GAMIFICATION AS A MEANS OF INTRODUCING TOOLS INTO THE STEAM LEARNING PROCESS TO REDUCE ROTE LEARNING

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Abstract - Higher Education students in science, technology, and engineering programs often approach their subjects in isolation due to curriculum design and departmental organization, which can prevent them from recognizing how these disciplines interact in real-world contexts. In this study, a card game was specifically designed to translate STEAM education principles into an engaging, activity-based learning environment, generating a gamified framework for instruction.
This research evaluates the impact of a card game on the academic performance of engineering students using a structured, systematic, and hypothesis-driven methodology. The central premise proposes that the game not only supports knowledge acquisition but also strengthens the capacity of students to integrate concepts across STEAM disciplines. The results confirm this hypothesis, demonstrating a positive relationship between the incorporation of gamification elements and improved outcomes in STEAM-oriented learning environments.

Keywords - Card Game, Engineering Education, Gamification, Higher Education, STEM Learning

I. INTRODUCTION

Although social transformation has always been constant throughout history, recent decades have been marked by an accelerated pace of change across all social domains. This rapid evolution requires individuals and institutions to engage in continuous learning processes that enable quick adaptation (García, 2007). Alongside the improvements in quality of life brought about by technological and scientific progress, new global challenges have also emerged or intensified.. Addressing these issues demands integrated and sophisticated solutions developed by creative and capable individuals (Rosenlund, 2018; Smith & Iversen, 2018) who can combine knowledge from multiple disciplines.

Challenges such as climate change, global food security, biosafety, and sustainable energy production illustrate the need for interdisciplinary approaches grounded in comprehensive knowledge (Roth, 2019). Such knowledge should support a holistic understanding aimed not at controlling the world, but at ensuring sustainable coexistence within it.

To respond to this interdisciplinary demand, STEM education (Science, Technology, Engineering, and Mathematics) (Pimthong& Williams, 2018) has expanded across various training contexts in recent decades. Rooted in constructionist learning theory (Sullivan & Bers, 2018), STEM education intentionally connects scientific and mathematical concepts with engineering and technological practice (Yanez et al., 2019). The historical roots of STEM-oriented reform can be traced to 1957, when the Soviet Union launched Sputnik 1. This event triggered concern in the United States regarding deficiencies in science and technology education, prompting reforms supported by the National Science Foundation and influenced by the work of Piaget, Ausubel, and Gagné (Marmeleira& Duarte Santos, 2019; Brien, 1990). These reforms aimed to strengthen student independence, creativity, and problem-solving ability. While the term STEM did not become widespread until the 1990s, its policy relevance grew significantly after 2010, when evidence showed improved academic outcomes, especially among initially lower-performing students (Han et al., 2015).

Despite the proven benefits of STEM-based education reported in the literature (Dreessen & Schepers, 2019; Perignat& Katz-Buonincontro, 2019; Thomas & Watters, 2015), its practical adoption within some national education systems, including Spain, remains challenging (Tapia & Martinez-Galarraga, 2018). To address this limitation, several instructional strategies have been proposed. Among them are innovative pedagogical approaches such as Problems Without Data (PWD) (Paniagua et al., 2019), which, when combined with gamification techniques, show strong potential for promoting autonomous learning and improving the students reasoning abilities (Calvo et al., 2018).

Johan Hizinga (1872-1945) was a Dutch philosopher, and he was one of the firstpersons who worked in a pioneer project about the influence of the game in educationprocess. In his book Homo Ludens (1938), he explained the influence of the game onthe brain process of the players.

In this way, when we introduce gamification and learning based games we canimprove the learning process of our students, reducing, at the same time, the commonstress situations present in higher education. It is important to know the difference between Game based Learning and gamification. Game based learning describes an approach to teaching where students explorerelevant aspects of games in a learning context designed by teachers. Teachers andstudents collaborate to add depth and perspective to the experience of playingthe game. Within an effective game-based learning environment, we work toward agoal, choosing actions and experiencing the consequences of those actions along theway. This keeps us practicing behaviors and thought processes that we can easilytransfer from the simulated environment to real life.

Gamification is a different type of learning experience. Gamification takes gameelements (such as points, badges, leaderboards, competition, achievements) andapplies them to a non-game setting. It has the potential to turn routine, simple tasksinto refreshing, motivating and mainly, reducing the stress situations in the engineeringuniversity class.

Although both (gamification and game-based learning) in education has been studied for decades, interest in this field has increased significantly in recent years. Bibliographic databases such as Scopus and Web of Science show a sharp rise in publications on gamification, growing from roughly 1,500 records in 2015 to more than 2,300 by 2018 (Rodrigues et al., 2019).

Gamification can be defined as the application of game-thinking principles and game mechanics to engage participants and support problem solving (Zichermann& Cunningham, 2011). Effective gamified systems should influence not only motivation and behavior but also help learners reach concrete solutions. As engagement and success increase, players typically develop greater commitment and willingness to continue participating (Kapp, 2012).Although the experience shown in this document refers to game-based learning, for search engine optimization purposes, we will refer to it as gamification.

While many educational institutions have incorporated gamified dynamics into their teaching practices, this tendency becomes less common at higher academic levels. University programs still show relatively few examples of structured gamified learning experiences (Rapp et al., 2018).

Based on this context, the present research proposes that gamification can be successfully introduced into university STEM learning environments without relying on digital games or screen-based tools. Using physical board-game dynamics may reduce screen exposure while maintaining — or even increasing — engagement time. At the same time, such formats can strengthen communication and social interaction skills, which are essential but often overlooked components of STEM education (Wijnia et al., 2016).

The main objective of this study is therefore to evaluate both the academic and experiential effects of a specially designed card game for STEM university students titled “Kepler”. The specific goals are:

- To statistically evaluate the academic impact of the Keplercard game on students.
- To statistically assess its effect on the students ability to integrate knowledge across STEM disciplines.

II. METHODOLOGY

II.1.- Materials

The teaching intervention was built around the card game Kepler, developed by the DINBIO teaching innovation group (Teaching in Biosystems Engineering) at the University of León, which also authored the study.

The purpose of the game is for players to accumulate points. Progress is achieved by solving engineering-design problems embedded in the gameplay. These challenges require combining knowledge from mathematics, science, technology, and engineering.

The game structure encourages teamwork and interaction. It is played in groups and allows exchanges and negotiations between teams, thereby promoting communication and collaborative decision-making skills.

The game instructions, as given to the players, are shown in Figure 1. Examples of the different types of cards are shown in Figures 2-6.

Kepler´s instruction

Kepler is a card game based on the PWD teaching model (*Problems Without Data*), which consists of deducing the minimum data required to solve a problem. The game is made up of different types of cards.

Problem cards.

Each card includes the statement of a problem (with no data provided), as well as a list of possible data that could be used to solve it, only some of which will be useful. There are three columns, resulting from three possible combinations of data for solving the problem. At the start, the players decide which of the three columns they wish to use (that is, each problem statement offers three different gameplay options). An example is shown in Figure 2

Data cards.

These consist of a matrix in which the values of the data from the Problem cards are encrypted. By way of example, if in the chosen column of the Problem card a variable is associated with the combination *1 B4*, this means that the player can find the numerical value of that variable in table 1, column B, row 4. These values may only be consulted once the game has been closed. An example is shown in Figure 3

Letter cards.

These are the cards used during play. Each one is characterised by a variable (defined by the letter shown on the card) and a score value (shown in the top right-hand corner). An example is shown in Figure 4

Kepler cards.

These act as wild cards and may be substituted for any variable. An example is shown in Figure 5

Solution cards.

For each problem, these indicate which variables (Letter cards) must have been acquired to solve it. In addition, for each column of each problem, the result of the problem is provided. An example is shown in Figure 6

Figure 1.- Instructions for playing Kepler (card game designed for this experience)

II.2.- Research Design

Participants and sample

The study involved all students enrolled in the Engineering Bases course in the second year of the Environmental Sciences and Biotechnology degrees at the University of León in the year 2025. This subject historically presents high failure rates (above 54%), largely due to student difficulty in applying first-year mathematics, science, and technology knowledge.

Because the full population was included, no sampling procedure was required. The total group consisted of 67 Environmental Sciences students and 55 Biotechnology students.

Experimental design and instruments

To determine compliance with the stated objectives, it was necessary to carry out an experimental design. This design made it possible to compare, in a statistically significant way, the effects of the designed card game on students. These effects included both academic performance and the ability to integrate concepts from STEM-related subjects. For this, an initial knowledge test was carried out on the entire sample population. This test allowed to know what the starting situation of the population was before carrying out the experience.

Voluntarily, the students decided whether to participate in the proposed activity (gamification experience), therefore it is necessary to determine that there are no statistically significant differences between the group that decides to participate in the experience and the group that does not.

Once the teaching of the subjects was finished, and in the period between the end of the teaching and the final evaluation, the subjects belonging to the experimental group were summoned to participate in gamification experiences through the designed card game.

The experimental design concluded with the completion of a final project consisting of a small-scale project of industrial design and the completion of the final exam of the subject.

In this way, the experimental plan had the following study variables:

- *Kepler*. Qualitative variable of dichotomous type in which the student who belongs to the control group (that is, who does not participate in the gamified STEM experience) was identified with 0 and the student of the experimental group (the one who does participate in the gamified STEM experience) with 1.
- PruebaNivel. Mark obtained by students in a test of knowledge in mathematics, science and technology carried out at the beginning of the course. The objective was to measure whether there were initial academic differences both between the control group and the experimental group and between the students of the two degrees.
- NotaFinal. Variable that determined the final grade obtained by the student in the Engineering Bases subject. It was obtained after having subjected the experimental group to the gamification process.
- TrabajoStem. Variable that measured the grade obtained by the students in a final project consisting of a small-scale industrial design project; in it, the student put into practice the integration of knowledge related to the subjects of a STEM environment.

Data analysis

A quantitative analysis of the collected data was performed using the IBM® SPSS® Statistics v.22 software.

III. RESULTS AND DISCUSSION

Table 1 shows, for the dependent variables, the values reached by their descriptive statistics, considering mean, mean at 95% confidence with a significance of 5%, mean trimmed at 5%, median, variance and standard deviation. Analyzing the results, important mean differences were observed between the experimental group and the control group for the variables Nota Final and Trabajo STEM, considered for each of the degrees studied (since, as explained in section in Table 3, there are significant differences between the initial knowledge of the students from the two degrees). However, it was necessary to determine if these differences were statistically significant, that is, if the probability that the differences were true was

greater than 95%.

Descriptives Environmental Sciences Students				Statistic	Std. Error
PruebaNivel	0	Mean		4.3675	0.31345
		95 % Confidence interval for Mean	Lower Bound	3.7183	
			Upper Bound	5.4072	
		5 % Trimmed Mean		4.5771	
		Median		4.5152	
		Variance		4.6121	
		Std. Deviation		2.12342	
	1	Mean		4.3751	0.33221
		95 % Confidence interval for Mean	Lower Bound	3.8711	
			Upper Bound	5.0672	
		5 % Trimmed Mean		4.3799	
		Median		4.0091	
		Variance		2.589	
		Std. Deviation		16.2211	
Nota final	0	Mean		3.9101	0.23092
		95 % Confidence interval for Mean	Lower Bound	3.4365	
			Upper Bound	4.291	
		5 % Trimmed Mean		3.9954	
		Median		3.9917	
		Variance		2.321	
		Std. Deviation		1.50011	
	1	Mean		6.8976	0.29991
		95 % Confidence interval for Mean	Lower Bound	6.2981	
			Upper Bound	7.5596	
		5 % Trimmed Mean		7.0580	
		Median		7.1201	
		Variance		2.699	
		Std. Deviation		1.61209	
Trabajo STEM	0	Mean		4.8929	0.22249
		95 % Confidence interval for Mean	Lower Bound	44.512	
			Upper Bound	5.3466	
		5 % Trimmed Mean		4.9254	
		Median		5.0000	
		Variance		2.321	
		Std. Deviation		1.55509	
	1	Mean		8.3122	0.21279
		95 % Confidence interval for Mean	Lower Bound	7.8847	
			Upper Bound	85669	
		5 % Trimmed Mean		8.2327	
		Median		8.1200	
		Variance		1.322	
		Std. Deviation		1.01540	

Descriptives Biotecnology Students				Statistic	Std. Error
PruebaNivel	0	Mean		5.6763	0.21956
		95 % Confidence interval for Mean	Lower Bound	5.1991	
			Upper Bound	6.2134	
		5 % Trimmed Mean		5.7531	
		Median		5.8880	
		Variance		1.8093	
		Std. Deviation		1.25991	
	1	Mean		5.7712	0.30001
		95 % Confidence interval for Mean	Lower Bound	5.1511	
			Upper Bound	6.4002	
		5 % Trimmed Mean		5.7411	
		Median		5.599	
		Variance		2.110	
		Std. Deviation		1.41098	
NotaFinal	0	Mean		4.7121	0.33892
		95 % Confidence interval for Mean	Lower Bound	4.0021	
			Upper Bound	5.4111	
		5 % Trimmed Mean		4.6984	
		Median		5.0112	
		Variance		3.301	
		Std. Deviation		1.80987	
	1	Mean		7.6991	0.30998
		95 % Confidence interval for Mean	Lower Bound	7.1001	
			Upper Bound	8.2981	
		5 % Trimmed Mean		7.7555	
		Median		7.8991	
		Variance		2.299	
		Std. Deviation		1.49917	
Trabajo STEM	0	Mean		5.3117	0.32332
		95 % Confidence interval for Mean	Lower Bound	45.027	
			Upper Bound	5.9233	
		5 % Trimmed Mean		5.3001	
		Median		5.2000	
		Variance		3.120	
		Std. Deviation		1.80001	
	1	Mean		8.2060	0.25998
		95 % Confidence interval for Mean	Lower Bound	7.6981	
			Upper Bound	8.6991	
		5 % Trimmed Mean		8.2852	
		Median		8.4100	
		Variance		1.859	
		Std. Deviation		1.24321	

Table 1.- Descriptive of the dependent variables

III.1.- Academic effect of board games designed on students.

After studying the normality of the variable PruebaNivel (Table 2), the authors analyzed the existence of significant differences using the test done by the students. Table 3 indicates that there are significant differences between them, which makes it necessary to study the academic effect of the card game designed in each of the degrees separately, that is, each degree has its own control group and its own experimental group.

In addition, to validate the study carried out, it was necessary to identify the non-existence of previous differences between the control group and the experimental group of each of the degrees. To do this, it was necessary to guarantee that the prior knowledge (variable PruebaNivel) of the control group and the experimental group was similar in each degree. This condition was verified for the control and experimental groups of the two titrations.

To be able to apply parametric statistical tests, a normality check was carried out (Table 2) on the variable considered (PruebaNivel) for the two degrees considered.

The results indicated a statistical significance of the tests greater than 0.05, thus confirming their normal distribution. Subsequently, the mean comparison test was carried out using the t-Student (Table 3); the result indicates that, in both titrations, there were no significant differences between the control group and the experimental group, validating the experimental design carried out.

Total Population						
	Kolmogorov-Smirnov (1)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PruebaNivel	0.075	121	0.075	0.970	121	0.082
(1) Lilliefors Significance Correction						

Environmental Sciences students						
	Kolmogorov-Smirnov (1)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PruebaNivel	0.075	67	0.196	0,969	67	0.402
NotaFinal	0.010	67	0.095	0.913	67	0.241
TrabajoSTEM	0.098	67	0.075	0.991	67	0.201
(1) Lilliefors Significance Correction						

Biotecnology students						
	Kolmogorov-Smirnov (1)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PruebaNivel	0.066	55	0.200	0.970	55	0.459
NotaFinal	0.076	55	0.200	0.972	55	0.365
TrabajoSTEM	0.091	55	0.200	0.965	55	0.211
(1) Lilliefors Significance Correction						

Table 2 – Normality tests for quantitative variables

Now it is interesting to know if the participation in the gamification process by the experimental group supposed a statistically significant difference over the control group in terms of academic results of the subject considered. Checking the normality of the NotaFinal variable (Table 2), the test wereperformed on it and for the two degrees. The results were shown in Table 4.

The results of Table 4 show how, for both cases, the mean differences, around 3 points, were statistically significant, which demonstrated the positive effect, at an academic level, that the use of the board game designed had.

The results obtained are in line with the literature on the use of gamification elements in teaching (Kayımbaşıoğlu, Oktekin, & Hacı, 2016; Paniagua & Calvo, 2019); however, the significant increase in the mean of the NotaFinal variable with respect to the students belonging to the experimental group is noteworthy. In addition, although there are still students who, belonging to the experimental group, do not manage to pass the subject, it is no less true that the percentage of students who pass the subject is much higher in the case of the experimental group with respect to the control group. Prince (2004) observed slight decreases in academic performance when applying STEM experiences to students (counteracted with an increase in the practical of the students problem-solving capacity), our experience indicates the opposite, surely due to the synergy produced using

learning processes.

		Total population								
		Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2 tailed)	Mean Difference	Std. Error Difference	95 % Confidence Lower	Upper
PruevaNivel	Equal variances assumed	10.771	0.002	-4.112	120	0.000	-1.22431	0.30998	-1.88991	-0.63146
	Equal variances not assumed			-4.326	117.998	0.000	-1.22431	0.29871	-1.85538	-0.67000
		Environmental Students								
PruevaNivel	Equal variances assumed	5.531	0.031	0.398	67	0.692	0.19111	0.48764	-0.77112	1.16001
	Equal variances not assumed			0.415	65.181	0.662	0,19111	0.45628	-0.70998	1.10231
		Biotecnologyl Students								
PruevaNivel	Equal variances assumed	0.814	0.371	-0.005	50	0.996	-0.00171	0.37484	-0.75459	0.75117
	Equal variances not assumed			-0.004	44.391	0.996	-0.00171	0.38020	-0.76777	0.76435

Table 3.- Tests conducted by students to compare means for the situation prior to the experimentation.

		Environmental Sciences Students								
		Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2 tailed)	Mean Difference	Std. Error Difference	95 % Confidence Lower	Upper
NotaFinal	Equal variances assumed	0.965	0.331	-8.003	67	0.000	-3.10221	0.38001	-3.87134	-2.34512
	Equal variances not assumed			-7.887	51.582	0.000	-3.10221	0.39001	-3.89000	-2.31112
TrabajoSTEM	Equal variances assumed	1.312	0.149	-9.411	67	0.000	-3.23032	0.34348	-3.91520	-2.54332
	Equal variances not assumed			-10.099	66.165	0.000	-3.23032	0.31978	-3.86875	-2.60011
		Biotecnology Students								
NotaFinal	Equal variances assumed	0.815	0.334	-6.323	54	0.000	-2.99112	0.47076	-3.94006	-2.04291
	Equal variances not assumed			-6.456	51.799	0.000	-2.99112	0.46956	-3.91332	-2.06179
TrabajoSTEM	Equal variances assumed	2.335	0.122	-6.563	54	0.000	-2.92342	0.44119	-3.80001	-2.04907
	Equal variances not assumed			-6.902	51.380	0.000	-2.92342	0.42401	-3.78714	-2.08332

Table 4.- T tests comparing mean differences between the control and experimental groups after experimentation

III.2.- Effect of the designed game on the ability of students to integrate knowledge of subjects from the STEM environment.

A final activity based on carrying out a small-scale industrial design project that involved the integration of knowledge of science, mathematics, and technology was used to validate students' perceptions of their ability to integrate subjects typical of a STEM environment. The grade obtained by the students belonging to the control group and the students belonging to the experimental group were compared. However, because the students' prior knowledge had an impact on it and to give the outcome value, it was required to compare the two in terms of degrees because, as was previously said, there were variances for the variable PruebaNivel between the two (Table 3).

Thus, after confirming the normality of the variable named TrabajoSTEM (Table 2), a parametric contrast of means was performed using the t-Student test to compare the experimental group with the control group. The findings, which are presented in Table 4, showed that students—regardless of their academic standing—obtained a statistically higher grade on the suggested task, supporting the students' judgment of their capacity to integrate STEM knowledge after the experimental period.



Figure 2.- Example of Problem Card



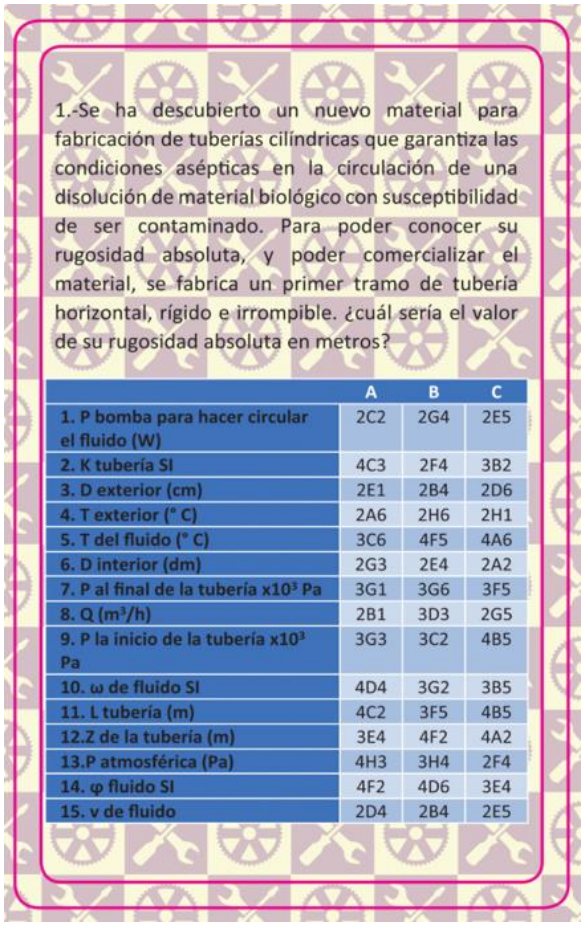
Figure 3.- Example of Data Card



Figure 4.- Example of Problem Card



Figure 5.- Example of Kepler Card



	A	B	C
1. P bomba para hacer circular el fluido (W)	2C2	2G4	2E5
2. K tubería SI	4C3	2F4	3B2
3. D exterior (cm)	2E1	2B4	2D6
4. T exterior (° C)	2A6	2H6	2H1
5. T del fluido (° C)	3C6	4F5	4A6
6. D interior (dm)	2G3	2E4	2A2
7. P al final de la tubería x10³ Pa	3G1	3G6	3F5
8. Q (m³/h)	2B1	3D3	2G5
9. P la inicio de la tubería x10³ Pa	3G3	3C2	4B5
10. ω de fluido SI	4D4	3G2	3B5
11. L tubería (m)	4C2	3F5	4B5
12.Z de la tubería (m)	3E4	4F2	4A2
13.P atmosférica (Pa)	4H3	3H4	2F4
14. φ fluido SI	4F2	4D6	3E4
15. v de fluido	2D4	2B4	2E5

Figure 6.- Example of Solution Card

IV. CONCLUSIONS

The outcomes reported in this investigation are based on a pretest–posttest experimental design conducted with undergraduate students enrolled in the Engineering Bases program, specializing in environmental sciences and biotechnology. The intervention consisted of an educational card game, named *Kepler*, specifically developed to reinforce disciplinary knowledge and facilitate the integrative understanding of concepts across STEM (Science, Technology, Engineering, and Mathematics) domains. The experimental manipulation involved the inclusion or exclusion of this gamification element, distinguishing the control group, which followed conventional instructional practices, from the experimental group, which engaged with the *Kepler*game.Statistical analyses conducted at a significance threshold of 5% ($\alpha = 0.05$) demonstrated that, after verifying the equivalence of baseline characteristics and initial academic performance between the two groups, students assigned to the experimental condition exhibited significantly greater levels of achievement in the post-intervention assessment. These results suggest that the incorporation of the Kepler board game effectively enhances not only the acquisition of disciplinary knowledge but also the capacity to integrate interdisciplinary STEM concepts.

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