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Boosting engagement and learning in the economic analysis of chemical processes through gamification

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ABSTRACT

This article explores the effectiveness of gamification in the course "Design of Chemical Products and Processes" of the Master's Degree in Chemical Engineering at the University of Granada. In particular, the gamified educational activities were developed in the thematic block on the economic analysis of chemical processes over three academic years. The gamification activities implemented included dominoes, bingo, word search, hangman, and passing the word. The results indicate that these activities improved student motivation, participation, and learning. Additionally, a positive perception of collaboration and teamwork was observed. Gamification not only made learning more attractive but also fostered deeper and more meaningful learning, providing empirical evidence of its benefits in higher education. The study includes a description of the activities conducted, perception and evaluation questionnaires from students regarding the proposed activities, and an assessment of the results (surveys and acquired competencies). This allows for identifying the advantages and improvements for future courses.

1. Introduction

Gamification can be defined as the application of game elements in non-game contexts, and, in recent years, it has emerged as an innovative strategy in higher education. The main objective of gamification in higher education is to increase student motivation and engagement, thereby improving both their academic performance and learning experience (Deterding et al., 2011; Hamari et al., 2014; Subhash and Cudney, 2018). Several works have shown that gamification can enhance knowledge retention, foster student collaboration, and increase classroom participation (Hamari et al., 2014; Subhash and Cudney, 2018).

In the last decades, the use of educational games in the classroom, including board games, card games, quizzes, and word games, between others, have been explored (Hanson, 2002; Capps, 2008; Costa, 2007; Pippins et al., 2011). Also, more recently, the implementation of educational escape games is gaining attention since they had shown promising results in terms of motivation and learning (Nicholson, 2015; Borrego et al., 2017; Vörös and Sárközi, 2017).

The relevance of gamification in higher education aligns with several theories, such as the Self-Determination Theory (SDT) proposed by Ryan and Deci (2000), which suggests that providing students a sense of control over their learning, opportunities to demonstrate competence, and a socially connected environment can improve their learning or the Csikszentmihalyi's (1990) Flow Theory that suggests that people are most motivated when they are fully immersed in an activity that balances challenge and skill. In addition, gamification in education is supported by the active learning approach, which emphasizes the importance of active student participation in the learning process (Prince, 2004).

Specifically, in the Chemical Engineering field, several gamification activities have been explored (Azizan et al., 2018; Rodríguez et al., 2018). For example, Suarez-López et al., (2023) analyzed the use of a board game in Thermal Engineering courses at two Spanish universities, the University of Oviedo and the University of Las Palmas de Gran Canaria, over several academic years (from 2015–2016 to 2019–2020), with the aim of increasing student motivation. Although students enjoyed the activity and were satisfied with the teamwork, organization, and grades obtained, they considered that learning concepts was more effective in traditional classes. Martín-Lara and Calero (2020) also designed a board game titled "Bioenergy & Biofuels" for Chemical Engineering students in the "Biofuels and Alternative Energies" course over two consecutive academic years. Rodríguez et al., (2018) designed a board game called "Triviachis," which is a combination of a trivia game,

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and a Spanish board game called Parchís. The authors divided the students into groups and structured the class as an elimination tournament. This increased student motivation and interest, helping them retain concepts better by focusing on game questions. Moreno-Medina et al., (2023) applied gamification techniques using Wooclap software in the Mechanical Equipment Design course in Chemical Engineering, showing an increase in motivation and academic performance, although with limitations related to connectivity. Aymard et al., (2021) presented a gamified learning activity that combines bibliographic research with oral argumentation in a competitive "battle" format, designed to engage and motivate students in chemical engineering topics. Process simulators, recognized as powerful supporting tools in engineering education, are employed across all educational levels (Caño de las Heras et al., 2021). Their contribution introduces a framework called P2Si for the systematic development and conceptual design of educational process simulators. This framework integrates learning design, gamification, process models, and participatory design with students to prepare future engineers.

Another interesting approach is educational escape games, which have gained popularity as a tool to foster teamwork and critical thinking (Nicholson, 2015; Borrego et al., 2017). La Flor et al. (2020) presented an interactive evaluation based on an escape game for third-year Chemical Engineering students in the Heat Transfer course. The activity, centered on the theme of a “mad scientist,” increased student participation, motivation, and performance, with students showing enthusiastic attitudes and achieving better grades than with traditional methods. Other authors proposed the use of an escape game called “Carnivorous Yogurts” to replace the first hour of a 4-h laboratory session in which agitation and mixing processes were learned. With the introduction of this one-hour game, the laboratory session was reduced to three hours. However, these games are often costly and limited to small groups (Bezard et al., 2020). Monnot et al. (2020) proposed digital alternatives to integrate these games into large classes, increasing motivation and facilitating their dissemination in universities.

Additionally, authors like Díaz et al. (2024) discussed the use of “serious games” in various chemical engineering subjects, presenting four game-based activities in subjects such as Process Control and Chemical Process Optimization. The results showed that these games helped students review concepts actively and relaxed, fostering participation and motivation. Similarly, Nunes da Silva Júnior et al. (2021) designed a multilingual mobile application to review organic reactions, with positive feedback from students. Azizan et al. (2018) also instructed students to develop a board game on kinetics and reactor design, highlighting creativity and teamwork as key elements.

This study aims to explore the effectiveness of gamification in the “Design of Chemical Products and Processes” course of the Master’s Degree in Chemical Engineering at the University of Granada. It seeks to provide empirical evidence on the benefits of this strategy and contribute to the development of innovative pedagogical practices in higher education.

2. Materials and methods

2.1. Context and participants

The present study was conducted in the thematic block on the economic analysis of chemical processes of the “Design of Chemical Products and Processes” course (Master’s Degree in Chemical Engineering, University of Granada, Spain). Students enrolled in this course during three consecutive academic years (2021–2022, 2022–2023, and 2023–2024) participated in the study.

Some examples of the concepts that are covered in this thematic block of the course are: the role of the company in the economy, its functions, and elements, as well as the functional areas of a company. It also includes types of companies, investment, financing, accounting, and the company’s accounting obligations. Additionally, it covers patrimonial elements, the balance sheet, the profit and loss account, and financial and economic analysis ratios. The block further delves into total capital, components of fixed capital, methods for determining fixed assets, cost estimation of equipment, working capital determination, price updates, production costs, and their classification. Finally, it addresses the profitability criteria for project evaluation, cash flow diagrams, inflation and interest rates, profitability calculation methods, both static and dynamic, and sensitivity analysis.

2.2. Description of the gamification sessions

Three gamification sessions were developed using different educational games: dominoes in the first session, bingo in the second, and word search, hangman, and pass the word in the third and last session. These gamification activities were designed to teach economic concepts in chemical engineering in a more accessible and engaging way. The sessions were conducted during regular class hours and had a total duration between 45 and 60 min each one. Table 1 provides a detailed summary of the different sessions’ objectives and thematic concepts covered.

2.2.1. Session 1: dominoes

For this activity, customized dominoes were created, each divided into two sections: one side featured a type of legal form of a company (e.g. cooperative society, individual entrepreneur, limited liability company, etc.), and the other included a corresponding characteristic (see Fig. 1). The class was divided into 4–5 groups to ensure active participation. All the dominoes were placed face down in a pile, and each student selected four pieces. One domino was placed face-up in the center of the table to start the game.

Following a clockwise order, each student examined their dominoes to determine if they had a piece that could be placed next to the one in the center by correctly matching the type of society with its respective characteristics.

If a student could not place any of their dominoes, they had to draw a new piece from the pile and wait for their next turn. The game continued until one group managed to use all their dominoes, completing the sequence successfully.

2.2.2. Session 2: bingo

For this activity, customized bingo cards were prepared, each consisting of 6 columns and 3 rows, like a traditional bingo card (see Fig. 2). Each student was provided with a randomly assigned bingo card.

Table 1
Gamification sessions and thematic concepts.

Session	Game	Thematic concepts covered	Didactic implications
1	Dominoes	Main legal forms of a company	Discuss and validate their choices as a team, reinforcing their understanding of the different legal forms of a company and their characteristics in an engaging manner.
2	Bingo	Fundamental accounting terms (balance sheet; assets; equity; liabilities)	Reinforce the students’ understanding of basic accounting terms related to developing a balance sheet by requiring them to recall and apply their knowledge in a dynamic, participatory setting.
3	Word Search Hangman Pass the word	Financing and investment terms	Reinforce key vocabulary and promote quick thinking and word cognitive skills.

Fig. 1. Examples of materials in the Dominoes game.

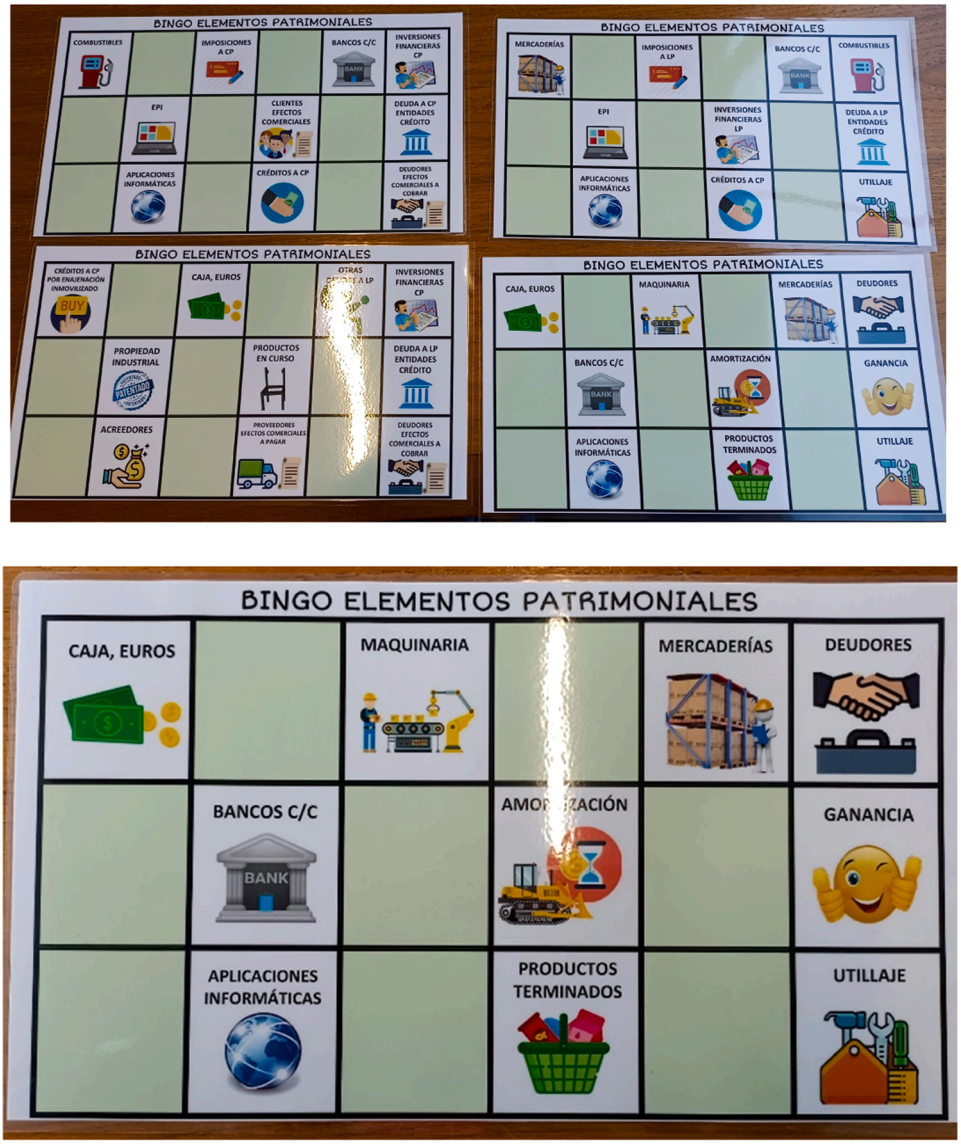

Fig. 2. Examples of materials in the bingo game.

However, unlike traditional bingo, the teacher did not announce the name of the basic accounting term directly. Instead, the teacher provided a definition, encouraging students to identify the correct element and mark it on their cards. When a student completed a line on the card, they had to announce it by saying "LINE". If they completed one or more bingo patterns, they had to shout "BINGO". The teacher verified that the identified elements on the student's card matched the definitions provided during the game.

2.2.3. Session 3: word search, hangman, and pass the word

In this session, knowledge acquired about financing and investment concepts was consolidated through three word activities developed in small groups (see Fig. 3): a) First, students had to find and define key terms in a word search puzzle; b) then, students had to discover and define words through the classic hangman game and, c) finally, students had to correctly answer a series of definitions following the game pass the word.

Word Search (known as "*Sopa de Letras*" in Spanish) is a puzzle game in which students are given a grid of letters and must find specific words hidden within it. The words can be spelled forward or backward and can be arranged horizontally, vertically, or diagonally. The objective is to find all the words within the grid and then define them correctly.

Hangman (known as "*Ahorcado*" in Spanish) is a classic game in which students try to figure out a hidden word by guessing letters, separately. If the letter is not in the word, a part of the figure (representing the "hangman") is drawn (head, body, one arm, other arm, one leg, other leg). The students pass the game if they can assume the entire word before the hangman figure is fully drawn. The objective is to find all the words and then define them correctly.

Pass the Word (known as "*Pasapalabra*" in Spanish) is a game in which students try to guess a word based on a given definition. The game typically involves a sequence of words that starts with one letter of the alphabet and is defined in alphabetic order.

2.3. Evaluation

To collect the students' feedback and perceptions, a Likert scale questionnaire was designed. The questionnaire included the eight statements summarized in Table 2, and students responded to each statement on a scale from 1 (strongly disagree) to 5 (strongly agree). The survey covers a range of aspects, including understanding learning objectives, content usefulness, time adequacy, enjoyment, learning enhancement, collaboration, participation, and the importance of gamification in education. Additionally, qualitative analyses of open-ended comments provided by students were conducted to identify recurring themes and gain a deeper understanding of their experiences and perceptions.

Finally, to evaluate the effectiveness of the gamification method, a comparison was made between the academic results of cohorts that did not use gamification and those that implemented gamification activities.

3. Results and discussion

Table 3 presents the survey results over three academic years, evaluating students' perceptions of the implementation of gamification activities in the classroom.

The results show that students consistently rated the activities positively across all academic years. They clearly understood the learning objectives (Q1) and the usefulness of the content (Q2), with mean scores above 4.0. This suggests that the games are well-designed and aligned with the educational goals. Similarly, the adequacy of the time dedicated to these gamification sessions (Q3) was perceived positively. This suggests that the duration of the activities is well-balanced, allowing sufficient time for learning without being excessively long. Additionally, students found the games fun and entertaining (Q4), which is crucial for maintaining their interest and motivation. Most students also felt that the games enhanced their learning in the subject (Q5), supporting the effectiveness of gamification as an educational tool to reinforce concepts and skills. Furthermore, there was a positive perception of the collaborative atmosphere during the development of the games (Q6), which is important as teamwork and collaboration are essential skills in educational and professional environments. Regarding question Q7, students indicated that they participate more actively in the subject with the implementation of these activities. Finally, students consider it important for teachers to develop gamification activities in different subjects, suggesting that students value these methodologies and see benefits in their application across various areas of study.

If different academic years are compared, the mean scores of the eight questions over the three academic years show notable consistency, with most means ranging between 4.0 and 4.7. In the 2023–2024 academic year, there is less variability in responses, reflected in lower standard deviations compared to previous years. Questions Q3 and Q5 stand out for their significant improvements in the last year, while question Q1 shows a gradual improvement over time. Additionally, some questions like Q8 have maintained notable stability in their means over the three years. Overall, the results indicate a positive trend and greater consistency in student responses in the most recent year.

Fig. 4 shows a comparative bar chart of positive responses (4 and 5 on the Likert scale) across academic years. The chart illustrates a stable trend in high rating, with improvements in all areas in the last academic year, which could indicate that modifications in the implementation of educational games have been effective. These findings align with prior research that underscores the benefits of gamification in promoting motivation, participation, and collaboration (Suárez-López et al., 2023;

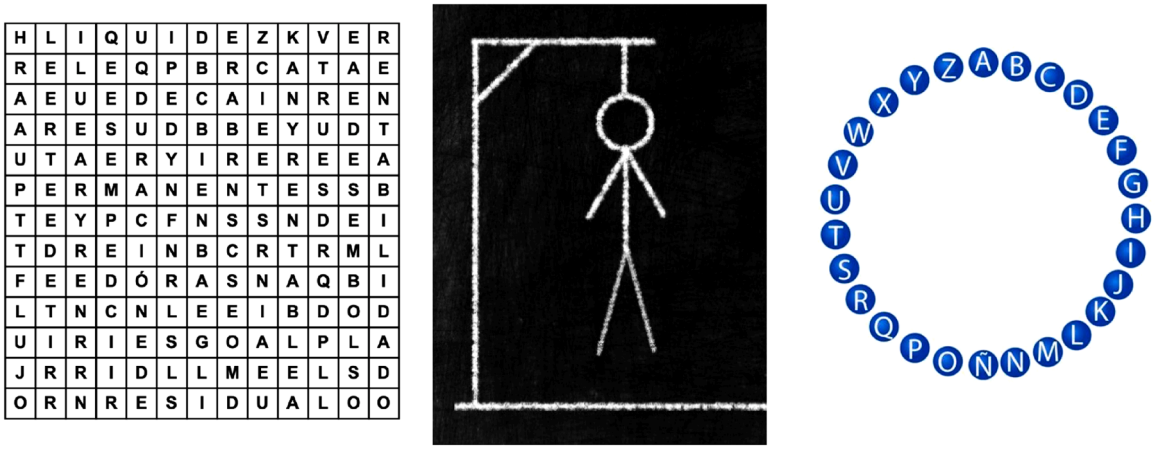

Fig. 3. Examples of materials in a) word search, b) hangman, and c) pass the word games.

Table 2
Likert scale questionnaire for the gamification sessions.

Q1: I have clearly understood the learning objectives and the fundamental aspects of each game developed.
Q2: The content developed in each game has been useful to me.
Q3: The time dedicated to the games seems adequate to me.
Q4: I found the games fun and entertaining.
Q5: The games have enhanced my learning in the subject.
Q6: During the development of the games, there was a good atmosphere of collaboration among classmates.
Q7: With the implementation of these types of activities, I participate more actively in the subject.
Q8: I consider it important for teachers to develop gamification activities in different subjects.

Table 3
Perception of the students of the gamification activities.

Question	Academic year (n = population)					
	23–24 (n = 9)		22–23 (n = 12)		21–22 (n = 15)	
	Mean	Deviation	Mean	Deviation	Mean	Deviation
Q1	4.3	0.71	4.2	1.03	4.0	0.93
Q2	4.2	0.67	4.3	0.75	4.1	0.88
Q3	4.7	0.50	4.3	0.78	4.3	0.80
Q4	4.1	0.93	4.3	0.75	4.3	0.70
Q5	4.6	0.53	4.3	0.78	4.1	0.64
Q6	4.4	0.53	4.2	0.72	4.3	0.70
Q7	4.4	0.53	4.5	0.67	4.2	0.68
Q8	4.3	0.71	4.3	0.75	4.3	0.72

Moreno-Medina et al., 2023; La Flor et al., 2020).

Table 4 presents student preferences for games across the academic years. In all three academic years, Bingo was consistently the most popular game among students, both in terms of fun and learning, with a growing preference each year. Dominoes also maintained constant popularity, being the favorite of some students and considered fun and educational. Hangman and Word Search showed variability in their popularity, with an increase in preference for Hangman in the 21–22 years. Pass the Word had moderate acceptance compared to other games, which could reflect a preference for games with more dynamic and competitive elements. However, its emphasis on vocabulary recall allowed students to effectively consolidate key concepts.

Fig. 5 shows the cumulative student preferences for educational games. Overall, the results indicate that more interactive and

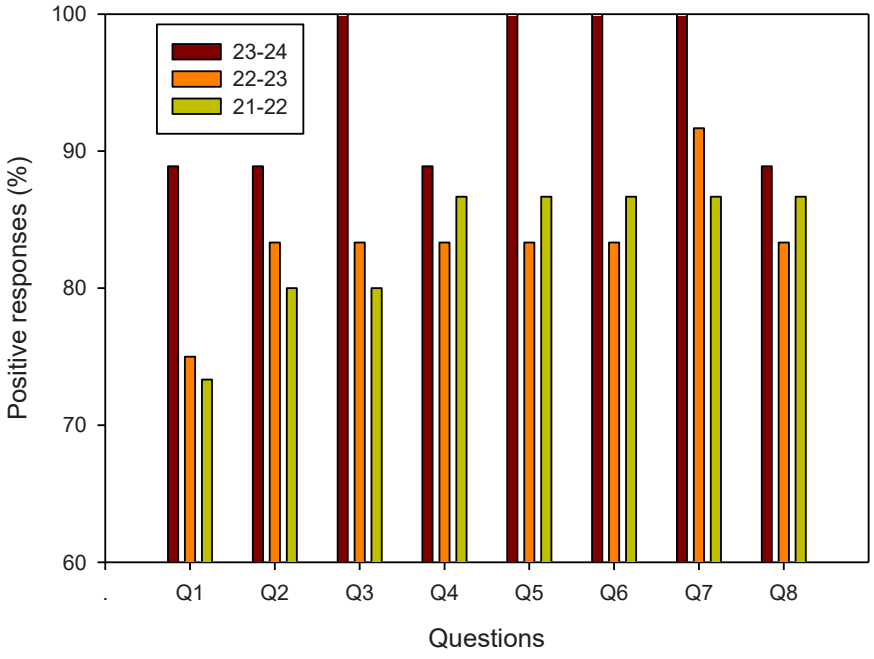

Fig. 4. Comparative bar chart of positive responses (4 and 5 in Likert scale) across academic years.

Table 4
Student preferences for educational games across academic years.

Game	Which of the games conducted has been your favorite? Academic year (n = population)			Which game did you find the most fun? Academic year (n = population)			Which game do you consider has provided you with the most learning? Academic year (n = population)		
	23–24 (n = 9)	22–23 (n = 12)	21–22 (n = 15)	23–24 (n = 9)	22–23 (n = 12)	21–22 (n = 15)	23–24 (n = 9)	22–23 (n = 12)	21–22 (n = 15)
Dominoes	3	3	3	3	4	4	2	3	3
Bingo	4	4	4	5	5	5	6	5	5
Word search	0	1	2	0	0	0	0	1	1
Hangman	0	1	3	0	1	3	0	1	3
Pass the word	2	3	3	1	2	3	1	2	3

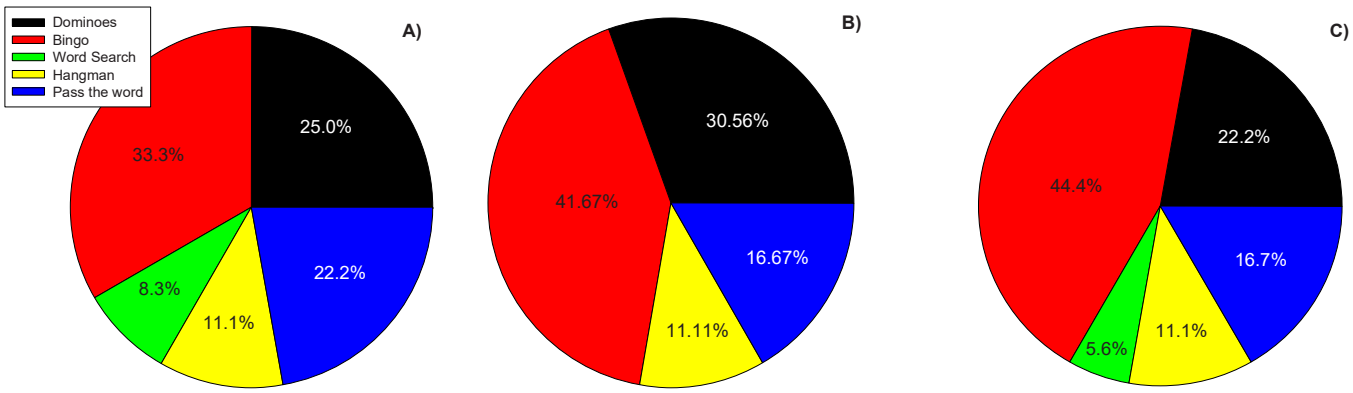

Fig. 5. Cumulative student preferences for educational games. A) Which of the games conducted has been your favorite?; B) Which game did you find the most fun?; C) Which game do you consider has provided you with the most learning?.

competitive games, such as Bingo and Dominoes, are the most effective in capturing interest and enhancing student learning. This could be due to their fast-paced nature and the immediate feedback they provide.

Some open responses for student feedback are summarized below.

"The truth is that the activities carried out in the subject Design of Processes and Chemical Products have motivated me a lot. Before, it was a little difficult for me to participate, but now I am much more involved in the class, and I am encouraged to talk and collaborate with my classmates." (course 23–24)

"I consider that these games should be an essential component of many subjects of the Degree in Chemical Engineering because they really help to better understand the concepts." (course 23–24)

"In my opinion, the use of games in the classes of this subject is interesting because studying with games makes students feel more relaxed and, consequently, they learn better." (course 23–24).

"The games have helped me better understand the things in this block of the subject." (course 22–23)

"I think it's good to include these game sessions in class. We have managed to learn economic concepts in a more entertaining way. The classes were not merely theoretical, but we also had fun." (course 22–23).

"The best thing of all is that these activities have made us collaborate as a team and we know each other better." (course 22–23).

"Classes have been more entertaining with these games. Before they were more boring." (course 21–22).

"Games are useful. I think they should implement them in other subjects as well. They make the classes more entertaining and less boring." (course 21–22).

"Thanks to the games, he was able to understand concepts that seemed very complicated to me before. The days when there was a game session, the classes were less monotonous." (course 21–22).

"Learning with games let I am more involved and animated in learning". (course 21–22).

From the statement above, students' response to the use of games in the thematic block on the economic analysis of chemical processes of the "Design of Chemical Products and Processes" course received a positive response from students.

It is evident that gamification can play a significant role in enhancing student engagement and learning outcomes (Rojas-López et al., 2019; Fernandez-Antolin et al., 2021). The positive reception and effectiveness of these activities suggest that incorporating gamification into various subjects could be highly beneficial. Future implementations should continue to refine and adapt these activities to maintain high levels of student satisfaction and performance. Emphasizing collaborative and interactive elements will further support the development of essential skills such as teamwork and problem-solving. Overall, gamification holds great promise for enriching the educational experience and fostering a more dynamic and engaging learning environment.

Finally, Table 5 compares the learning performance of students who received traditional sessions versus those who participated in gamification sessions. While the gamification cohorts achieved mean scores ranging from 7.9 to 8.3, with only slight variations over the years, the traditional cohorts showed a broader performance range (7.1–8.8). However, an analysis of variance (ANOVA) showed a p-value of 0.0878 (higher than 0.05), indicating that there is no statistically significant difference to conclude that there are differences in learning performance between the two teaching methods.

While the results of this study provide valuable preliminary insights, they should be interpreted with caution and considered as exploratory. Future research should aim to replicate and extend these findings with larger, more representative sample sizes to ensure the robustness and applicability of the results across varied educational contexts.

The games developed for this study primarily focused on foundational knowledge, which served as an effective starting point for exploring the potential of gamification in higher education. However, the incorporation of more advanced gamification strategies, such as simulations and problem-solving activities, is important for further enhancing learning outcomes.

In addition, testing gamification techniques across a wider range of subjects within chemical engineering such as process control, thermodynamics, or reaction engineering would offer a broader understanding of their applicability and effectiveness. Moreover, implementing similar activities in different universities or educational settings could provide comparative insights and account for the variability in student demographics, enriching the evidence base for gamification in education.

4. Conclusions

This contribution presents the implementation of gamification activities in the "Design of Chemical Products and Processes" course for the Master's Degree in Chemical Engineering at the University of Granada, which has yielded positive outcomes. Three gamification sessions were conducted: dominoes in the first session, bingo in the second, and a combination of word search, hangman, and pass the word in the third session. In the first session, dominoes help students discuss and validate their choices regarding the main legal forms of a company, engagingly reinforcing their understanding. The second session used bingo to teach fundamental accounting terms, requiring students to recall and apply their knowledge dynamically. The last session allowed for reinforcing key vocabulary related to financing and investment,

Table 5
Comparison of learning performance between gamification and traditional methods across academic years.

Academic year (n = population)	Gamification method			Traditional method					
	23–24 (n = 9)	22–23 (n = 12)	21–22 (n = 15)	19–20 (n = 32)	18–19 (n = 26)	17–18 (n = 11)	16–17 (n = 17)	15–16 (n = 23)	14–15 (n = 9)
Mean score	8.1	8.3	7.9	7.4	7.1	8.4	8.2	7.3	8.8
Stand. Dev.	1.4	0.8	1.2	1.1	1.7	0.9	1.5	1.1	1.2

promoting quick thinking and cognitive skills. The didactic implication is the enhancement of vocabulary and cognitive abilities in a fun, interactive manner.

This study provides empirical evidence that gamification can be an effective pedagogical tool in higher education, especially in technical disciplines such as chemical engineering. By making learning more interactive and engaging, gamification not only improves student motivation and engagement but also fosters deeper and more meaningful learning. Although no significant differences in academic results were detected between traditional schemes and the gamification-based alternative, student feedback was positive, and the increase in motivation for the covered content was noticeable.

Regarding the time allocated to these gamification sessions, most students considered the duration appropriate. This balance ensured that the activities provided enough time for learning without becoming excessively long. Additionally, students found the games entertaining, which is crucial for maintaining their interest and motivation. Furthermore, most students felt that the games enhanced their learning in the subject, supporting the effectiveness of gamification as an educational tool to reinforce concepts and skills. There was also a positive perception of the collaborative atmosphere during the development of the games.

In terms of active participation, students indicated that they were more engaged in the subject with the implementation of these activities. Gamification appears to be foster greater involvement in the learning process. Additionally, students expressed the importance of incorporating gamification activities in different subjects, suggesting that they value these methodologies and recognize their benefits across various areas of study. Most responses associated with the perception of the activities were rated between 4 and 5 (maximum). The average rating across all years and for all questions was above 4 points. In the last year, questions Q3 and Q5 received the highest scores, with average ratings above 4.6. These questions were related to the appropriateness of the duration and the improvement in terms of skill acquisition in the subject, respectively.

CRediT authorship contribution statement

Martín-Lara M.A.: Writing – review & editing, Writing – original draft, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Altmajer Deisi:** Writing – review & editing. **Vicaria José María:** Writing – review & editing. **Muñoz-Batista Mario J.:** Writing – review & editing, Writing – original draft.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors have used AI-assisted technology to improve language and readability.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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