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Methodology to assess the resolution of complex engineering problems in production process optimization

Metodología para evaluar la resolución de problemas complejos de ingeniería en la optimización de procesos productivos

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Abstract

Introduction: this study presents the application of a game-based learning methodology to support the assessment and evaluation of learning outcomes in higher education. By aligning macrocurricular and microcurricular elements, this approach aims to improve pedagogical practices through the use of interactive learning spaces and technological tools, thus reinforcing the educational objectives of the program.
Objetive: the main objective of this study is to design and implement a pedagogical activity that uses serious games to assess students' ability to identify, formulate, and solve complex organizational problems by applying engineering principles within the context of an optimization course.
Methodology: the proposed methodology includes aligning the program's learning outcomes with the purpose of the game, considering the players' profiles, evaluating and selecting viable alternatives, designing game mechanics that integrate specific knowledge, and developing prototypes and perception assessment instruments. This case study employs serious games in the classroom to foster the resolution of complex problems.
Results: the results show a comparison of the teams' performance metrics, evaluated in terms of net utility, highlighting the differences between the teams' results and the optimal solution derived from optimization techniques. Additionally, collaborative gameplay scenarios are explored, emphasizing the benefits of teamwork over competition.
Conclusions: the conclusions validate the hypothesis that game-based learning enhances the achievement of learning outcomes, strengthening the students' educational process. Furthermore, the study evaluates the usability of the game, the player's experience, and the effectiveness in achieving or reinforcing disciplinary and transversal learning outcomes through a perception survey.

Keywords: Engineering education; Educational games; Game-based learning; Learning outcomes; Serious games.

Resumen

Introducción: este estudio presenta la aplicación de una metodología de aprendizaje basada en juegos para apoyar la valoración y evaluación de los resultados de aprendizaje en la educación superior. A través de la alineación de elementos macrocurriculares y microcurriculares, este enfoque busca mejorar las prácticas pedagógicas mediante el uso de espacios de aprendizaje interactivos y herramientas tecnológicas, con el objetivo de reforzar los objetivos educativos del programa.
Objetivo: el objetivo principal de este estudio es diseñar e implementar una actividad pedagógica que utilice juegos serios para evaluar la capacidad de los estudiantes para identificar, formular y resolver problemas organizacionales complejos aplicando principios de ingeniería en el contexto de un curso de optimización.
Metodología: la metodología propuesta incluye la alineación de los resultados de aprendizaje del programa con el propósito del juego, la consideración de los perfiles de los jugadores, la evaluación y selección de alternativas viables, el diseño de mecánicas de juego con integración de conocimientos específicos, y el desarrollo de prototipos e instrumentos de evaluación de la percepción. En este estudio de caso se emplean juegos serios en el aula para fomentar la resolución de problemas complejos.
Resultados: los resultados muestran la comparación de las métricas de rendimiento de los equipos, evaluadas en términos de la utilidad neta, destacando las diferencias entre los resultados de los equipos y la solución óptima derivada de las técnicas de optimización. Además, se exploran escenarios de juego colaborativo, enfatizando los beneficios del trabajo en equipo en comparación con la competencia.
Conclusiones: las conclusiones validan la hipótesis de que el aprendizaje basado en juegos potencia la consecución de resultados de aprendizaje, fortaleciendo el proceso educativo de los estudiantes. Además, se evalúa la usabilidad del juego, la experiencia del jugador y la efectividad en la consecución o refuerzo de resultados de aprendizaje disciplinares y transversales mediante una encuesta de percepción.

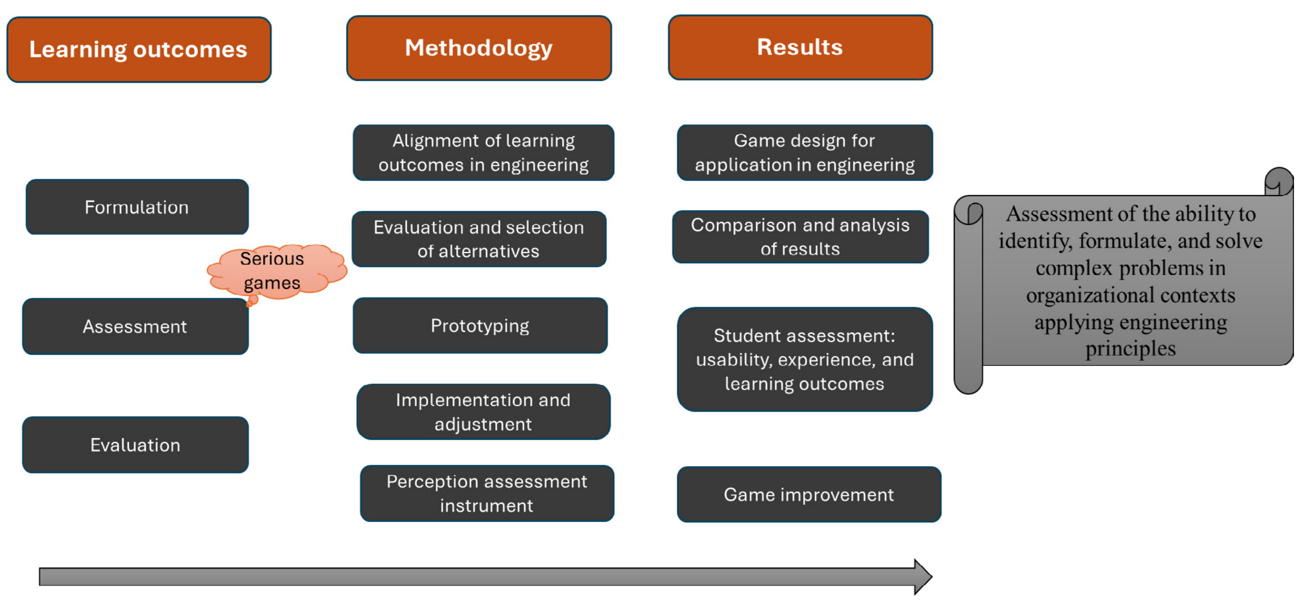
Palabras clave: Educación en ingeniería, Juegos educativos, Aprendizaje basado en juegos, Resultados de aprendizaje, Juegos serios

Contribution to the literature

Why was it done?
The project's idea arises based on reflections about the need for formulation, assessment and evaluation of learning outcomes in engineering programs, considering the guidelines of the ministry of national education in Colombia, and international engineering accreditation standards. In addition, aimed to implement a game-based learning methodology that dynamize the pedagogical practice in the classroom, allowing that it to be considered as an evaluation and motivation alternative.

What were the most relevant results?
A methodological proposal is shown with guidelines from the curricular design, as well as with elements of game-based learning methodologies. A case study is also shown within the framework of an optimization course, for the assessment of the ability to solve complex problems in organizational contexts by applying engineering principles.

What do these provide results?
These results show aspects to be considered in the design of training activities that use game-based learning methodologies to assess learning outcomes, as well as the consideration of criteria used for the assessment of practice, such as usability, student experience and those related to the achievement of learning outcomes.



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Introduction

The incorporation of technological tools into higher education enhances the learning experience by diversifying pedagogical strategies and fostering student participation and collaboration. This approach not only strengthens essential disciplinary skills but also nurtures creativity, autonomy, and critical thinking, preparing students to successfully navigate contemporary challenges.

Professional training in engineering and administration programs demands the development of competencies related to analysis and decision-making in organizational processes. In this regard, several international frameworks emphasize that engineering professionals must possess "the ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics" (1). Similarly, the CDIO Initiative highlights the importance of personal and professional skills and attributes, particularly in engineering reasoning and problem identification, formulation, modeling, analysis, and solution (2).

Engineering design is an iterative, creative, and critical process in which basic sciences, mathematics, and engineering are applied to transform resources into solutions (1). Engineering as a discipline is rooted in the transformation of the environment through the identification and response to societal needs. This foundation has spurred the development of innovative and relevant educational models aimed at equipping future professionals with the skills needed to propose 'appropriate transformations.' Consequently, engineering education has begun to evolve, incorporating changes in teaching structures (3).

Traditional assessment methods often fail to fully capture the multidimensional skills necessary in professional training. As a result, there is a growing need for more dynamic and authentic assessment approaches that better reflect the competencies required in the field. In this context, serious games represent a significant innovation, as they create interactive environments where students face realistic and complex challenges, integrating pedagogical design with contemporary technological tools. Moreover, simulations of real industry scenarios allow students to apply technical knowledge, collaborate in teams, and make strategic decisions, while educators can gather detailed performance data, identify areas for improvement, and tailor the learning experience to individual needs.

These games enable continuous and formative assessment of problem-solving abilities and soft skills essential for professional practice. However, they can also facilitate summative assessment by providing objective, observable metrics of student progress in specific engineering skills. Furthermore, game-based learning has been identified as an effective strategy for increasing student engagement, motivation, and participation in the learning process. Nevertheless, a key question that arises is how it can improve students' ability to solve complex engineering problems, and how this improvement can be appropriately measured.

In today's dynamic educational landscape, accurate evaluation of learning outcomes is essential for ensuring the quality and effectiveness of academic programs. Learning outcomes are defined as explicit statements of what a student is expected to know and demonstrate upon completion of their academic program and serve as the cornerstone of the improvement process (4). However,

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it is important to distinguish between the concepts of assessment and evaluation of learning outcomes.

Although these terms are sometimes used interchangeably within the context of classroom assessment, particularly in technology and engineering professional programs, they hold distinct meanings. Assessment refers to "processes that identify, collect, and prepare data to evaluate the attainment of student outcomes," while evaluation involves "processes for interpreting the data and evidence accumulated through assessment processes" (1). In this sense, the evaluation of students' learning progress is fundamental to any educational intervention (5), as it not only measures attainments but also provides real-time feedback that allows for the adaptation of learning environments to meet individual needs (6).

The effectiveness of serious games in science education has been underscored in the literature (7), emphasizing how meaningful learning is achieved by identifying actions that lead to rewards through experimentation (8). This approach not only promotes active student participation but also deepens their understanding of complex concepts through guided practice. In various fields, performance assessment is affected by uncertainty (9), which highlights the need for flexible and adaptive strategies. In this regard, games hold considerable potential for designing strategies and instructions (10), as it enhance the assessment of multidimensional competencies and facilitate the acquisition of practical skills in complex contexts (11).

In today's educational and organizational landscapes, games are increasingly valued for their capacity to reinforce learning policies by pinpointing key drivers of integrated resource management (12), as well as for their ability to foster essential competencies such as problem-solving (13). This approach is gaining traction as an effective tool for supporting decision-making across educational and business contexts (14), particularly as educators and leaders encounter major obstacles in implementing effective training and learning systems (15). Likewise, simulations through educational games have shown notable improvements in the understanding of business processes and decision-making skills (16).

As a result, engineering education continues to evolve to offer flexible, high-quality learning experiences (17), incorporating educational games that promote adaptive and enriched learning environments (18). Gamified teaching further diversifies educational tools by integrating gaming elements and digital technologies, thereby favoring interactive and effective learning (19). This approach is particularly beneficial for developing problem-solving skills in engineering, where game-based learning has proven to be a successful strategy (20).

Becker makes a clear distinction between the terms *game, serious games, games for learning, game-based learning, game-based pedagogy*, and *gamification*, especially in aspects such as their basic definitions, purposes, motivations, approaches, and business models, among other aspects (21). Game-based learning, for example, involves utilizing interactive and engaging elements to enhance the learning process, with a focus on achieving educational objectives rather than entertainment alone.

Game design has emerged as a strategic tool for addressing educational gaps (22,23). It is based on a constructivist paradigm that incorporates advanced technologies, such as algorithms, into

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teaching methods (24). Recent studies suggest that digital technologies can significantly enhance students' cognitive performance (25), although current machine learning techniques often lack a multidimensional approach (26). In addition, innovative methods in deep learning are being applied within games to monitor the immersive experiences of users (27).

Educational games aim not only to improve the efficiency of the learning process but also to adapt teaching methodologies to respond to the evolving needs of students and current educational contexts (28). This requires integrating traditional academic disciplines with interdisciplinary technology to foster innovative talent (29). Consequently, educational designers must leverage Information and Communication Technologies (ICTs) to transform learning environments, tailoring them to the individual needs of students and exploring new educational strategies through serious games (30).

The incorporation of advanced learning and knowledge transfer techniques offers new opportunities in areas such as spatial exploration and technological development (31). The effective integration of ICTs in education is critical for providing high-quality, up-to-date learning experiences (32), particularly in fields like engineering, where solving complex problems requires creative and innovative approaches (33). By utilizing these cutting-edge resources, educational institutions can not only improve knowledge retention but also better prepare students for the complex professional environments they will face in the future.

Methodology

The methodology outlined in this article integrates three main components. The first component addresses curriculum design from a macro-curricular perspective, focusing on key aspects of the learning process within academic programs at higher education institutions. The second component emphasizes the evaluation and assessment of learning outcomes, achieved by incorporating game-based learning activities into the curriculum. The third component is the practical application of these concepts within an optimization course.

Curricular and instructional design

Figure 1 provides a summarized overview of curriculum design and continuous improvement processes within higher education institutions, centered on student learning outcomes. The curriculum design phase aligns with both institutional and program objectives, incorporating the needs of various stakeholders (students, graduates, professors, employers, and society). It is guided by the institutional education project, which serves as a normative framework, outlining the key pillars and principles that shape the program. This phase also involves formalizing the professional graduate profile, competencies, and student learning outcomes, addressing the unique characteristics of the academic program within the knowledge–professional performance–context triad.

The instructional design phase focuses on ensuring the alignment with micro-curricular aspects and on detailing the relationship between *program learning outcomes* and *curriculum structure, pedagogical practices, and evaluation processes*. In the case under study, emphasis is placed on defining a measurement plan for each learning outcome, disaggregating them as needed to relate

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course-level learning outcomes to overall program goals. This phase also includes the design of activities that can be implemented and evaluated in the classroom.

The analysis phase consolidates data and conducts a comprehensive evaluation, providing insights for the improvement phase. This final phase evaluates the effectiveness of the entire process, with specific actions taken to enhance and strengthen student learning outcomes. The cycle then restarts, supporting the continuous improvement of the learning process.

This paper focuses on the instructional design phase, where the learning outcomes assessment process is carried out in an optimization course of an engineering program, using a game-based learning methodology.

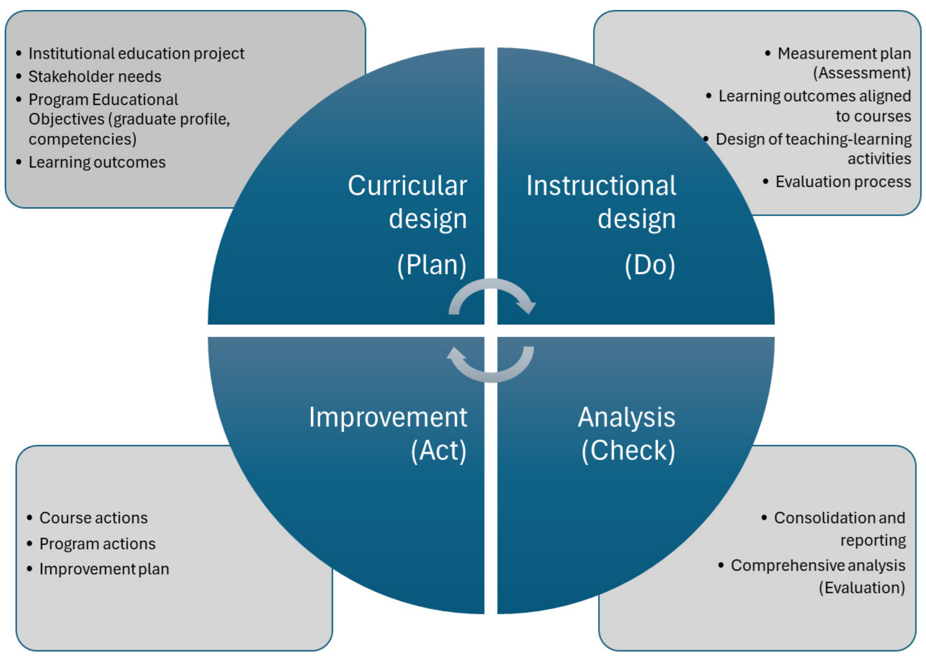

Figure 1. Curriculum design in higher education institutions

Game-based learning methodology

Figure 2 presents a summary of the proposed game-based learning methodology, centering on student learning outcomes and leveraging the advantages of serious games. A crucial starting point is the shared responsibility in the game design process, which should involve multidisciplinary focus groups with diverse profiles, including both higher education stakeholders (professors, students) and participants in the gaming dynamics (with varying ages and personalities).

The methodology follows a step-by-step approach, considering key aspects such as aligning with program and course learning outcomes; defining the purpose of both the educational activity and the game; characterizing the student/player profile, which involves understanding their personalities, habits, and behaviors; exploring alternatives for game design, which challenges creativity, encourages the incorporation of best practices from other games, and emphasizes contextual relevance; and designing game mechanics, which entails establishing rules, roles, scenarios, symbols, narratives, technology, formats, and other elements.

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The phase of integration of specific knowledge is key, as the game must fulfill a clear educational purpose. Furthermore, prototyping and adjustment phases provide opportunities for practical evaluation, revealing elements not initially apparent during the planning phase, and generating new ideas from both game designers and early players. In the final stage, players assess aspects such as usability, player experience, and the effectiveness of the educational process, particularly regarding the achievement of the intended learning outcomes.

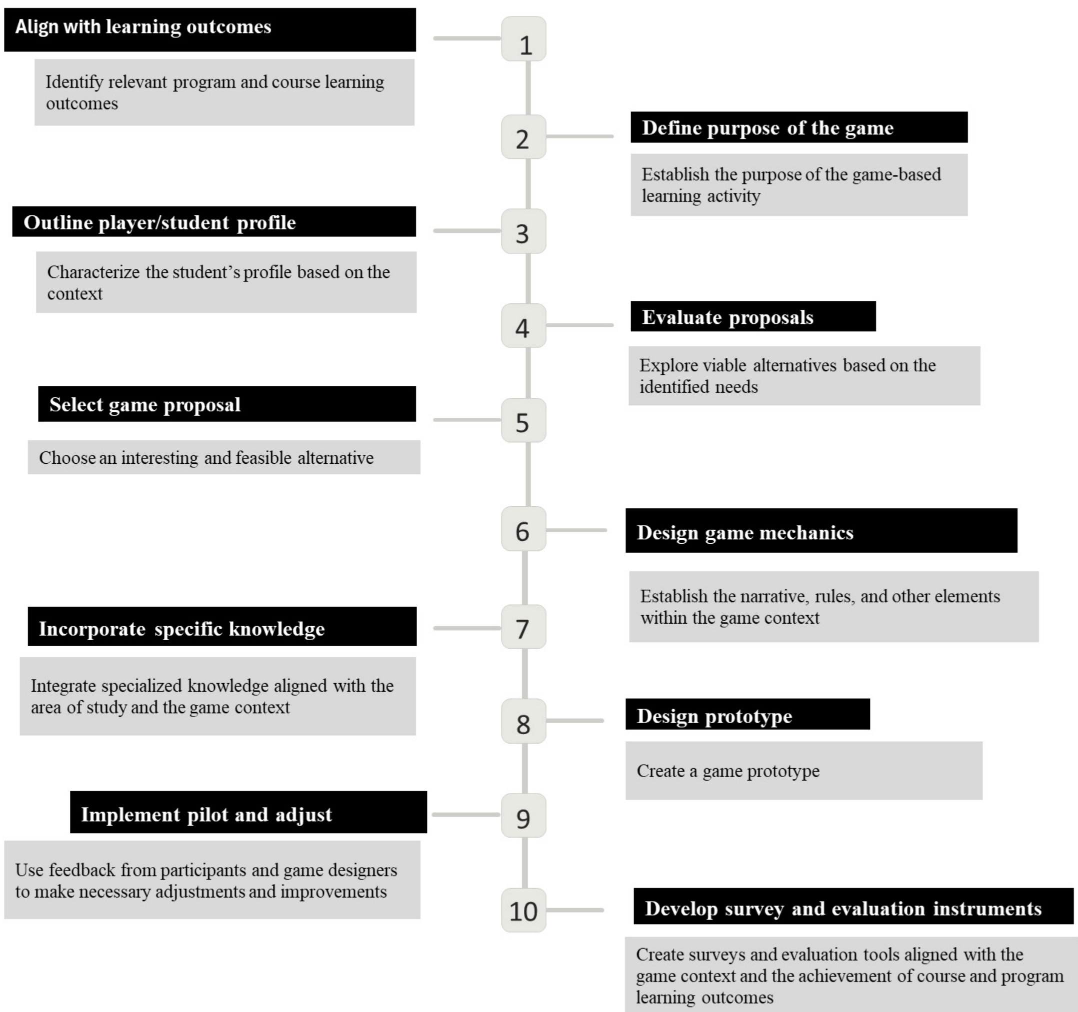

Figure 2. Game-based learning methodology

Study case in the field of production process optimization

To evaluate the ability to solve complex problems by applying engineering principles in an optimization course, a game was designed with the objective of maximizing the net profit of an organization through the production and sale of two products. This includes meeting quality specifications, achieving the investor's minimum required return, and considering constraints like budget, raw material availability, and demand.

Players were divided into three work teams, each representing a company with defined roles. The relevant stakeholders are shown in Figure 3, which simulates a typical supply chain. The game involves a raw material supplier, customers who purchase the finished products, and an investor providing seed funding.

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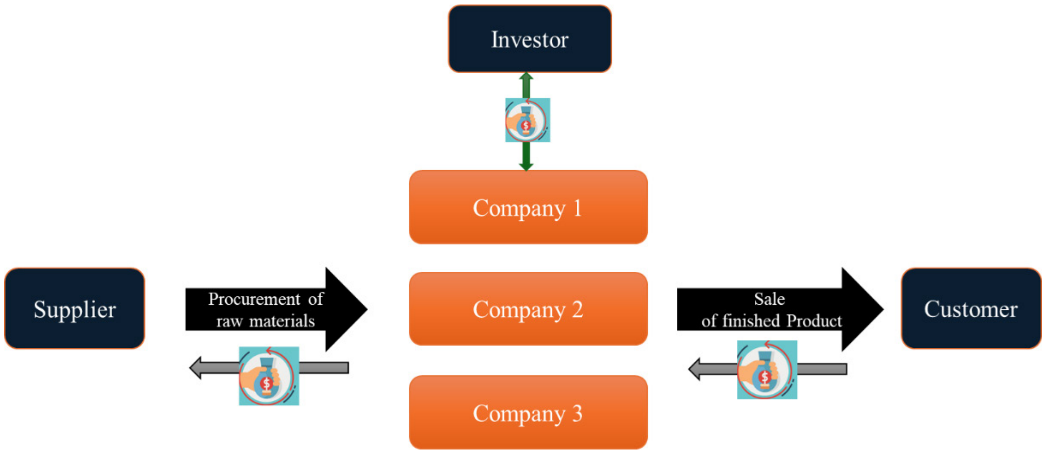

Figure 3. Schematic of the optimization game-based activity

The phases and suggested timings of the game are listed in Table 1.

Table 1. Phases and timing of the game

Phase	Description	Time (minutes)
1	Information and organization	15
2	Planning and prototyping	10
3	Purchase of raw materials	15
4	Production	25
5	Sale	5
6	Winners and awards	5
7	Model formulation, optimal solution, and analysis	5
8	Survey and reverse logistics	5

Table 2 shows the physical and digital information available to each team, including the list of required materials for producing one unit of each product, unit costs, inventory availability, selling prices, maximum demand, seed capital, and expected returns for the investor by the end of the activity.

Table 2. General information for teams

Component	Product 1	Product 2	Unit cost (in COP)	Availability/Team
5-hole piece	0	2	$ 16,000	20
4-hole piece	1	3	$ 14,000	40
3-hole piece	5	2	$ 12,000	90
2-hole piece	4	3	$ 10,000	90
Large screw	3	3	$ 2,000	90
Small screw	4	4	$ 1,000	90
Nuts	7	7	$ 1,000	160
Price/Unit (in COP)	$ 200,000	$ 220,000		
Maximum demand	20	20		
Budget/Team (in COP)	$ 3,000,000			
Return/Team (in COP)	$ 4,000,000			

This activity incorporates dynamic elements into the game environment, making it suitable for educational contexts. These elements include QR codes, online forms, digital files for monitoring

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orders and enforcing restrictions, printed formats, tickets, music, and more. Figure 4 shows examples of some QR codes.

Information | Purchase raw material | Survey

Figure 4. Incorporation of QR codes in the game

After the experimental activity, a mixed-integer linear programming (MILP) mathematical model was formulated and solved using both AMPL, a large-scale programming language, and Excel. This approach demonstrates, in a straightforward and practical way, how real-world situations can be modeled and complex problems can be solved using optimization techniques. The complexity in this case arises from dealing with broad and sometimes conflicting technical issues, where no simple solution is readily apparent (1). Figure 5 presents the formal mathematical model of the case under study.

SETS

RM = Raw material (i)

i = 5hole, 4hole, 3hole, 2hole, 1bolt, 0.5 bolt, nut, angle

FP = Finished product (j)

j = donkeys, giraffes

PARAMETERS

$\boldsymbol{quantity_{ij}} = Amount\ of\ raw\ material\ (i)\ required\ per\ product\ (j)$

$\boldsymbol{cost_i} = Unit\ cost\ of\ raw\ material\ (i)$

$\boldsymbol{max\_inventory\_RM_i} =$ Maximum availability of raw material (i)

$\boldsymbol{price_j} =$ Price of finished product (j)

$\boldsymbol{max\_FP_j} =$ Maximum demand for finished product (j)

$\boldsymbol{budget} =$ Available budget per team

DECISION VARIABLES

$\mathbf{x_j}$ $Integer\ values, amount\ of\ finished\ products\ (j)$

$\boldsymbol{revenues} \geq 0$

$\boldsymbol{expenses} \geq 0$

OBJECTIVE FUNCTION

Maximize profits: $revenues - \text{expenses}$

CONSTRAINTS

$$\text{revenues} = \sum_{j\ in\ FP} price_j * x_j$$

$$\text{expenses} = \sum_{i\ in\ RM, j\ in\ FP} cost_i * quantity_{ij} * x_j$$

$$\sum_{j\ in\ FP} quantity_{ij} * x_j \leq \max\_inventory\_RM_i \quad \forall i$$

$$\sum_{j\ in\ FP} x_j \leq \max\_PT \quad \forall j$$

$$\sum_{i\ in\ RM, j\ in\ FP} cost_i * quantity_{ij} * x_j \leq budget$$

Figure 5. Proposed mathematical model

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Results and discussion

The formulation, processing, and analysis of the model that represents the problem under study underscores several aspects to consider. One key aspect is the evaluation of feasible solutions, given the need to comply with multiple constraints. In addition, although production time was not explicitly included in the mathematical model—assuming that teams would be efficient enough to complete orders, production, and sales within the designated timeframes—it remains an important factor in the practical context. Moreover, in the experimental practice, finding the optimal solution is not necessarily the primary goal. Instead, the focus is on providing feedback throughout the learning process and comparing results against initial expectations.

The analysis can be conducted either by each team individually or through broader collaborative strategies, as the game's objective is not specific to each company but rather aims at overall optimization. Furthermore, aspects such as role assignment and task distribution within teams, based on individual competencies, are examined under a self-management framework. The activity also facilitates the assessment of both technical and soft skills.

The optimal solution generated by the proposed model results in the production of fourteen units of Product 1 and eight units of Product 2, yielding a net profit of COP 566,000 while meeting all constraints. Table 3 presents the profit and loss statement for this optimal solution.

Table 3. Profit and loss statement for the optimal solution

Item	Amount (in COP)
Seed capital (+)	$ 3,000,000
Income from sales (+)	$ 4,560,000
Raw material cost (-)	$ 2,994,000
Return to investor (-)	$ 4,000,000
Net profit	$ 566,000

The practice was designed and refined between the first half of 2023 and the first half of 2024. Figure 6 shows a comparison of results from two of these practical exercises. A central component of the activity is analyzing the outcomes and discussing the factors that influenced the results.

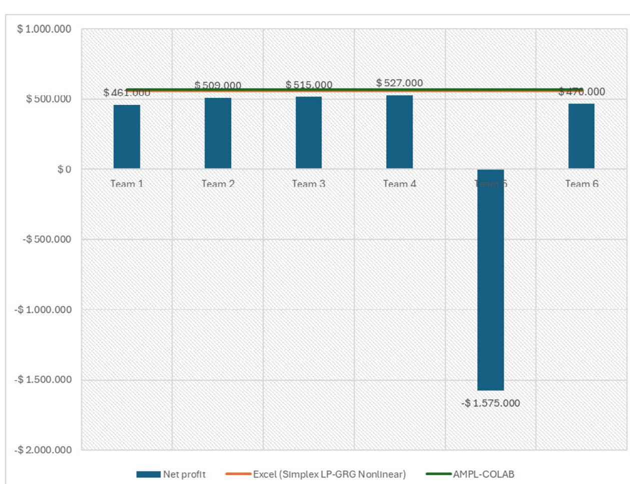

Figure 6. Net profit by teams

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The objective of the game is framed within a global collaborative scenario, which requires communication and collaboration among the three companies. This approach presents a significant challenge for activity coordination but proves more efficient in terms of both the learning curve for each role within the game and qualitative and technical aspects, as synergy results in a more significant impact than the mere sum of individual efforts. For the case under study, simulations were conducted to explore a scenario where the three companies merge and triple their resources. The results showed that the global optimal solution (COP 1,713,000) exceeds three times the individual optimal solutions (COP 1,698,000), as illustrated in Table 4.

Table 4. Analysis of collaborative game

Product	Individual optimal (one company)	Triple individual optimal (three companies)	Global optimal (three companies)
Product 1	14	42	52
Product 2	8	24	15
Net profit (in COP)	$ 566,000	$ 1,698,000	$ 1,713,000

To assess students' perceptions on the game usability and user experience, a survey was conducted evaluating the following aspects: mastery of the topics by the presenters, resource management, time organization, and relevance. The survey was completed by 41 students who participated in the game, and the results are displayed in Figure 7. Subsequently, items were included to gauge perceptions of the achievement of both disciplinary and transversal learning outcomes, as shown in Figure 8, which presents data from 17 students.

The survey also featured open-ended questions, with several answers affirming that the activity significantly enhanced understanding of optimization models, which are often abstract. Participants also highlighted subsequent phases related to learning outcomes, particularly in modeling, formulation, solution, and analysis. Furthermore, students mentioned positive aspects of the activity, such as the reinforcement of transversal skills, including communication, leadership, and teamwork. Emotions such as enjoyment and pressure were also noted by students, which underscores the need to develop competencies required for professional practice.

These findings demonstrate that the goal of the study was achieved: implementing game-based activities aimed at helping higher education students to better understand mathematical models. The proposed model optimized an objective function based on decision variables, was subject to multiple constraints in an organizational context, and was aimed at solving complex problems by combining engineering principles with fun elements.

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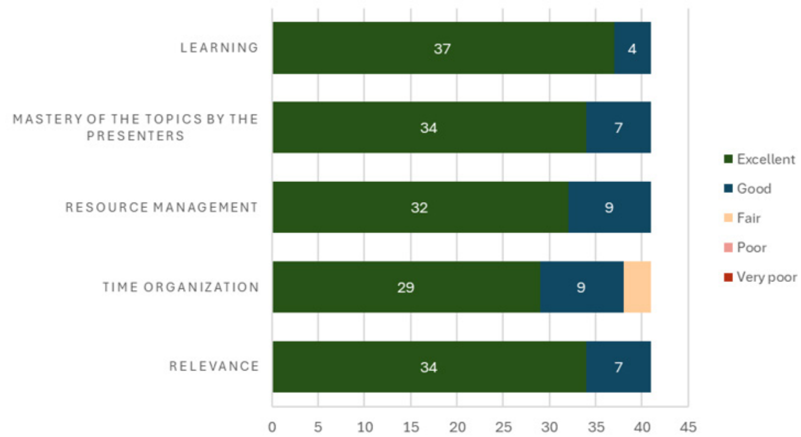

Figure 7. Results of the survey on perception of the learning activity

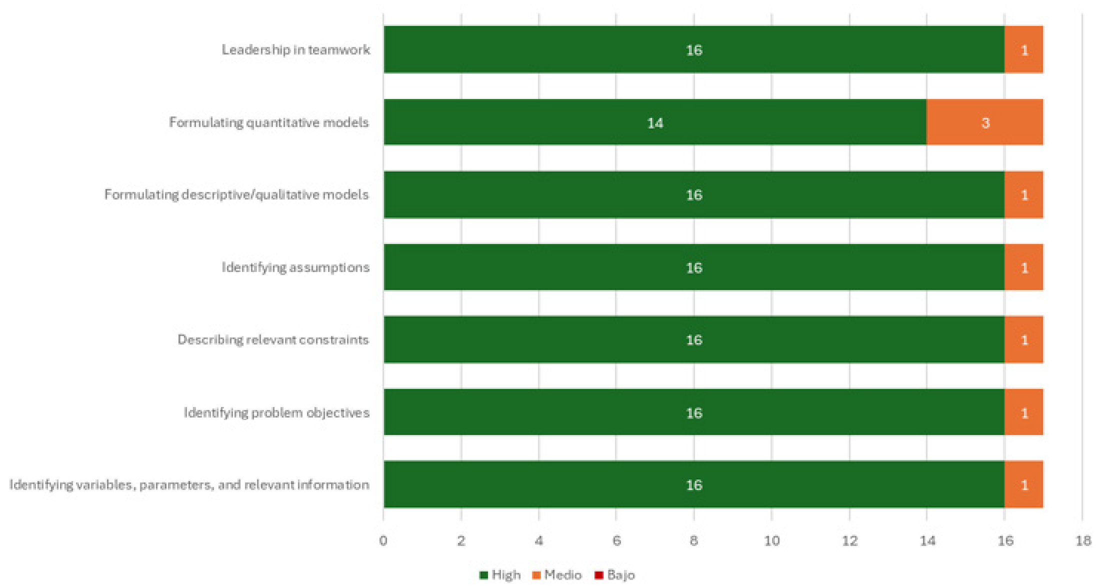

Figure 8. Results of the survey on perceived contribution to learning outcomes

Finally, to maintain traceability of the process and track adjustments made in each academic period, Table 5 provides details of the analyses conducted after each practice and the corresponding adjustments progressively incorporated to improve the learning outcomes.

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Table 5. Control of changes

Practice Period	Analysis	Adjustments
1 (2023-1)	Bottleneck observed in the warehouse	- Improve parts disposition by separating them into batches, stationing at least two people at the warehouse, and organizing a physical space for order preparation and delivery.
2 (2023-2)	Difficulty handling play money	- Change bill denominations to be larger and more similar to local currency. Adjust starting monetary values.
	Lack of consensus on the choice of background music	- Eliminate background music.
3 (2024-1)	Low availability of a component in the list of materials	- Remove the component (angle) from the list of materials and replace it with a more readily available piece (nut).
	Difficulty assembling products due to worn-out short bolts	- Suggest renewing lab supplies.
4 (2024-1)	Changes in activity timing and participant variability	- Regain control of the timer to ensure attention to detail. - Review total and specific activity times. - Print important instructions in color and enhance the instruction guide to prevent confusion. - Add automatic conditionals to the purchase order form to reduce errors related to availability.

The target population of the case study consists of ninth-semester students enrolled in the Quality Engineering program at a higher education institution in Colombia. The program requires the assessment of learning outcomes related to the ability to identify and formulate complex problems in quality and metrology, applying knowledge of mathematics, science, and quality engineering, specifically in an optimization course.

The assessment used a rubric with the following performance indicators: identifying variables, parameters, and relevant information on the problem under study; identifying the objectives of the problem under study; describing relevant constraints to be considered in the problem under study; identifying assumptions to simplify and represent the problem or system under study; formulating descriptive or qualitative models to represent the problem or system under study; and formulating quantitative models to represent the problem or system under study. Figure 8 lists some of these performance indicators, based on the perceptions of the participants involved in the activity during two academic periods.

The learning outcomes were then assessed using a spreadsheet-based tool. This tool integrates qualitative and quantitative data collected during each academic period, ensuring alignment with institutional guidelines and specifying the level of achievement observed for each performance indicator. The data were then consolidated into a Power BI dashboard, allowing access to assessments and learning outcomes from other courses subjects across various academic periods. This dashboard serves as input for a subsequent phase in which a focus group of teachers and the curriculum committee review the results to create an improvement plan. These actions

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are integrated into the program's self-evaluation, accreditation, and continuous improvement processes.

This paper proposes an alternative approach to assessing program learning outcomes in the classroom in the context of engineering. The approach emphasizes key aspects, such as aligning course subject-level indicators at the micro-curricular level with program-level indicators at the macro-curricular level; leveraging the experimental and pragmatic nature of engineering programs through the use of laboratories and/or interactive scenarios; and incorporating didactic aspects into learning and assessment processes. Conventional methods, such as lectures and individual exams, may not fully support the assessment of certain learning outcomes and, in some cases, may hinder the achievement of educational objectives, especially considering the profiles of today's students. Adopting alternative assessment strategies that foster inclusivity and holistic approaches can enhance the assessment and achievement of learning outcomes in engineering education.

A key area of interest is comparing the advantages and disadvantages of digital and non-digital educational games. While the commercial context shows a strong preference for digital formats, educational contexts require additional considerations. These include observing players' behavior and conducting both formative and summative evaluations to assess disciplinary and transversal learning outcomes, including critical thinking, problem solving using engineering techniques, teamwork, and oral and written communication. These evaluations aim to align the training process with the graduate profile expected by society, the state, and the business sector, ensuring long-term professional competence.

In the case under study, the game is categorized as a non-digital educational game supplemented by digital tools for information processing. It incorporates both digital and physical formats for parameterizing relevant data, QR codes for completing critical phases of the methodology, real-time data collection forms for formalizing orders, perception surveys, and online tools for formalizing and solving the optimization model derived from the game activity. This approach has made it possible to simulate controlled scenarios that closely resemble business contexts, thereby challenging students to solve specific problems by applying skills developed throughout their academic journey rather than relying solely on memory. Furthermore, the game explores kinesthetic intelligence in teamwork under pressure and activates motor skills, which, according to players' feedback, have a positive effect on cognitive processes and the achievement of learning outcomes.

The game's validation and refinement were carried out through discussions with students and academic peers, along with analyses of perception instruments containing both open- and closed-ended questions. Looking ahead, future studies should expand the initiative by incorporating it into academic networks at regional, national, and international levels; collaborating with multidisciplinary student research groups; developing related research projects; and evaluating the long-term impact on performance indicators.

Conclusions

The incorporation of non-traditional elements for assessing learning outcomes in higher education, particularly in fields like engineering, is crucial for enhancing student learning experience. This

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approach not only diversifies pedagogical strategies and encourages active participation and collaboration among students but also strengthens essential skills such as complex problem-solving, critical thinking, and creativity.

Equipping future professionals to overcome contemporary challenges is vital in an increasingly technological and dynamic world. The adoption of innovative methods, such as serious games, has been demonstrated to enhance student motivation and engagement, while providing tools for accurately evaluating the competencies required in the engineering domain.

In essence, these pedagogical approaches are devised to train engineers and management professionals capable of addressing real-world problems and making meaningful contributions to the development and transformation of modern society. In addition, they provide higher education institutions with tools for carrying out comprehensive learning outcomes assessment and evaluation processes.

CRediT authorship contribution statement

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