New Learning Method for Structural Understanding in Architecture Based on Gamification

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Abstract—**One of the challenges architecture students face is understanding static structural and mathematical procedures as part of the structural design concepts they need to apply in their work. This research hypothesizes that gamification and smartphone apps with games using topics of structural design applied to architecture could improve the results in architectural education. Based on gamification and e-learning software, a new learning method was created consisting of six strategies: understanding the target audience, definition of learning objectives, designing the experience, identifying resources, application of gamification elements and recap of the process; the method's importance was found in being the first in its kind at the architecture undergraduate level. To assess the effects of this method, a comparison between two classes (with and without the method) was made. The results obtained were promising: most students gained motivation, engagement, and higher final scores in their structural analysis and design courses.**

Keywords - educational innovation; higher education; gamification; architecture; structural design.

I. INTRODUCTION

In the field of architecture, physical and mathematical concepts are integral to the structural design process. However, considering the abstract nature of these concepts, architectural students often find it challenging to understand the mathematical simplifications for solving the behavior of structural elements, such as frames, bearing walls, slabs, columns, and many other built-in structures. In the School of Architecture at Tecnologico de Monterrey, Campus Ciudad de México, e-learning is encouraged as a tool for facilitating course objectives. Thus, in the courses of structural design, we first implemented an existing smartphone app, designed by the principal author of this paper exclusively for practicing physical-structural concepts in architectural design [1]. This app is a game-based learning method built on the potential of video games to improve understanding of structural design concepts such as stresses (tension and compression) and flexural moment and their effect over buildings and other structures, such as bridges, following the game elements of mechanics, story, aesthetics, and technology.

The software is designed as a virtual laboratory with practices to help students review the main concepts by a step-by-step guide to win each game. In the first semester, students were invited to play with this app as an additional learning tool. From a total of 22 students in the two groups of a structural design course, only 13 downloaded the app and played the games, while the others only followed the lab practice to win each level and comply with the assigned task. Even though the content of the application was part of the course syllabus, the students were not analyzing the concepts and were not engaging with the subject.

Therefore, the need for a different learning method to improve student engagement in the structural design course in architecture became clear. We hypothesized that gamification, as a learning method that occurs in a non-game context and focus on students´ engagement and challenge [2], could potentially provide better results in the understanding of structural design for architects. Even though recently, gamification has been gaining momentum in education [3], very few studies measure the impact of the teaching process in the educational context and explore methods for improving the program by gamifying the course literature and material from teachers' point of view [4]. Moreover, no studies have been found by the authors that explore the gamification method in the field of architectural education; this is due to most architecture schools' lack of knowledge on gamification and the existence of free applications that can be used in education.

This research aimed to design and measure the impact of a new learning method based on gamification to improve the structural understanding of architectural education from the teachers´ point of view. The purpose was to facilitate the learning of abstract physical and mathematical concepts related to structural design for architectural students and improve the overall quality of their architectural proposals. The benefits of such a method can bring in improving architectural education are multiple: from better structurally designed buildings to increasing students' satisfaction and self-confidence.

The work done for the research is based on a specific successful educational experience, but the methodology described could be adapted to other areas using mathematics and physics, such as civil engineering.

In order to understand the development and results of the proposed gamification method and its application, Section II of this paper presents the steps used to create the proposed method; in Section III, the working method and class

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experience are presented, while Section IV presents the assessment of the learning method results. Students' feedback and conclusions/future work are presented in Sections V and VI, respectively.

II. CREATING THE METHOD FOR STRUCTURAL UNDERSTANDING IN ARCHITECTURE

Following the six steps proposed by Hsin et al. [3] for gamification at the Management School at the University of Toronto, we designed a new learning method for structural design understanding in architecture with the following six strategies:

A. *Understanding the target audience and the context*

Within the architecture undergraduate program, the Steel Structural Design course is the last of four courses regarding Structural Analysis and Design. In theory, that implies that the students should have already mastered the structural analysis concepts in previous classes, and the students should be capable of immediately applying structural analysis in the course of Structural Design. The first strategy revolves around verifying students' abilities in structural analysis and setting the app tool and course dynamics.

- Strategy:

Architecture students arrive at this course with different levels of understanding of the basic concepts about structural analysis. To accomplish equal student's understanding, the following actions are considered: explaining different kinds of structural solutions, analyzing iconic architectural buildings, and downloading the smartphone app for the course. Most of the students at Tecnologico de Monterrey have a smartphone at hand, so the downloading and checking the app´s function is done relatively fast.

B. *Defining learning objectives*

Architecture students go through Structural Analysis courses without understanding their real application in designing buildings´ structural elements. The second strategy is aimed at defining the learning objectives of the Structural Design course in applying structural analysis concepts to propose correct, new, and/or sustainable architectonical solutions.

- Strategy:

Explaining general structural concepts and consequences of using them in architectonical solutions.

C. *Structuring the experience*

Students need to understand every stage of the structural design process. The third strategy deals with structuring the students' experience hierarchically, from solving smaller to more significant tasks, in order to gradually achieve the course objectives. If students do not understand every stage of the structural design, they will lose interest in the subject.

- Strategy:

Assigning starting exercises focused on smaller tasks to review the main concepts of the pre-courses and gradually increase the difficulty of the tasks to achieve the final solution of the structural design. As an example, we start in class solving a problem where the relation between the tension stress, the tension load, and the cross-section area of a steel cable are related in order to design a staircase suspended with cables from the ceiling.

D. *Identifying resources*

The course followed ¨Problem Based Learning¨ (PBL) [5] strategy before introducing gamification. To have a smooth course transition and become acquainted with this new strategy, at the end of every topic, a PBL challenge was introduced as part of an everyday exercise in the classroom.

- Strategy:

Activities from the gamification process were introduced as part of everyday work in the classroom; the first exercise of each theme was developed by writing down each step used to get the right answer. The following tasks are from the app, where scenarios are more real and displayed with the same topics. The students practiced one game per week.

E. *Applying gamification elements*

The fifth strategy builds upon the previous experiences in using the app and introduces more complex challenges to deepen the students' understanding of structural design problems. By using the gamification elements introduced in this strategy, the students have an opportunity to conceptualize better structural solutions and improve their course evaluation grade.

- Strategy:

The app selected must include one of the topics of the course and the professor should know how the app works to solve the problem, in order to help students to get the right answer, play the app and win each game.

The student has to solve problems with different levels of complexity and win the game at each level in order to move on to the next level. Every completed practice brings points when finished successfully, and these points were calculated as additional points in the monthly evaluation. Since not all students have the same capacity for solving mathematical problems fast, extra time was assigned to specific individuals to complete the task.

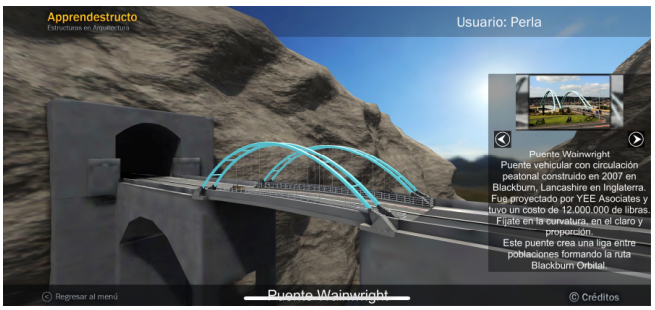

Figure 1. Application use in class 1 for steel design.

They would take the app practice as homework, getting an extended timeframe to finish the task. The course teacher followed up with those students after class by WhatsApp to answer any doubts. We concluded that it is quite important to allow students to work in teams since teamwork discussions encouraged students´ confidence in solving problems.

In Figure 1, the app scenario for a compression problem using a parabolic biarticulated arch is presented; the objective is to understand how the structural design is applied over an architectural project as this bridge.

F. Recap

Previous strategies were tested within the real course focus groups, adapting the strategies to calibrate and improve the method.

- Strategy:

Adapt the method´s strategies to the group´s needs and capabilities in order to get the best results in the learning process.

III. LEARNING EXPERIENCE AT THE CLASSROOM LEVEL

The above-described learning method was applied to three different groups of Structural Design courses in the last three semesters. The courses where the method was applied were "Design of Reinforced Concrete Structures" and "Design of Steel Structures." The main topic of both courses was the structural design of steel or concrete bearing elements, through theoretical explanation of structural behavior and application of building codes equations.

The classes were held twice a week and follow the PBL strategy. The first weekly class was dedicated to an explanation of a theoretical structural analysis approach and a presentation of structural element design on the blackboard with the participation of the students. Since the class time was limited, we focused on solving small problems concerning structural element design.

The second weekly class was dedicated to problem-solving assignments. To evaluate the students' performance, a scenario of a structural problem was presented for students to solve using the concepts learned in class. Since the problems tackled in the class were focused on stand-alone structural elements, students´ found it hard to understand the relationship between that single element and the complete structural system. The PBL strategy was found particularly helpful in establishing the relation between theory and real examples with a constructive problem.

To incorporate the gamification method in the first-weekly class concerning the theory of structural analysis, numerical exercises were designed to be solved together with the students on the blackboard. The exercises were based on small real cases of buildings with the same structural solution so that the students can understand the numeric results over real elements; different structural solutions were analyzed as well.

In the second weekly class, the previous exercise was recalled, and the steps to solve the problem were written on the blackboard. Working in teams, the students used the e-learning app to solve the class assignment. The students were instructed first to read and analyze the problem, and after that, to start proposing solutions. Each virtual practice (e-learning software) contained two or three problems, with the level of complexity increasing as students fulfill each task (adaptive strategy); while using the virtual practice, students must choose an Avatar as part of the game mood. The Avatar is important for game-based learning and gamification in order to allow students to feel part of the game, get a new identity that, in some cases, could be more fierce and challenging.

Students were also allowed to work alone; however, the formation of teams with 2 to 4 students was encouraged for better results. At the beginning of the class, the teacher verified that every student in the class understood the problem correctly and helped them to confirm the steps needed to solve the virtual practice.

As each student finished all the tasks (quest) included in the e-learning software, they got two prizes: game points and a virtual tour of the case study structure using augmented reality. The game points could be exchanged for additional monthly grade points (0.25 additional points for each task finished, so at the end of each month, they could get one extra point on their grade). Since some students needed more time to understand and finish the game quest, they could ask for additional time, with a week being the maximum time allowed to finish the task and earn the same amount of points as the other students. The students showed low interest in the virtual tour of the building, where information about the architect and the project was displayed. Students were already acquainted with this kind of virtual experience as they have played games with more sophisticated imagery (i.e., Nintendo or X-Box), so students have not considered the augmented reality as a grand prize.

After the quests were completed, each team presented their conclusions about: i) the game; ii) the theory involved; iii) the architectural project used for the practice. This part was as important as the game itself because it allowed students to process all the information and understand the relationships between theory and practice. As the experience sank in, the students were able to comprehend the process of application of theoretical analysis and design in the real world and to realize the implications structural design has on the quality of the architectural project.

As teachers, we know that the synthesis of learning and acknowledgment is very important for students thus, when a student archived all the learning goals in the one-course theme, he/she was entitled to a badge: structure expert. This badge made students feel recognized and more engaged with the topic. If a student acquired three badges, he/she was eligible for an exemption from the final exam.

The exams for the structural design courses were also designed using a PBL strategy. The new learning method based on gamification helped the students to a) analyze complex scenario problems with a step-by-step approach; b) improve the design thinking process to solve the problem in

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stages; and c) gain confidence in their work, therefore leading to better results in the exam evaluations.

IV. ASSESSMENT OF THE LEARNING METHOD RESULTS

Even though the introduction of the new learning method based on gamification has been challenging for us as teachers, the students' performance in the class improved. The improvement was observed in the better final evaluation grades that were mostly due to the better exam performance, as well as to the extra grade points acquired during the class activities.

To confirm the effects of the new gamification method on students learning, we compared partial and final grades from a selected previous group that did not use the method (defined by the authors as control group using just PBL) and a group where the gamification method was used during the same course with the same length and number of students (defined by the authors as experimental group using PBL and gamification).

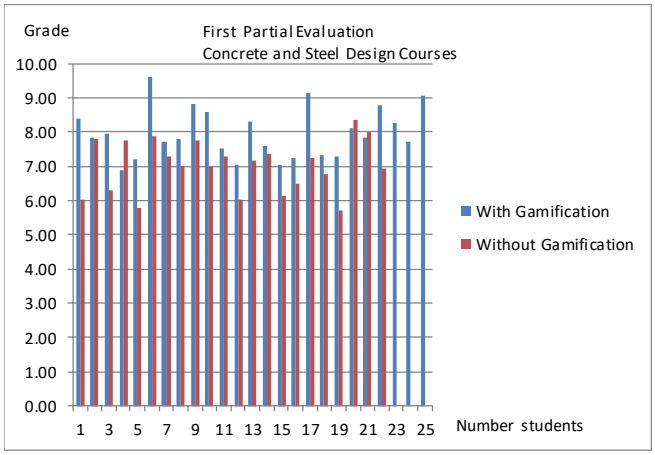

Figure 2. Comparison of group first partial evaluation.

At Tecnologico de Monterrey, the grade evaluation range is from zero to ten, where ten is the highest score, and grade below seven is considered a fail.

In Figure 2, the first partial grades of 52 students were presented. Red lines correspond to students that took the courses without the gamification method, and blue lines are the grades of students that took the same courses with the gamification method. As can be seen from the graph, the grades were relatively higher in the courses with the gamification method. More importantly, there were no grades below seven in the gamification courses. These results are essential for the class, as dropping out from the course is diminished.

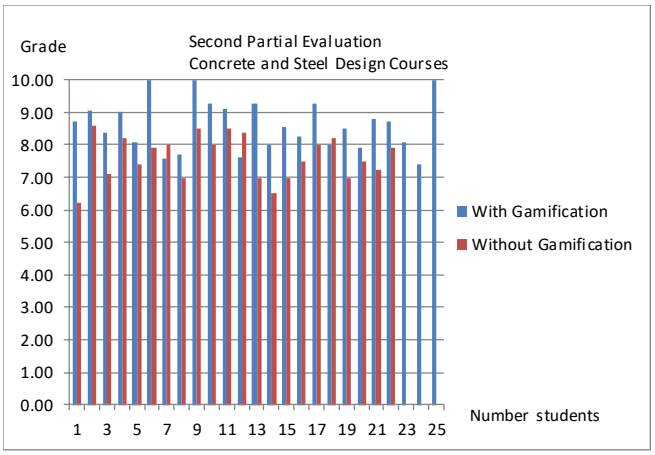

Figure 3. Comparison of group second partial evaluation.

In the second partial evaluation (Figure 3), the students from both courses, with and without the gamification method, had higher grades compared to the first partial evaluation. This behavior could be explained by the fact that as students progress through the course, they get better acquainted and more confident with structural design topics.

In Figure 4, we compared the final exam grades in courses with and without the gamification method. We found a considerable improvement of the average final grade in the courses with the gamification method (average of 8.0), compared to the average grade in the courses using just PBL without gamification (average of 6.8). The increment in the course grades means that students got a better understanding of each topic and its application in real-life problems, like the ones solved in the mobile app.

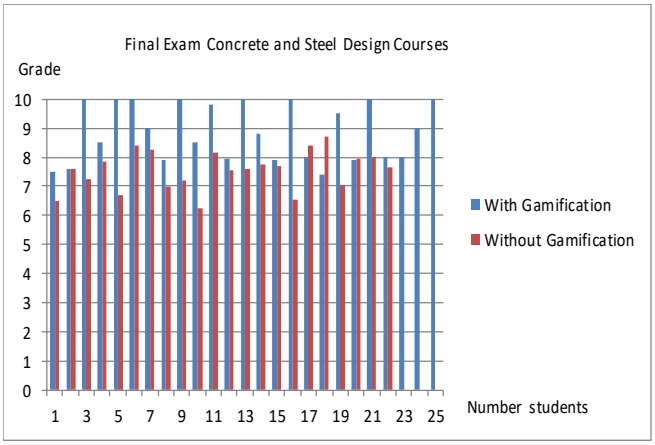

Figure 4. Comparison of final exam grades between courses.

V. STUDENTS FEEDBACK REGARDING THE NEW METHOD

We designed and conducted a questionnaire to analyze students´ feedback regarding the effectiveness of the new learning method based on gamification in the experimental groups. The purpose was to quantitatively assess student personal achievement using the Likert scale [6], ranging from 1 = not at all characteristic of me, to 5 = very characteristic of me. To understand the results in the context of previous courses without the gamification or control group, we conducted the same questionnaire to those groups as well. The mode (statistic) is presented as the evaluation result for each subject.

As presented in Table I, students in the experimental groups were more engaged during the class, asking more questions, and putting more effort into completing the tasks assigned. The experimental groups were also more inclined to using the e-learning software app after class.

TABLE I. EVALUATION OF STUDENTS COURSE ENGAGEMENT QUESTIONNAIRE (SCEQ)

No.	Evaluation		
	Behavior, thoughts, and feelings	***Control group***	***Experimental group***
1	Participating in class	3	4
2.	Asking the instructor questions for a better understanding	3	5
3.	Asking the instructor questions to get the application game done	0	3
4	Playing the application game after class	0	3
5.	Putting forth effort	3	4
6.	Desire to learn the material using the application game	1	3
7	Playing the application in teams	0	4
8	Explaining the solution to solve the app quest between companions	0	4

Looking at the answers for questions 7 and 8, and watching their behavior in class, we discovered that teamwork is one of the necessary conditions for better student engagement. The students felt that within a team, they could quickly clarify misunderstandings from the theoretical aspect and achieve faster and better solutions. The teamwork also positively affected the feeling of confidence while working.

We also evaluated the students´ satisfaction with the courses based on the new learning method. The scores were again based on a Likert scale in five-point grade, five being the best score (Table II). It was assessed that the students´ experience with the course using gamification was overall positive; students were motivated by the prizes and considered the application fun to use, which led to a better understanding of the theory.

TABLE II. EVALUATION OF STUDENTS METHOD PERFORMANCE

No.	Evaluation	
	Phrases	***Evaluation***
1	Performance of the course	4
2.	The application game helps to understand structural behavior	4
3.	Playing the application in the classroom was challenging but fun	4
4	The application clarifies the theory applied to real cases	4
5.	Getting badges and points is adequate	4

Finally, students were asked to evaluate the course teaching approach of mixing the new learning method for class activities in 70% of the course with a more traditional lecture style for the theoretical part in the rest 30%. To our surprise, students considered interesting the combination of strategies during the course that provided time for playing with the app and standard lecture time. Moreover, most of the students were grateful for the extra time allowed for finishing the tasks, as they could try out different answers while playing that led to a better understanding of the theory.

VI. CONCLUSIONS AND FUTURE WORK

By analyzing the grade results and students´ feedback, we concluded that the students´ understanding of structural design was enhanced in the courses that applied the new learning method based on gamification. 90% of students finished all the games assigned in the semester, and 60% got the badge ¨structure expert¨, which implies significant improvement in students´ engagement compared to previous courses that did not utilize the gamification method. Since the first courses using the new method also included 30% of more traditional lectures, we assume that students´ performance could improve even more if the new method is applied more consistently.

One of the most interesting observations was that millennial students do not consider competition as an incentive; they prefer to work at their own pace without pressure and in teams. The preference for teamwork was found in the opportunity to collaborate with more skillful or well-informed students. In fact, students confirmed that giving level awards made them feel uncomfortable, thus in the future, we will only focus on awarding one type of badge to all who complete the game quest.

Time was found to be an important factor in the success of the learning method since less skillful students needed extra time to accomplish their tasks at their own pace. Avatars were found to be slightly significant while playing with the e-software app, however extra points that students acquired for the class activities were found to be incentivizing. Immediate feedback was also appreciated, as

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students could quickly adjust their work and search for better solutions without wasting time.

The gamification method proposed is more than game points; it is a strategy where the professor gets more acquainted with the student, giving confidence while learning how to solve real-life problems using today's technology; the virtual environment experimentation to solve real-world challenges offers the students a better understanding about the mathematical solution and its application over real architectural projects. In the real world context where stakes are high and human lives at risk, better-prepared architects with a deeper understanding of structural problems are the goal of education.

With the game-based learning app used, made especially for this courses, students knew immediately when they were making a mistake, and that instant feedback allowed them to progress faster, ultimately providing them with a better understanding of structural design. In Mexico, the gamification method has not been developed; there is a world of free apps that can be used for teaching, but a method is needed in order to achieve each course objective.

Teachers may find the following difficulties using the method proposed for other courses: a) finding the best app for each subject; it should get the results needed to get the students understanding and engagement; b) the app must exist for IOS and Android system so every student can use it; c) time should be programmed in order to give the student the theory, its application and solving the problem while playing with the app.

However, there is still more work to be done to improve the method, mainly to increase students´ participation and engagement further. The level of challenges has to be reconsidered carefully since time management is crucial for the success of the method — professors using apps in class need to know how they work and the theoretical concepts they follow in order to choose the one that fits for the subject of each class and guide the student learning with a specific purpose. Finally, further studies are necessary to enrich the students´ educational experience and find ways for better access to teachers' feedback.

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REFERENCES

[1] P. Santa Ana and L. Santa Ana, "Apprendestructo: Learning app joining together structural analysis with architecture project," [Apprendestructo: Aplicación que integra el conocimiento estructural dentro del proyecto arquitectónico], Repentina, UNAM, México, pp 23-25, September 2017.

[2] S. Snezana, Z. Nada, and M. Tripo, "Gamification in higher education learning –state of the art, challenges and opportunities," Proc. The Sixth International Conference on e-Learning, (eLearning 2015), pp 128-134, September 2015.

[3] W. Hsin, H. Yuan, and D. Soman, "A practitioner's Guide to Gamification of Education," Economic School, University of Toronto, 2013.

[4] G. Barata, J. Gama, and D. Goncalves, "Engaging engineering students with gamification," Proc. 5th International Conference Games and Virtual Worlds for Serious Applications (VS-GAMES), pp 1-8, September 2013.

[5] E. Christiansen, M. Leena, and B. Lindstrom, "Problem-based learning for the 21st Century," Aalborg Universitet, Denmark, 2013.

[6] M. Handelsman, W. Briggs, N. Sullivan, and A. Towler, "A measure of college student course engagement," The Journal of Educational Research, Vol. 98, No. 3, pp. 184-192, 2005.

 ISBN: 978-1-61208-764-1