TESLA: A Gamification framework to motivate students in Industrial Engineering

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***Abstract*—. Innovative learning techniques aim at promoting the motivation of students while improving the acquisition of the most relevant concepts of a subject. Towards this goal, this paper presents a gamification-based implementation executed in the industrial engineering degree of the University of Málaga (Spain). Specifically, the technique is used in the subject named Fundamentals of Electrical Engineering. The design of the gamification framework takes into account the particularities of the students. In particular, the application is intended for non-integrated groups formed by some students who have coursed the same subject in previous courses. An individual-based competition framework is developed in the context of the construction of a wireless charger for an electric vehicle, which is a topic of interest for the students. The results show that the students considered the application of this kind of technique as positive.**

Keywords—electrical engineering, gamification, university.

I. INTRODUCTION

The correct inclusion of innovative learning techniques facilitates the student's process of acquiring new concepts. This is especially convenient when the concepts are abstract and students struggle in understanding and in applying them, as it occurs in engineering studies.

There are diverse innovative learning techniques and their appropriateness depends on several factors such as the competence that needs to be reinforced, the ratio between the number of students and the number of teachers involved in this practice, the scenario (on-line lessons or in-presence), the time to implement it or the interaction required among the students.

Competitive learning is an innovative learning technique that is gaining popularity in recent years. Basically, this approach makes students compete through the resolution of some tasks/problems. The practical applications of competitive learning are usually associated to extrinsic motivation [1] so that being the best in the resolution of some tasks implies an augmentation of the students' final grades.

Competitive learning and gamification in particular are considered mechanisms that promote the motivation and autonomy of students as shown in [2]. An important issue of this technique is how the students compete. This could be done individually or in groups. Considering a well-stablished set of students, group-based implementations provide some advantages. Firstly, students develop some social competences (e.g. the ability to discuss about a technical problem). Their learning is also considered to be improved as it involves a peer. However, the definition of the team size and the grouping of students are not trivial tasks and in fact, these two configuration parameters clearly impact the success of this technique [3]. The team size is usually defined basing on some space restrictions or taking into account the additional work to be done by the supervisors. Concerning the composition, teams could be defined randomly, chosen by the students themselves, or following a mixed-strategy [4]. The selection of these criteria should be based on the type of relationship the students maintain.

In this sense, engineering degrees in Spain are seen as hard studies so that the students usually need to take some subjects more than once. This implies that the group of students do not maintain strong relations among them. In addition, the attendance to the lessons is not mandatory once they have enrolled them. Consequently, an important number of students start to attend the lessons of a subject but then, they decide not to continue with this study and postpone it for a next year.

Taking into account this behavior, group-based competitive learning implementations are advised against. Indeed, negative consequences may be provoked due to the particularities of these students. The first consequence is that members of the groups start to miss the lessons and, in turn, those students still attending the classes need to put extra efforts to finalize the group-based activities on a competitive approach. Most of them are unable to finish the tasks properly and on time so they do not gain any additional points (extrinsic motivation) and they are discouraged to continue involved in this practice. In addition, the students do not know each other well as they do not share common subjects. Some social problems arise because of this fact.

Based on this analysis, we have designed and implemented a set of gamification-based activities to be done individually in the subject "Fundamentals of Electrical Engineering" for the Industrial Engineering degree at the University of Málaga (Spain). The subject is based on the knowledge of multiple and simple concepts, most of them supported by previous ones. Continuous knowledge facilitates the understanding, so tools oriented to promote it are highly recommended. Gamification helps students to engage to the approach [5]. The activities are oriented to reinforce concepts explained in the classroom and to make students develop their competence to apply them in the resolution of electrical circuits. The gamification design was specifically focused on gaining the students attention. Towards this goal, the gamification world regards the building of a wireless charger for Electric Vehicles (EVs). Real electronics

implementation and the practical use of wireless power transfer techniques are of interest for the students.

The results of this approach show that students considered the gamification activities as attractive at the beginning but their motivation decreased throughout the subject.

The remainder of the paper is structured as follows. Section II presents some details about the design process of the gamification approach. Section III describes the implementation of this mechanism for the course 2016/17. Section IV describes the results obtained. Finally, Section V summarizes the main conclusions.

II. DESIGN OF THE GAMIFICATION TECHNIQUE

The design of a gamification technique implies the consideration of several issues, as exposed in [6]. Following the guidelines of this work the design is based on the next five steps:

Step 1: Analysing users and environment

The proposed practice is used with nearly 286 students divided into 4 groups. Each group is mentored by a different teacher. The experience of the teachers involved in this subject is heterogeneous: three of them have extensive practice working on this subject and the last one teaches the subject for his first time.

The subject, titled "Fundamentals of Electrical Engineering" is programmed in the second year of the Industrial Engineering degree at the University of Málaga (Spain). The age of the students ranges from 19 to 25. A high percentage of the students (30%) have done the same subject in previous courses but they have not passed it. 30% of the students are women. An important aspect to consider is that attendance to the classes is not mandatory.

Step 2: Defining learning objectives

The goal of the gamification approach is to reinforce some basic concepts explained during the lessons while working with a real electrical system. The system is a wireless charger for EVs. By managing this circuit, the competences that the students will acquire are:

- The ability to understand real and up-to-date electrical circuits.
- The use of coils as essential components of wireless power transfer. They will learn about Ampère's law and Faraday's law, both are fundamental concepts for other relevant applications in electrical engineering; i.e. electrical machines.
- The different use of Alternating Current (AC) and Direct Current (DC) electricity waveforms.
- The use of diodes to convert from AC to DC.
- The need for power converters.

Step 3: Designing the experience

There are multiple possibilities to decide the game world. In our case, we wanted to motivate the students about the importance of the concepts taught in the subject. Thus, we considered an electrical system of actual interest: wireless chargers for electrical vehicles. Wireless power transfer and the interaction of electrical vehicles with the grid are research topics of the department responsible for the subject so the professors could easily elaborate materials related to these concepts. In particular, a video is shown with the application of wireless power transfer to charge a vehicle in the same building where students attend the course, that is, in the Engineering School of the University of Málaga (Spain). With this practice, the students see the usefulness of knowing about coils, capacitors, diodes and other elements, all of them explained in the course. The goal of the game, named Tesla, is to construct a wireless charger from its pieces.

The mechanism and the rules of the gamification need to be simple for two main reasons. Firstly, one teacher is in charge of nearly 90 students so that the resolution of questions related to the dynamics of the game should be minimal. On the other hand, the teachers do not have much time to implement it in class as the amount of content of the subject is considerable. We opted for short questions to be solved individually during the classes and by which the students could get some points. The acquisition of the components demands a certain number of points, as explained in next section. When getting a certain number of points/elements, the students are promoted to a level. Following an extrinsic motivation, reaching a level implies an additional contribution in their final grade.

Ten activities are programmed throughout the 14-week term. Omitting the first two weeks when no gamification activity is performed, one activity is executed nearly every week.

The implementation of our gamification is simple but effective. There are four groups, each one conducted by a different professor. We eluded any coordination complication so the implementation of the gamification practice is done separately. The ranking of the students for the four groups is exposed in the same Learning Management System that the students use to obtain their materials. In this way, students are alerted when they get to a milestone, that is, when they are promoted to a different level.

Step 4: Identifying resources

The activities are not programmed so that the students do not know beforehand if a session will feature a game or not. The activity is done at any time throughout one lesson. The teacher simply announces when a new Tesla activity is going to take place and then the students prepare a sheet of paper with their names on it. Then, he explains the problem to be solved and the students have a maximum of 10 minutes to answer the question. Answers are collected in order, so that the students answering first get more points in the game.

Step 5: Applying gamification elements

The gamification approach uses two types of awards. Firstly, the promotion in the different levels stablished in the activity implies an additional contribution to the students' final marks. In this way, an extrinsic motivation is employed to engage students. On the other hand, from a social point of view, the gamification approach relies on a dashboard where

the students who have already obtained any points are ranked. This ranking is updated every time a Tesla activity is performed. The leaderboard is shown in the Learning Management System.

Finally, the effectiveness of the implementation is evaluated with a short survey, which is not mandatory and it is accessible by the end of the subject through the Learning Management System.

III. TESLA

This Section explains the main aspects of the proposed gamification teaching method in details. As we have previously commented, the goal of the proposed gamification tool is the acquisition of the components to form a wireless charger for Electrical Vehicle (EV). The gamification teaching method has been used in four different student groups of the same university course "Fundamentals of Electrical Engineering" at the University of Málaga (Spain). By the end of the course, students answered a survey on the degree on which the method motivated them to follow the course and learn its contents.

The mechanics of our gamification approach counts on points, levels, leaderboards and awards, in a similar way to [7].

The gamification teaching method is based on the proposal of conceptual questions or small problems related to each weekly lesson and called Tesla exercises. The exercises proposed to students usually evaluate the correct understanding of basic concepts, leaving out of the game more advanced exam-type problems. Throughout the duration of the course, a total of 10 Tesla exercises were proposed.

Once a Tesla exercise is proposed, students have to write in a piece of paper their name and their answer to the exercise. Once a student has solved the exercise, the teacher checks it and tells the student whether the solution is correct or not. If the solution is incorrect, the student cannot continue participating in the game on that day. When four students have correctly solved the exercise, the game stops and these students get the following points:

- First student answering correctly: 3 points
- Second student answering correctly: 2 points
- Third student answering correctly: 1 point
- Fourth student answering correctly: 0.5 points

As students get points, they could increase their level in the game. Table I shows the association between the number of points obtained and the level achieved in the Tesla game.

Table I. Levels in Tesla gamification tool

LEVEL ACQUIRED	POINTS OBTAINED
Basic	4-6
Medium	7-9
Advanced	10-14
Expert	15 or more

In order to motivate students and encourage competition among them, a student ranking was published in the course website every week. Reaching a level of the game implies that the student has obtained certain electric elements of a wireless charger for electric vehicles. Specifically, each level is associated with a group of components, as exposed in Table II.

Table II. Components of the EV wireless charger obtained in each level

LEVEL ACQUIRED	COMPONENTS OBTAINED
Basic	Voltage source, inductors and battery
Medium	Reactive elements for compensation of reactive power
Advanced	Diodes
Expert	Power converters

The sequence by which the students can get the EV wireless charger is illustrated in the following Figure.

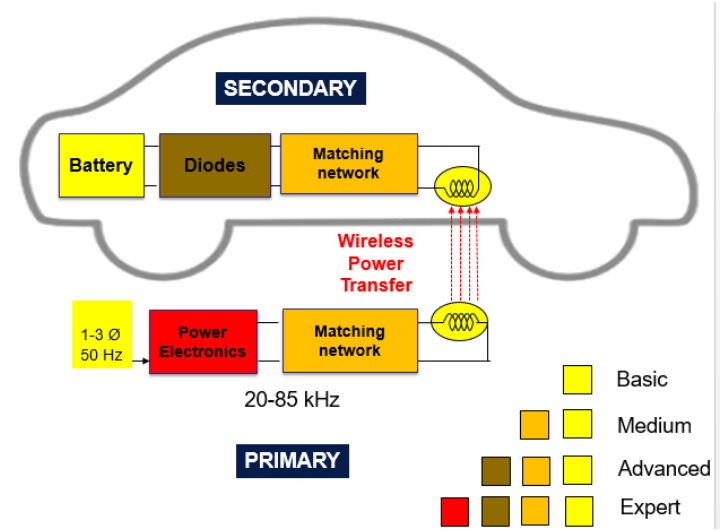

Figure 1. Relationship between the levels of the gamification technique and the components of the EV wireless charger that are acquired in each level.

Coherently, the electric elements of lower levels are related to the theory covered in the first chapters of the course, while the theoretical aspects of the elements obtained in the final levels correspond to concepts of the last part of the course.

Furthermore, reaching each level implies a certain number of extra points in the final exam of the course.

Table III. Extra points in the student's final marks gained in the Tesla gamification technique

LEVEL ACQUIRED	ADDITIONAL POINTS AWARDED
Basic	0.25
Medium	0.5
Advanced	0.75
Expert	1

IV. Results

This section provides some information about the usefulness of the gamification and the degree of user satisfaction. Students have been challenged with the Tesla game for the first time during 2016/2017 course, and the feedback is essential to evaluate the tool and to design procedures for improvement in subsequent courses.

An informal feedback has been firstly obtained from interviews with students within the classroom. The general feeling is that they appreciate the novelty of this tool and it has provided a higher degree of motivation. From the quantitative point of view, the number of students who passed the subject in the course 2016/2017 is roughly the same as in the previous course 2015/2016, but a higher number of these students passed the subject in the preliminary exams rather than in the final exam. Even though there are many factors involved in the final scores, this might indicate that the gamification provided a higher motivation to study the subject from the beginning of the course, that is, a continuous work done by the student seems to have been promoted.

Beside this, some qualitative information was obtained through a questionnaire that students could respond to in an anonymous and volunteer manner. Specifically, we have used a Likert-based survey to measure 9 concepts; the concepts considered were: 1) student's initial motivation degree; 2) evolution of the motivation throughout the course; 3) amount of motivation to attain the following level; 4) effect of ranking publication, i.e. motivational or demotivational; 5) general complexity of the questions proposed; 6) adequacy of the number of games presented; 7) helpfulness of the questions to understand the concepts; 8) usefulness of the questions as a preparation towards the final exam; 9) would you recommend that the game be repeated next year? From the scores of 51 students, the degree of satisfaction is summarized in Figure II (scores range from 1 to 5).

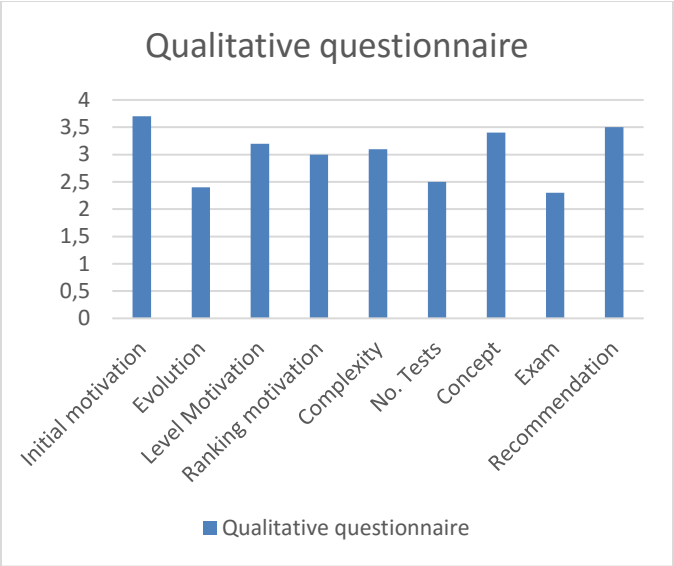

Figure II. Qualitative questionnaire to evaluate the satisfaction of students in different items/dimensions of the Tesla's game.

Some analysis on these data follows:

1) *Initial motivation*: It can be observed that the students had a good motivation at the beginning of the gamification practice. This can be due to the fact that the lecturers showed some videos explaining the Tesla game and this part seemed to be well-accepted by students.
2) *Evolution*: it is found, however, that the evolution of the motivation decreased during the course. It is clear that the manner in which the Tesla game was implemented did not fully fulfil the initial student's expectations. This can be related, among other factors, to a poor connection between the Tesla game and the type of problems that were selected for the final exams (see item 8).
3) *Level motivation*: it seems however that the students were motivated to get a certain level and get the bonus and recognition. It must be highlighted here that the four groups used for the experience had a different number of students and in groups with a high number of students (e.g. group A), the possibility of achieving a higher level was scarce because they had to compete against many other students, so the scores were highly diversified. Solving this problem can further increase the score in this point.
4) *Ranking motivation*: students proved to be motivated to compete among them, but this competitive attitude can be improved if the number of students that get the bonus becomes proportional to the number of students attending the course. A restriction could be included to keep this number above a certain threshold (e.g. no. of students that score $\approx 10\%$ of students attending the lecture). The use of a fix number provides lower motivation in groups with a high number of students.

5) *Complexity*: According to this item it is apparent that students are reasonably satisfied with the level of complexity of the Tesla game tests.
6) *Number of tests*: a low score is provided in this item, indicating that students are not fully satisfied with the number of tests. It is likely that students would have liked a higher number of tests within the lectures, but it must be highlighted that there is a restriction of time that prevents the lecturers to increase excessively the number of tests. They can be slightly increased in the next years, but there is no room for a high growth in the number of tests because of the limitation in the lecture hours.
7) *Concept*: according to this item the students perceive the tests used in the gamification as a useful tool to consolidate the main concepts of the subject.
8) *Exam*: this item shows a low score, which, in conjunction with the previous one, indicates that the students feel that the Tesla game is useful to understand the concepts but not so much to pass the exam. Maybe the explanation of this paradox is that the structure of the problems in the exam is quite different to that in the gamification tests. While in the Tesla game the problems are short and conceptual, in the exam the problems are time consuming and more mathematically intense. For this reason, the students feel that the tests are good to understand relevant concepts in the subject but the participation on these tests do not fully prepare them for the exam. Some efforts can be done to approach the type of problems in the tests and the exam and thus save this gap.
9) *Recommendation*: in this item students are asked if they recommend the continuation of the gamification as a useful tool for the subject. In spite of the low score in the item *Exam,* students recommend to go on using this tool. This item encourages the authors to continue the gamification with an aim to improve the rest of items to get a high satisfaction in all dimensions.

As a summary, the gamification can be considered a useful tool to provide additional motivation and conceptual understanding but some improvements are also due in future editions of the Tesla game in order to increase the satisfaction in some items.

V. Conclusions

In an engineering degree context, students' engagement and motivation are particularly challenging in difficult and demanding fundamental courses. We have presented a gamification process specifically designed for a second-year course titled "Fundamentals of Electrical Engineering". The design of the approach takes into account the particularities of the students, concluding that an individual-based competition with short questions is the best option. The context for the gamification practice is the construction of a wireless charger for EVs, which is composed of components about which students learn throughout this course.

The results indicate that most students are positive about the gamification experience; however, there is room for further improvement in next editions. The survey results show that students consider the gamification activities attractive at the beginning, although their motivation decreased throughout the term. The number of tests and bonus that students can obtain should be also effectively determined in terms of number of students so that a reasonable level of competition is achieved among participants.

The authors conclude that the proposed gamification has a positive effect by increasing extrinsic motivation, making difficult technical concepts more accessible, fostering interest in the course and increasing students' final marks.

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