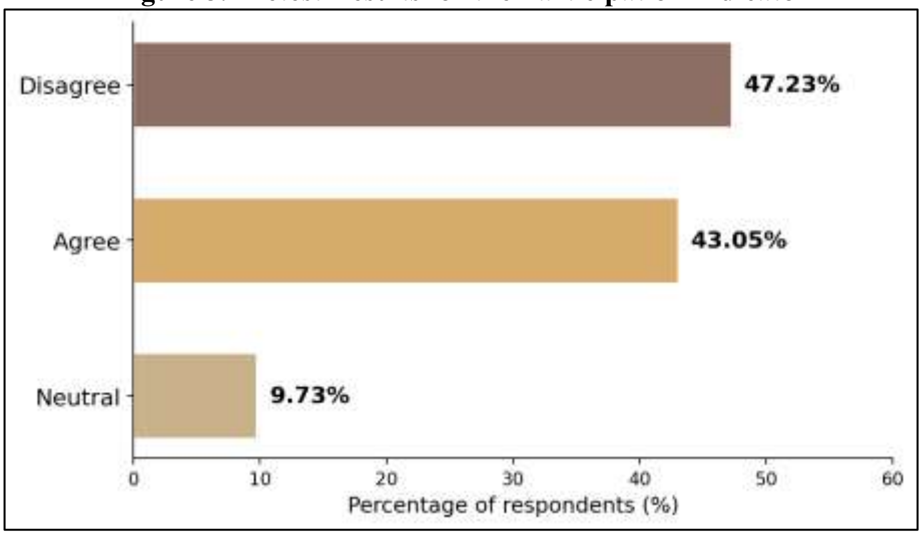
Figure 4. Posttest Results for the Perception Indicator



Note. Author's own elaboration based on questionnaire data from the posttest (n = 18).

The results obtained are similar to those reported by Pastás et al. (2024), who found that in subjects such as mathematics, activities can be diversified using Genially, as it allows the incorporation of multimedia resources, interactive buttons, and links, providing a visually engaging and dynamic experience. Within the intervention, Genially enabled the incorporation of images in the formulation of problems and in conceptual explanations, favoring comprehension, whereas more traditional teaching offered fewer opportunities for the use of images, sometimes imposing the task of imagining the situation on students' part.
The results support the recommendations of other researchers that conceptual understanding is more easily reinforced through multimodal presentation (Aponte, 2021; Bermúdez & Pazmiño, 2022), but this depends on the design of the presentation, consideration of the user, and the cultural context (Maguiña & Padilla, 2024). The results were analyzed before and after the pedagogical intervention to assess students' collaboration during the gamification activities. According to the preliminary survey results shown in Figure 5, 43.05% of the students were willing to collaborate; 47.23% disagreed; and 9.73% were neutral (indicating slight opposition or indifference).

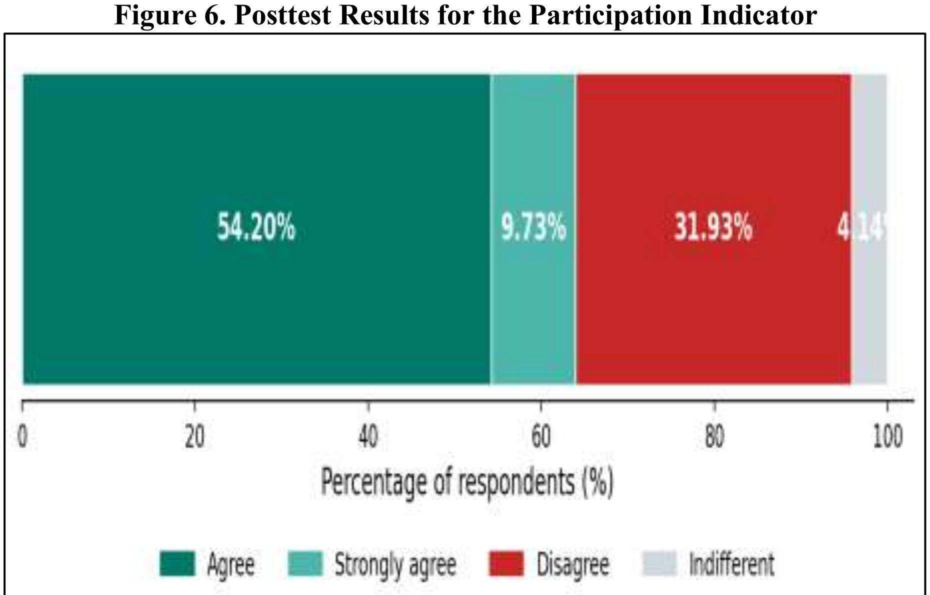
Figure 5. Pretest Results for the Participation Indicator



Note. Author's own elaboration based on questionnaire data from the pretest (n = 18).

However, following the intervention, 54.20% agreed and 9.73% strongly agreed to using group work; 31.93% disagreed, and 4.14% gave neutral responses (Figure 6). Based on these results, there was a slight change in students' desire to work collaboratively with peers in the game environment.

Figure 6. Posttest Results for the Participation Indicator

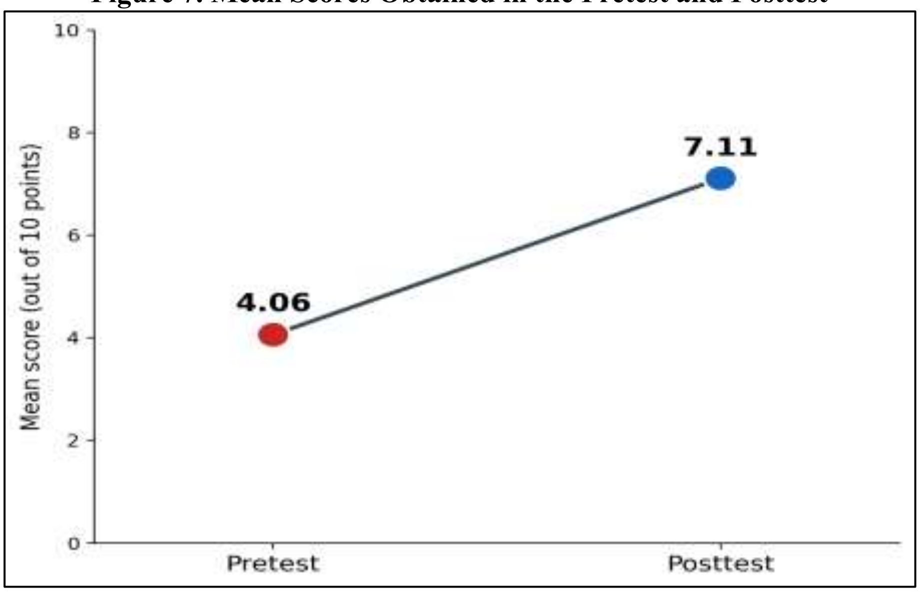


Note. Author's own elaboration based on questionnaire data from the posttest (n = 18).

All these results align with those presented by Reyes (2021), who believes that rhetorical missions within a gamified activity help foster teamwork. However, while the learning benefits are significant, one or more person- or culture-level differences may persist and prevent collaborative work entirely. This aligns with the results of Araya et al. (2019), which noted that not everyone responds positively to gamified dynamics due to personal factors that affect their sense of involvement. Similarly, Serrano et al. (2018) observed that team collaboration issues may emerge naturally within teams and that while gamification boosts motivation, it will not resolve them completely. Therefore, it is important to keep an eye on how the team interacts.

Group-learning technologies that involve gamification can be challenging because personal attitudes may undermine students' group mentality, especially when students prefer to work individually due to prior negative experiences (Uz Bilgin & Gul, 2020). It's therefore best to identify observed social interaction behaviors before designing these activities, as some students may exhibit negative ones. The academic gains of students after applying the pedagogical intervention were evaluated by comparing the pretest and posttest quizzes for the combinatorial-analysis knowledge test, each worth 10 points. The mean scores for both measurements are displayed in Figure 7. A difference of 3.05 points between pre and post is observed, with a mean of 4.06 points on the pretest and 7.11 points on the posttest for students' scores.

Figure 7. Mean Scores Obtained in the Pretest and Posttest



Note. Author's own elaboration based on the results of the combinatorial-analysis knowledge test (n = 18).

It was assumed that this difference was statistically significant because the Shapiro-Wilk test, appropriate for samples of fewer than 50 students, indicated so. The normality test results (Table 3) showed that the data were significantly below the significance level of .05 (p = .003), indicating that the data did not follow a normal distribution. However, a non-parametric Wilcoxon test for related samples was used.

Limitations and Scope for Future Research

The results should be considered within the methodological scope of this research. The pre-experimental design offers evidence for the use of gamification in Gam2Liv within a particular educational context (a private pre-university institute), and students in this setting may not be representative of other students or contexts. This decision was made because of the nature of the setting, in which leveling-course enrollment fluctuates throughout the year, limiting the design choices. Caution should be exercised when generalizing these findings due to the small number of participants and the single-group design. Notably, significant differences were observed between pre- and post-testing; however, because there was no comparison group, it was difficult to compare the impact of gamification with other teaching methods.

The results, despite these limitations, do offer empirical evidence for the potential of gamification in Genially to support learning in combinatorial analysis and should serve as a starting point for comparative studies across different content areas of mathematics, using larger samples, comparison groups, and longer intervention periods. Variations, permutations, and combinations could be analyzed individually to determine which are best suited for gamification with Genially. Future research would also consider the transfer of skills gained in the game to related computational scenarios, such as those based on combinatorial encoding embedded in genetic algorithms and sequence-enumeration methods widely used in bioinformatics (see the introduction for connections). Experimental designs with a control group, along with extended follow-up of students into university STEM-related majors and continued assessments of motivation and performance, would enable researchers to determine whether any benefits in motivation or performance found in this study persist over time.

Conclusion

This research examined the effectiveness of incorporating gamification, particularly Genially, as a pedagogical approach to enhance the learning of combinatorial analysis, using students from the Eugenio Espejo Pre-University Institute as the sample. The main principles of gamification were first clarified in a survey administered to students and then incorporated into the creation of didactic sequences on combinatorial analysis in Genially to increase students' engagement with the material. The findings revealed that the gamification elements evaluated (points, badges, challenges, difficulty level, stories, and immediate feedback) positively influenced students' motivational mechanisms, as shown by the survey, which indicated that a high percentage of students accepted the gamification elements used. Another gamified approach to teaching was also developed with the help of Genially and was well received by students because of its ability to make learning the content of combinatorial analysis easier; this was again confirmed by the post-intervention survey, in which students reported that the images and interactive aspects suggested during the didactic sequences in Genially were satisfactory.

The gamified approach was perceived as a positive and acceptable way of working, although some students exhibited minimal cooperation with group members during group activities. The results of this research confirmed that game-based methods can encourage students' active involvement in the learning process, but not all students responded positively to group dynamics. Therefore, it is expected that future empirical research will further confirm the role of group dynamics in students' learning activities. Academic outcomes were evaluated to assess the learning effects of gamification as a pedagogical intervention to enhance combinatorics learning through a pre-test/post-test comparison. The nonparametric Wilcoxon test revealed statistically significant differences in the overall mean score between the pretest and posttest after the gamified teaching strategy; the posttest score increased by 3.05 points. These results, together, strongly advocate for gamification, using the tool Genially, not just as a method to provide reinforcement for combinatorial analysis as a topic of mathematics, but as a way to help develop the associated skills of combinatorial reasoning that have further uses in mathematical contexts like the design of genetic algorithms and the enumeration of biological sequences, which support the broader educational value of investing in this competency during the pre-university curriculum.

References

1. Alarcón, M., Alarcón, H., Rodríguez, L., & Alcas, N. (2020). Educational intervention based on gamification: Experience in the university context. Revista Eleuthera, 22(2), 117–131. https://doi.org/10.17151/eleu.2020.22.2.8
2. Aldalur, I. (2025). Enhancing software development education through gamification and experiential learning with Genially. Software Quality Journal, 33(1). https://doi.org/10.1007/s11219-024-09699-9
3. Almeida, C., Kalinowski, M., Uchôa, A., & Feijó, B. (2022). Negative effects of gamification in education software: Systematic mapping and practitioner perceptions. Information and Software Technology, 156, 107142. https://doi.org/10.1016/j.infsof.2022.107142
4. Alvarez, N., Rivadeneira, J., & Montero, S. (2023). Difficulties in the teaching and learning of statistics and probability: A student perspective. Ecos de la Academia, 8(16), 81–97. https://doi.org/10.53358/ecosacademia.v8i16.772
5. Araya, R., Arias, E., Bottlan, N., & Cristia, J. (2019). Does gamification work in education? Experimental evidence from Chile. https://doi.org/10.18235/0001777
6. Attali, Y., & Van Der Kleij, F. (2017). Effects of feedback elaboration and feedback timing during computer-based practice in mathematics problem solving. Computers & Education, 110, 154–169. https://doi.org/10.1016/j.compedu.2017.03.012
7. Bai, S., Hew, K. F., & Huang, B. (2020). Does gamification improve student learning outcome? Evidence from a meta-analysis and synthesis of qualitative data in educational contexts. Educational Research Review, 30, 100322. https://doi.org/10.1016/j.edurev.2020.100322

8. Bermúdez, O., & Pazmiño, M. (2022). Multimedia tools and learning skills at the "Manuel Inocencio Parrales y Guale" Educational Unit. Revista Científica Multidisciplinaria Arbitrada YACHASUN, 6(11), 91–103. Retrieved from https://www.redalyc.org/journal/6858/685872167006/html/
9. Bravo, F. (2020). Difficulties faced by incoming university students in mathematics. INNOVA Research Journal, 5(1), 1–13. https://doi.org/10.33890/innova.v5.n1.2020.994
10. Brítez Silvero, J. de la C. (2016). Ethics in human research and the Ethics Committee (Part 2). Revista Virtual de la Sociedad Paraguaya de Medicina Interna, 3(1), 8–10. https://doi.org/10.18004/rvspmi/2312-3893/2016.03(01)08-010
11. Castro-Molina, F. J. (2020). Ethics vs. research. Cultura de los Cuidados, 24(57), 4–8. https://doi.org/10.14198/cuid.2020.57.01
12. Catalán, F., & Pérez, M. (2020). Genially: New forms of content dissemination and development. In Motivating and learning: The challenge of ICT in the humanities classroom (Vol. 1, pp. 19–28). Retrieved from https://www.academia.edu/42101179
13. Chávez, S., Esparza, A., & Moreno, L. (2020). Pre-experimental and quasi-experimental designs applied to the social sciences and education. Enseñanza e Investigación en Psicología, 2(2), 167–178.
14. Corchuelo, C. A. (2018). Gamification in higher education: An innovative experience to motivate students and energize classroom content. Edutec. Revista Electrónica de Tecnología Educativa, 63. https://doi.org/10.21556/edutec.2018.63.927
15. Dichev, C., & Dicheva, D. (2017). Gamifying education: What is known, what is believed and what remains uncertain: A critical review. International Journal of Educational Technology in Higher Education, 14(1). https://doi.org/10.1186/s41239-017-0042-5
16. Espinoza, J., & Roa, R. (2013). Theoretical development of the combinatorics topic in secondary-school mathematics textbooks in Spain. Actas de las Jornadas Virtuales en Didáctica de la Estadística, Probabilidad y Combinatoria, Universidad de Granada, 181–188. Retrieved from https://dialnet.unirioja.es/descarga/articulo/5487211.pdf
17. Fuentes, S., & Roa, R. (2014). Deriving the multiplicative principle: An exploratory activity with first-year secondary students. In F. J. España (Ed.), Proceedings of the XV Congress on Mathematics Teaching and Learning (pp. 441–449).
18. Hadijah, H., Isnarto, I., & Walid, W. (2022). The effect of immediate feedback on mathematics learning achievement. Jurnal Pijar MIPA, 17(6), 712–716. https://doi.org/10.29303/jpm.v17i6.4172
19. Hakulinen, L., & Auvinen, T. (2014). The effect of gamification on students with different achievement goal orientations. Proceedings – 2014 International Conference on Teaching and Learning in Computing and Engineering, LATICE 2014, 9–16. https://doi.org/10.1109/LaTiCE.2014.10
20. Ineval. (2017). Results report: Ser Bachiller, 2014–2015 cycle. Retrieved from https://cloud.evaluacion.gob.ec/dagireportes/nacional/2014-2015.pdf
21. Ineval. (2019). National results report: Ser Bachiller, 2018–2019 school year. Retrieved from https://cloud.evaluacion.gob.ec/dagireportes/nacional/2018-2019.pdf
22. Jama, V., & Cornejo, J. (2023). Building mathematics through gamification resources. Revista Docentes 2.0, 16(2), 138–142. https://doi.org/10.37843/rted.v16i2.388
23. Jiménez, C., Arís, N., Ruiz, Á. A. M., & Orcos, L. (2020). Digital escape room, using Genial.ly and a breakout to learn algebra at secondary education level in Spain. Education Sciences, 10(10), 1–14. https://doi.org/10.3390/educsci10100271
24. Lamanna, L., Gea, M., & Batanero, C. (2022). Do high school students' strategies for solving permutation and combination problems change with instruction? Canadian Journal of Mathematical Sciences and Educational Technology, 22, 602–616. https://doi.org/10.1007/s42330-022-00228-z
25. Lanuza, M., & Lanuza, M. H. (2020). Integrative gamification technique in teaching specialization courses in mathematics. International Journal of Scientific & Technology Research, 9. Retrieved from https://www.researchgate.net/publication/351062497
26. López, P., & Fachelli, S. (2016). The research process. In Methodology of quantitative social research (Digital ed.). Universitat Autònoma de Barcelona. Retrieved from https://ddd.uab.cat/record/163564
27. Maguiña, L., & Padilla, J. (2024). Technological innovations in mathematics learning in basic education: A systematic review. Revista Invecom, 5, 1–9. https://doi.org/10.5281/zenodo.14271210
28. Mosquera, K. D. Q., Guerrero, J. M., Trujillo, A. V. R., Pilaquinga, T. A. B., & Tipán, M. G. P. (2024). Escape room for assessing mathematical competencies. LATAM Revista Latinoamericana de Ciencias Sociales y Humanidades, 5(4). https://doi.org/10.56712/latam.v5i4.2360

29.Ochoa, L., & Moscoso, S. (2024). Genially as a didactic resource for teaching chemistry: An experience with high-school students. Revista Metropolitana de Ciencias Aplicadas, 7, 315–327. Retrieved from https://remca.umet.edu.ec/index.php/REMCA/article/view/754/743
30.Pastás, X., Zumba, E., & Imbacuán, D. (2024). Genially, a gamification tool for teaching and learning mathematics. Imaginario Social, 7, 81–97. https://doi.org/10.59155/is.v7i1.151
31.Picoita, E. I. V., Cedeño, L. M. C., Morocho, M. F. G., Domínguez, J. M. G., & Ibáñez, M. V. P. (2025). Influence of student motivation on the academic performance of sixth-grade students in mathematics. LATAM Revista Latinoamericana de Ciencias Sociales y Humanidades, 6(5). https://doi.org/10.56712/latam.v6i5.4742
32.Portier, C., & Sanchiz, M. (2024). Effects of the instructional message used to introduce game-based learning, prior knowledge, prior gaming experience and flow on learning. Information and Learning Sciences, 125, 943–965. https://doi.org/10.1108/ILS-11-2023-0185
33.Prieto, J. M., & Moreno, P. (2024). Playing correctly: Empirical validation of the Gamertype scale for game-based learning in higher education. Revista Española de Pedagogía, 82(288), 243–270. https://doi.org/10.22550/2174-0909.4056
34.Quintana, J., Diaz, T., Suarez, A., & Almeida, I. (2020). Teaching strategy for developing the skills needed to solve combinatorics problems in discrete mathematics. Revista Publicaciones UCI, 13(6). Retrieved from http://publicaciones.uci.cu
35.Reyes, W. (2021). Gamification and online collaborative learning: An analysis of strategies at a Mexican university. Alteridad, 17(1), 24–35. https://doi.org/10.17163/alt.v17n1.2022.02
36.Robson, K., Plangger, K., Kietzmann, J. H., McCarthy, I., & Pitt, L. (2015). Is it all a game? Understanding the principles of gamification. Business Horizons, 58(4), 411–420. https://doi.org/10.1016/j.bushor.2015.03.006
37.Rosenthal, R., & Rubin, D. B. (2003). r-equivalent: A simple effect size indicator. Psychological Methods, 8(4), 492–496. https://doi.org/10.1037/1082-989X.8.4.492
38.Sánchez, C. (2019). Gamification: A new approach for Ecuadorian education. Revista Internacional Docentes 2.0. https://doi.org/10.37843/rted.v7i2.16
39.Serrano, F., Berdún, F., & Armentano, M. (2018). From "tactical discussion" in collaborative games to "behaviors": A stage-based classification approach. Inteligencia Artificial, 21(61), 82–94. https://doi.org/10.4114/intartif.vol21iss61pp82-94
40.Toda, A., Klock, A., & Oliveira, W. (2019). Analysis of gamification elements in educational environments using an existing gamification taxonomy. Smart Learning Environments, 16, 6. https://doi.org/10.1186/s40561-019-0106-1
41.Torres, L. (2021). Reliability of scales: Interpretation and limitations of Cronbach's alpha. Retrieved from https://www.researchgate.net/publication/350590351
42.Uz Bilgin, C., & Gul, A. (2020). Investigating the effectiveness of gamification on group cohesion, attitude, and academic achievement in collaborative learning environments. TechTrends, 64(1), 124–136. https://doi.org/10.1007/s11528-019-00442-x
43.Vázquez, H., Cruz, A., Solano, F., & Cervantes, H. (2014). Combinatorics: Why is it so difficult for some? In Instituto Tecnológico de Costa Rica (Ed.), Proceedings of the IV Meeting on Statistics, Probability, and Data Analysis Education (pp. 1–7). Instituto Tecnológico de Costa Rica.