

## Alternative gamification approaches in engineering education

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### Abstract

*Motivating students eases their learning process. In this line, gamified activities are presented as an effective strategy but dependent on the context and students' profile. The procedure to gamify several activities of a master course in engineering is detailed: preliminary analysis, justification of the selection of alternative gamifying strategies, definition of the indicators, including the proposal of a novel mood self-assessment strategy, and discussion of the obtained academic results. The main conclusion is that gamification improve students' mood. In addition, time trial activities motive students but are detrimental to their marks, whereas the importance of choosing a suitable activity type and placing it in the correct calendar date is essential to its effectiveness.*

**Keywords:** Gamification; Engineering; Motivation; Mood; Self-assessment.

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### 1. Introduction

The motivation of the students is a key point to impulse their learning process. With this aim, different gamified experiences were introduced in *Concrete Structures* course of Structures and Construction specialization of the Master in Industrial Engineering at ESEIAAT-Polytechnic University of Catalonia (UPC). The specific objectives were: to increase the class attendance up to 90%, to reduce the theoretical lectures to a maximum on 20 continue minutes and to include at least one gamified activity per session. It was also intended to test different types of gamified activities to asses which were the more suitable ones.

To implement these activities a previous analysis of the context, a comparative discussion of the alternatives and the preparation of the required resources was carried out. During the application of the gamified activities, mood surveys were answered by the students and objectives and subjective indicators were acquired. Finally, the academic results are analyzed in comparison with previous courses to conclude about the pros and cons of the proposed activities, being possible to distinguish the most efficient changes.

## **2. Theoretical background**

First uses of gamification in learning environments date back to 1980's. However, scientific research on its relationship with motivational aspects is more recent and critical references appear just 10 years ago. A literature review on gamification for undergraduate students performed by Bodnar et al. (Bodnar et al., 2016) pointed out the general result of improving the attitude and learning performance. However, the same authors indicated that more evidence-supported research was necessary. In this line, some researchers presented their corresponding studies on educational and professional field (Indriasari et al., 2020), highlighted its usefulness for simulating work life (Alanne, 2016) or the importance in developing decision-making competences (Legaki et al., 2021). Particular empirical applications were performed together with other active-learning methods (Rodríguez et al., 2018), to improve laboratory practice also reporting students' perspective (Kim et al., 2018) or using it continuously along a semester being gamification volunteer (Díaz-Ramírez, 2020). Nevertheless, some researchers pointed out that there may be also negative effects related with wrong gamification design (Toda et al., 2018). A review study (Hamari et al., 2014) pointed out that gamification effectiveness highly depended on the context and the profile of students, or that technical resources are required (Dicheva et al., 2015). In addition, it seems that results are also variable, improving global marks but reducing the proficiency in written activities or face-to-face participation (Domínguez et al., 2013).

For all these reasons, the current research is based on analyzing different gamification approaches in a well-defined group-context, to provide additional data to the literature.

## **3. Research context and previous learning evidence**

The specific characteristics of the students is highly related with the performance of gamified activities in the learning process. To objectively characterize the group, the first research task was to submit a brief questionnaire about the students' profile to the people who took the course in the three previous editions and the last course the gamified activities were applied in. The participation was 85% and the results showed that the average age was 24, all of them worked apart from studying with an average job dedication of 25h/week, most of them (76%) came from Engineering in Industrial Technologies Bachelor indicating little (70%) previous knowledge on the matter (in a scale of no-little-intermediate-high previous knowledge).

To assess the starting control situation, SEEQ questionnaires, firstly defined by (Marsh & Roche, 1994), of previous editions of the course were analyzed from five particular questions regarding motivation: (A) I have found the course intellectually challenging and stimulating (4.75/5); (B) My interest in the subject has increased as a consequence of this course (4.50/5); (C) Instructor enhanced presentations with the use of humor (4.88/5); (D) Instructor's style of

presentation held my interest during class (4.75/5); and (E) Course difficulty, relative to other courses, was (1)Very easy, (2)Easy, (3)Average, (4)Difficult, (5)Very Difficult (3.63/5).

Finally, the academic results of the previous editions of the course were analyzed. The selected concepts had to had been continuously assessed with activities or exam questions in the past three editions (2020-2022); it was gamified in the studied edition. The following table summarizes the results through numeric marks out of 10.

**Table 1. Previous academic results.**

Concept	2020	2021	2022	Avg.	2023
To calculate the mechanical properties of concrete	10.0	10.0	8.8	9.6	8.1
To name concrete	10.0	10.0	10.0	10.0	7.2
Durability	8.5	5.8	5.7	6.7	8.9
To calculation of flexural strength	5.3	4.2	6.2	5.2	5.0
To calculate deflection	6.8	6.2	5.4	6.1	7.0
Pouring and curing procedure	9.8	10.0	7.5	9.1	9.6
Strengthening of concrete structures	5.0	5.3	6.9	5.7	7.5

## 4. Methods

### 4.1. Previous analysis

#### 4.1.1. Objectives definition

Two potential objectives are set to justify the application of gamified activities. The first one aims to increase the motivation of the students. A motivational issue can be detected if SEEQ questions (A)-(D) in section 3 show marking below 4/5. The second potential objective would be to easy hard-learning concepts. This need can be observed if the question (E) in section 3 obtains a punctuation higher than 4/5. It is important to highlight that adopting a gamification strategy is not the only way to deal with the previous two challenges, but it is the studied one in the current research. Regarding the particular application case, the results of previous SEEQ questionnaires did not indicate the need of modifying the course. Nevertheless, it was decided to apply the gamification to easy the hard-learning process.

#### 4.1.2. Group characteristics

The size of the group will determine which activities are preferable for operating limitations. The age of the students together with the job occupation are considered to indirectly assess the daily contact with game playing. Hence, older people or people with greater job responsibilities are supposed to have little time to play, thus gamification may be effective at providing a stress release, helping students to be in positive mood when dealing with complex concepts. Finally, the class attendance may be used as an additional indirect measurement of students' motivation.

Regarding the case study, most of this data is provided in section 3. The group size was little (4 students in the 2023 edition) and the class attendance of previous editions was 85%.

#### *4.1.3. Content type*

Complex transversal concepts are commonly included in the first years of engineering bachelors at UPC. These more abstract ideas can benefit from gamification but it would be recommended to introduce the changes at a slower rhythm than in technological higher courses that are more oriented to practical applications. This later situation is the current case study and introducing a wide range of possible gamified activities was possible.

#### *4.1.4. Calendar limitations*

Analyzing the calendar allows to cross the information about the more stressful dates for students (exams, delivery of course projects) and the gamified activities that require more time out of the classroom to avoid their coincidence. In the case study, the more time-consuming activities were placed out of the stressed periods (early November and last December) and the short activities to be developed in the classroom are moved to these periods, except for one control activity.

#### *4.1.5. Available resources*

Having access to the time, human and material resources is necessary to introduce any teaching innovation in a course. The case study benefited from the support of a teaching team committed with the innovation, six months' time to implement the changes and the material resources and support of the laboratories from CATMech research group.

### **4.2. Alternative gamified activities and selection**

Six types of activities are considered in the research to be used as part of the gamification process. Others are possible but not considered. A brief description of each activity type is provided with no aim of in-depth analysis. The prize to the student/group winning each activity was the direct addition of 0.1 to 0.5 points, depending on the complexity, in the final course mark.

Debate/role playing consisted in randomly assign roles to the students that had to convince a volunteer person that acts as a jury/referee with technical arguments (e.g. constructor vs client representative discussion about particular construction techniques). Experiments were typical laboratory practices that used recorded data to calculate some parameters (e.g. flexural test of reinforced beams). Peer tests were short questions asked by students to students in anonymized way (e.g. defining durability requirements based on peer's definition of the construction). Peer problems followed the same idea but involved solving more complex calculation problems (e.g. first student set a calculation problem about deformation and the second solves it). Environment

exploration consisted in getting pictures of particular elements or processes analyzed in the classroom in time trial (e.g. searching for concrete joint types). Assisted calculation activity refers to a common computer assisted calculation of structures practice (e.g. Finite Element Analysis of a reinforced beam). Combining the data from the previous study and the characteristics of the combined activities, the following generic selection table was set.

**Table 2. Selection table for gamified activities.**

<b>Activity</b>	<b>Objective</b>	<b>Group</b>	<b>Content</b>	<b>Calendar</b>	<b>Resources</b>
Debate/Role playing	Motivation	Small-Medium size Adult age	Complex cases	Stressed	Little
Experiments	Motivation Ease learning	Small size Young age	Complex concepts	Stressed	High economic
Peer tests	Motivation	Medium-Big size Adult age	Simple concepts	Stressed	Little
Peer problems	Motivation	Medium-Big size Young age	Complex problems	Non-stressed	Little
Environment exploration	Motivation	Any size Young age	Descriptive concepts	Non-stressed	Little
Assisted calculation	Ease learning	Small-Medium size Any age	Complex problems	Non-stressed	High economic

Specific characteristics of the course would justify implementing debate/role playing, experiments and environment exploration. However, with the aim of assessing the performance of different alternatives at improving students' mood, all six types were considered. The previous table was used to assign the concepts of the course to the different type of activities. Debate/Role playing was used to deal with concrete pouring/curing and strengthening of structures. Experiments were introduced to focus concrete production, concrete characterization, flexural calculation of reinforced concrete and truss-tie models. Peer tests were used to learn about concrete and cement labeling and advanced concrete types. Peer problems were used in durability analysis and calculation of deflection of reinforced concrete. Environment exploration was incorporated at explaining concrete structural elements and types of joints. Finally, computer assisted was applied in non-linear calculation. Calendar limitations were also researched by including experiments, computer assisted calculation, peer tests and debate/role play in stressed dates, being assisted calculation the time-demanding activity to be used as control item. In total, 12 gamified activities were prepared.

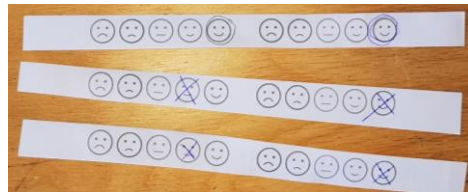
### **4.3. Preparation of activities**

Before implementing activities, the corresponding activity card was prepared including title, topic, objectives, duration, materials, tools, equipment, previous preparations tasks,

development tasks, gamification strategy and marking. For the debate/role playing activities the specific stories and databases were prepared. Specimens and tooling for experimental activities and digital files for computer assisted calculation activities were also prepared in advance.

#### **4.4. Setting the follow up strategy**

Two types of evidence were gathered. First, objective evidence like class attendance, results of activities and exams and SEEQ questionnaires were collected to compare with data from previous editions. Second, subjective evidence from students' opinion gathered through open questions in SEEQ and face to face discussion. The students' mood was also asked through anonymous graphical assessment (see Figure 1) at two different times in all sessions. These two asking times were set to analyze the mood before and after the gamified activities. However, in some cases these were placed to analyze the effect of a longer theoretical explanation or to analyze the mood evolution from the ending of a gamified experience to the end of the session.



*Figure 1. Graphical students' subjective mood assessment.*

## **5. Results and discussion**

The first result is that class attendance increased from 85% to 92%, indirectly indicating a motivation improvement. Regarding the marks (see the last two columns of Table 1) it was observed that including time trial activities caused more mistakes that resulted in 15% lower marks for the calculation of the mechanical properties of concrete, the calculation of the flexural strength or the concrete labelling. However, it has mentioned that all students choose these topics to answer open-selection questions in the exam getting an average mark of 7.5/10. In contrast, with no time restriction (durability, deflection calculation and strengthening of concrete) the marks clearly increase (over 15%). Assisted calculation, which was placed in the wrong calendar time, got the worst results with any student completing the activity even though it had the highest reward. Moving to SEEQ questionnaire, the four questions presented in section 3 related to motivation obtained the maximum mark, whereas the question about the difficulty of the course improved to “average”.

Graphical mood assessment showed that the mood self-assessment increased 0.9/5 points comparing the states before and after gamified activities. The two more effective activities in this line were debate/roleplaying and experiments. In the control cases, comparing the mood

state before and after a theoretical session, 1.3/5 points were reduced, whereas from the finishing of the gamified activity to the end of the session the mood reduced 0.25/5 points.

Subjective students' opinion indicated that the preferred activities were the ones conducted out of the classroom, followed by debates. They also explained that solving calculations in time trial was also motivating. Surprisingly, this was the opinion of the student who got less additional mark in this type of activities. Long peer problems were the ones that liked less. From the teacher point of view, experimental activities involve far more preparation but help students at understanding, whereas debate activities are the most effective ones. Peer tests contribute to change the rhythm of the session and increase motivation at a lower cost in time.

## **6. Conclusions and practical implications**

Different gamified activities were introduced in a Concrete Structures master course together with a mood self-assessment strategy to identify the types of activities that are more effective at motivating students. Academic results and SEEQ questionnaires results are also considered and compared with previous editions to conclude that:

- Gamified activities improve students' mood during sessions.
- Time trial activities caused calculation mistakes but settled down students' knowledge that selected these activities in an open-exam.
- Debate/Role playing activities improve academic results of students and are assessed as the preferred ones, together with experimental activities, by the students.
- Gamified activities have improved the SEEQ questionnaire results on students' perception of the quality of the course in relation to motivational aspects.
- Setting the suitable activity types in the correct calendar dates is essential to bring positive results.

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