Abstract: The idea of utilizing game elements in non-gaming situations has sparked a lot of attention in recent years, especially in topics such as education and training. Game-based techniques appear to be an increasing trend in a wide range of learning areas, including health, social policy, and engineering, among others, not only in primary school but also in higher formal education. Using this methodology, the learning process becomes more stimulating while also reaching a competitive level in some circumstances. In the present work, the authors propose a new gamification strategy based on an escape-room in which all the puzzles to be passed are related to the area of optics and photonics and use readily available or low-cost equipment. The major field of application of this novel teaching strategy will be the practical section of a course, that is usually carried out in a laboratory, and will be aimed at both undergraduate and master’s degree students. A coevaluation method is also proposed where the rest of the students will provide valuable feedback to each one of their colleagues and to the instructor.

Keywords: gamification; game-based learning; technology enhanced learning; serious game; motivation

1. Introduction

In recent years, there has been growing interest in the application of game mechanisms to different non-gaming areas, with a particular focus on their usage in education [1]. Gamification is an educational technique that uses game elements in learning environments to stimulate students [2], maximizing their engagement and enjoyment during the lectures by capturing their interest and inspiring them to continue learning. However, organizing activities using game design ideas is a difficult task because there are currently no practical recommendations for doing so in a consistent and efficient manner [3].

Serious games [4,5] have gained increasing attention among the various available proposals for the integration of gamification in learning environments. This technique is based on the organization of activities that include all the elements associated with games but whose goal is to achieve something predetermined, that is, they are designed not just for fun but also for a specific purpose related to training. This way, the result of taking part in these activities is always beneficial for the player, as it enhances the learning experience. There are an increasing number of serious games proposals [6] but escape rooms (ERs) [7] are gaining popularity as a substitute for more traditional in-class activities [8]. ERs are activities in which a group of players must gather clues and solve riddles on the premises to achieve a specific goal, usually escape from the game’s location, in a limited amount of time. The enormous success of ERs in the entertainment industry has sparked increased interest in their use in education [9], as they provide an active-learning environment that encourages student collaboration.

The use of ER as a gamification element in educational environments has been applied in both primary and secondary education, but most of the experiences published in scientific journals have been mainly developed in higher education [10] covering a wide range of topics such as STEM [11,12], foreign languages [13], engineering [14–17] or medicine [18].
These educational areas present one major advantage for the design of an ER: the required equipment is typically readily available and has a low or moderate cost, simplifying the design of the activity and reducing the inversion required for their implementation. However, in other experimental areas the high cost of the required equipment has hampered the use of ERs. One such area is photonics, where the budget necessary for the implementation of an ER would be excessive due to the optoelectronic equipment needed. In this proposal, we attempt to circumvent this limitation by presenting the planning and design of an ER where the puzzles to be solved are related to the disciplines of optics and photonics but use readily available or low-cost equipment.

2. Contextualization

The aim of the proposed gamification activity is the Optical Communications course taken by the undergraduate students of the Telecommunication Engineering degree at the Public University of Navarra. Nonetheless, this plan can be easily extended to other courses where optics are studied, such as physics, or even master’s degrees. The main goal of the activity is to replace the laboratory sessions that correspond to the experimental part of the course. During these sessions, several stations in the laboratory are already set up, and the students must execute several experiments in pairs, such as:

- Make fiber optic splices using commercial equipment (see Figure 1);
- View the different modes propagating through an optical fiber (see Figure 2);
- Evaluate the losses introduced using different types of fiber optic cable;
- Measure the intensity–power relationship on a LED and on a laser;
- Visualize the optical spectra for different types of lasers.

Figure 1. Fiber optic splicer.

Figure 2. Four first LP modes.
The students are guided through these tasks by a laboratory notebook supplied by the teacher, which outlines and explains the activities to be completed in the different stations. Furthermore, the activity is evaluated based on the answers that the students provide in the laboratory notebook, where they have to explain and justify the outcomes of each experiment. However, despite the strong link between the theory presented in the lectures and these experiments, students’ interest in these tasks has recently declined. As a result, students do not sufficiently prepare for these sessions, not even reading the laboratory notebook ahead of time, which makes impossible to fully carry out the proposed exercises and results in unsatisfactory learning outcomes.

To overcome the existing demotivation, a variety of laboratory session alternatives were considered which ranged from standard solutions (rearranging the laboratory activities, substituting some of the stations, conducting a review test before the laboratory session) to a complete overhaul of the sessions, which included replacing them with something different. After careful evaluation, the conclusion was that a complete rearrangement was preferable in order to obtain the desired goals, existing two possible strategies: the introduction of Project Based Learning (PBL) in the course by forcing the students to develop a photonics related project or the introduction of gamification by implementing an ER. The final decision was reached after a comparison of both approaches (Table 1), with the conclusion that gamification via an ER would increase student motivation, particularly owing to the competitiveness created amongst the various teams.

Table 1. Comparison of PBL with Gamification.

|                      | PBL                                         | Gamification                                      |
|----------------------|---------------------------------------------|---------------------------------------------------|
| Topics covered       | In-depth but focused on the topic of the project | Broad but shallower                                |
| Student interest     | Depends on the topic                        | Depends on the course                              |
| Cost                 | High cost depending on the project          | Depends on the puzzles designed                   |
| Possibility of copying | High, as they can replicate previous projects | Medium, as the puzzles might be similar but the solutions different |
| Competition          | Not competitive                             | Highly competitive                                 |
| Teambuilding         | Potential unbalanced workload               | Required to accomplish the challenge               |
| Decision making      | Harder to evaluate                          | Quick and in real time                             |

3. Design

The proposed ER’s objective, as previously stated, is to offer a teaching environment that stimulates and engages students in optics and photonics while simultaneously improving their communication and teambuilding skills. In order to fulfil these goals, a team size of four student is selected as it provides an environment where each member can be proactive and involved in the group process [19]. Additionally, the total time for the resolution of the activity is established as 60 min, creating a pressure factor that requires the students to make quick decisions. However, in order to prevent frustrating the students, the puzzles will be designed so that most of the groups can solve the game in 45 min, providing the participants a sense of achievement and increasing their motivation.

The activity will take place in a separate room in one of the university laboratories and, to guide the students, a computer will serve as the narrator, providing a backstory that introduces each puzzle with a riddle and tracking the progress of each group. Interaction with the narrator will be required for the resolution of the ER, as after completing some of the puzzles the students will have to enter a code into the computer to prove that they have indeed solved the puzzle in order to progress with the story. An instructor will also be present and her or his role will be limited to monitoring the progress, ensuring that no cheating occurs and providing a debriefing at the conclusion of the session. During the debriefing, two crucial points will be discussed: the resolution of the puzzles and the students’ performance. The first aspect will give feedback to the students on how the concepts studied in theory had to be applied, allowing a connection between the
knowledge and skills developed in both areas; on the other hand, the teacher will have valuable feedback in the form of students’ opinions about the activity. The second aspect allows students to determine if they have met the required learning goals and, from the teacher’s perspective, which topics need to be reviewed in theoretical classes or reinforced in subsequent years.

To design the activity, a sequential puzzle path was chosen as it is easier for the students to understand the concepts applied and it simplifies the monitoring of a group’s progress. Furthermore, adopting a linear path allows for the independent study of distinct themes in each problem, as well as the management of the difficulty associated with each one’s resolution. The primary disadvantage of a sequential approach is the impossibility of finishing the activity if a group gets stuck on one of the puzzles. To address this possibility, a hints system is introduced where the students can receive information from the narrator, but this includes a time penalization in the resolution time. In the proposed design, two hints will be available for each puzzle, with the first one being just a clue to the solution and the second the complete solution of the puzzle. These hints are designed so that if the resolution of the puzzle requires the use of certain equipment available in the ER, the first hint points out which is the one to be used, whereas the second one provides a full explanation on how to use it to solve the puzzle. For example, in one of the puzzles the students will have to extract certain information from an unpolarized LCD panel. The first hint will indicate that they have to use a polarizing element to solve the puzzle, such as sunglasses, whereas the second hint will provide a complete explanation on how polarization works and why sunglasses act as polarizers. This hints system is complementary to the master lectures, where all the required subjects to complete the puzzles would have been already covered. Additionally, all the manuals required for the proper operation of the equipment present in the room will be printed out and available, so that the students can consult them.

The high expense of the equipment needed, as previously stated, is the greatest limiting factor in the use of gamification in the optical and photonics field. To overcome this limitation, we propose to design puzzles based on three fundamental ideas:

1. Reutilization of the material which was previously used in the different stations set up for the laboratory sessions. Additionally, some of the experiments which were performed at these stations will be used for the design of some of the puzzles.
2. Use of readily available low-cost optoelectronic components such as RGB LED strips, CD’s, TFT screens, polarizers, laser pointers, optical power meters, among others.
3. Use of instructional experimental kits, such as Photonics Explorer [20], which include all the components needed to conduct simple experiments. Some of the puzzles will be designed using the kit’s recommended experiments as a foundation.

Based on these three ideas, a sequence of eight puzzles has been planned for the ER, which covers the following four topics: fundamentals of light, operation of an optical transmitter, optical fiber as transmission medium and operation of an optical receiver. As shown in Figure 3, the four topics address in order the different elements of an optical communications system. Two puzzles have been prepared for each of them in the initial design, yet this number may change based on the feedback obtained from the students.

In the first part of the escape room, some fundamental concepts associated with light will be used for the puzzle design, more specifically, the multiplexing of different wavelengths and the polarization of light. Although the students have already studied the fundamentals of electromagnetic waves in the radiofrequency domain and are familiar with these ideas, we consider that a more visual approach can help them interiorize them. In the first puzzle, the students will have to use a CD as diffraction grating and demultiplex the different spectral components of a multicolored LEDs strip (Figure 4 left). The strip will be turned on, generating a seemingly white light that is really made up of multiple discrete spectral components in the visible range. By identifying these components on an electromagnetic spectrum poster available in the room, the students will be able to extract the required clues to pass the puzzle, solving the riddle proposed by the narrator.
This riddle, which serves an introduction to the puzzle, will be a simple sentence such as “A rainbow of colors you must find, and from the colors the rightful symbols extract”. The goal of the second puzzle is for students to comprehend the breakdown of light into two polarization components. For this purpose, a code will be displayed on an LCD panel that has had its polarizer removed, making it impossible to read (Figure 4 right). To retrieve the code, the students will need to utilize a polarizer, such as a photography filter or polarized sunglasses, which will be available in the room.

Gamification for Photonics: LabEscape

![Gamification for Photonics: LabEscape](image)

**Figure 3.** Topics and puzzles for the Escape Room.

![Gamification for Photonics: LabEscape](image)

**Figure 4.** Schematics for the puzzles corresponding to the first stage of the ER: light decomposition using a CD (left) and visualization of information using a polarizer (right).

After completing the previous challenges, the students will advance to the second stage of the escape room, where they will have to prove their understanding of optical transmitters. In this stage, to pass the first of the puzzles, the participants will have to differentiate between distinct optical spectra (SLED, Fabry–Perot, or DFB laser). This puzzle will require the use of a rather costly piece of equipment, an Optical Spectrum Analyzer, but this equipment is already being utilized in the laboratory sessions. Once this part is completed, for the second puzzle the students will have to find out the required electrical intensity that has to be injected into a laser to obtain a predetermined optical output power level. The equipment required for this task (laser, optical power meter and power source) is already available, as one of the laboratory stations required the students to characterize the P-I curve of a laser.

Following this, the students will have to use their fiber optics knowledge to complete the next phase. The puzzle will require them to be capable of distinguishing between the different electromagnetic field distributions that can be obtained in a transmission medium, such as an optical fiber in our case, when projected onto a screen (see Figure 5). These field distributions are called longitudinal modes or linearly polarized (LP) modes, and Figure 2 shows an example of the four first LP modes. Different cards with field patterns will be offered as a catalogue and participants will have to pick the appropriate ones, which will be the ones in the screen when manipulating the fiber properly, in order to solve the puzzle.
To add some difficulty to the puzzle, the fiber utilized for projection on the screen will be damaged at first, requiring working it out before they can complete the riddle by splicing it.

Finally, and in order to cover all the elements that make up an optical communications system, two puzzles related to the operation of optical receivers will be presented. The information needed to solve the first puzzle will be provided by a curvature sensor based on the usage of an optical fiber Bragg grating (FBG). The students will have to determine the wavelength shift associated with a certain curvature, which will provide the clue to pass to the final puzzle. In this last puzzle, an optical wavelength division multiplexing (WDM) bidirectional link will be utilized, and the students will have to interpret a secret message sent across the link. The students will have to prove their understanding of circulators and demultiplexers to extract the correct wavelength and then, using a photodetector and an oscilloscope, extract the codeword being sent. Both puzzles will need some specific hardware, which will be recycled from prior laboratory operations.

4. Evaluation

Although the major aim of the proposed activity is to increase students’ motivation, a formal assessment technique is necessary to evaluate the formative goals on an individual basis. The evaluation of the students’ performance is an important component of the proposed activity, as it replaces the grading that was given during the laboratory sessions and which was determined by the delivered notebooks. Furthermore, it will offer feedback to the teachers, allowing for the gradual adjustment of the activity by fine-tuning the design and altering the difficulty of the puzzles.

The evaluation method will take into consideration three different elements, as can be seen in Table 2. The first evaluation item will assess the performance of each group and will be based either on the number of puzzles solved or the total time taken for the complete resolution of the escape room. These two parameters will score a grading system, considering the penalties associated with the use of the hints, so that higher grades are associated with a better performance by the group. The objective of this item is to provide information about the group performance, allowing the assessment of the group as a whole and evaluating their competence in problem solving and teamwork. Logically, this part of the grade will be similar for all the students in the same group.

The second evaluation item is based on the debriefing session at the end of the activity with the instructor and replaces the reports which were previously delivered at the end of the laboratory sessions. During this activity, the instructor can interact with the students to discuss the puzzles’ solutions, as no document explaining the resolution will be provided after the activity, and ensure that the teaching goals have been met, having acquired the required competences. Moreover, although the interaction is with the entire group, specific questions to each group member will allow the teacher to differentiate the performance of the various students, allowing the individual grading of each group member. The instructor will utilize an evaluation rubric for this second item, which will clearly indicate the minimal level of knowledge required to pass the exercise. This rubric will not be available to the students. Finally, if the students have not completed the escape room in the

![Figure 5. Schematic for the puzzle corresponding to the third stage of the ER: fiber optic propagation modes recognition with a broken fiber.](image-url)
assigned time, during this evaluation the lecturer can assess their knowledge of the topics covered in the unsolved puzzles by asking them direct questions on how they would have faced them.

Finally, the third evaluation item is based on a survey administered individually after the previous item where the students must weigh the performance of their group partners during the whole activity using an assessment rubric provided by the instructor. The deviation of the score for each member will be considered to evaluate the cohesion of the group, so the whole team will be penalized if this parameter is beyond a certain value. This item can provide a very significant feedback regarding students’ opinions about their classmates, allowing the individual assessment of their teamwork, group cohesion and oral skills performance during the activity.

Table 2. Evaluation items for the ER.

| Activity          | ER Resolution | Debriefing Session | Student Survey |
|-------------------|---------------|--------------------|----------------|
| Type              | External evaluation | External evaluation | Coevaluation   |
| Objective         | Group         | Individual         | Individual     |
| Based on          | Objectives    | Rubric             | Rubric         |
| Evaluates         | Problem solving | Level of knowledge | Teamwork       |

5. Conclusions

The application of gamification for the teaching of photonics in higher education courses is proposed in this study. The suggested method is based on the usage of an escape room to replace laboratory sessions in an optical communications course with the primary goal of overcoming the monotony associated with such activities and motivating students to pursue optics and photonics as a field of study. Additionally, this gamification exercise is intended to assist students in practicing valuable abilities that are highly demanded in the job market, such as collaboration and rapid decision-making. Three distinct techniques for the creation of the puzzles based on the use of low-cost equipment, the reuse of previously existing material, and the use of widely accessible experimental kits are used to avoid the high costs associated with optoelectronic components. Teamwork and competitiveness are important aspects of this gamification approach, and they are supported throughout the activity (even after the game has finished), providing a distinct advantage over other learning proposals. Although the implementation of the proposal is very time consuming and requires a great effort on the part of the instructors, especially the first year, it is expected that greater engagement with the activity will improve students’ interest in the area of photonics. Additionally, the students’ additional interest is expected to have a positive impact on the obtained grades, though this is not the primary objective of this proposal. Finally, an assessment technique is proposed that takes in all the stages of the activity, including the coevaluation between the members of the same group as a way to evaluate their collaboration as well as provide useful feedback to the teacher in order to enhance the game’s performance every academic year.

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