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EscapeCell: Serious Game Integration to a University Biology Course on an E-learning Platform

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Abstract. This paper presents *EscapeCell*, a Serious Game to help undergraduate students understand plant cellular biology. Each chapter is matched with one mini-game., a gamification module integrated into the e-learning platform and several reminders of the game in the course material. We conducted a study on 117 students to compare their exam results with a control group from last year. We also correlated the collected feedback from the students and usage tracks. This helped us measure the usefulness of specific game elements, such as a non-player character that provides help and bonus information modules hidden throughout the mini-games. The preliminary results indicate that the integration of EscapeCell improves students' learning outcomes in the final exam and that Blob, the virtual tutor, facilitates the usage of mini-games. Although the bonus information modules do not directly correlate with the final exam result, but they show a positive correlation with the scores of the intermediate tests - the multiple-choice questions (MCQs) - taken by the students just after playing the mini-games.

Keywords: Serious Games, cellular biology, university, e-learning platform, gamification.

1 Introduction

The context of this paper is a plant cell biology course, part of the undergraduate curriculum of first-year students (approx. 120) at the Biology Faculty. The teacher in charge of this course noticed that its content was often challenging for students. They have difficulties grasping concepts, vocabulary, and phenomena, and staying motivated. Gamification and Serious Games (SGs) have proven to be efficient tools to engage students and favour learning [1, 2]. Hence, we present an attempt to overcome these challenges by using both dedicated serious mini-games and a specific gamification module for the e-learning platform used by students. Together, they form a whole called *EscapeCell*.

EscapeCell's design and usage are the opportunity for a study that aims to address two key research questions. On the one hand, does the use of SGs improve students'

learning outcomes? This question aims to understand if *EscapeCell* is effective in this learning context. On the other hand, the game designers of *EscapeCell* added two special game elements to the mini-games: A non-player character, called "Blob", and bonus information modules. Our second research question is about understanding the influence of Blob and the bonus information modules on the student's game experience. To this end, Section 2 begins with a brief review of SGs and gamification in higher education and biology courses. Section 3 elaborates on the context surrounding the creation of *EscapeCell*, along with some game design elements. The experiment and data collection method will be described in Section 4. The results gathered will be presented and discussed in Section 5. Finally, Section 6 will conclude our research.

2 State of the Art and Scientific Positioning

Literature shows many examples of SGs about biology and cell biology for secondary school. Kara and Cheng propose systematic reviews that show that most of them are adventure games, simulations or sport-type games [3, 4]. Authors also share the need for a strong integration of the SGs in the courses and the learning environment, as suggested by the biology teacher working with us. Nonetheless, there are few publications about SGs in (cell) biology for higher education, and the studies are not thorough enough to explore learning outcomes [5, 6].

Recent work on biology also confirms main findings of the prior state of the art [7]: SGs must help explore things that teachers cannot provide, teachers should accompany the learners during the play, SGs must be very interactive and their design must include the teachers.

Following our cell biology teacher needs and Kara's findings [3] about the importance of SGs' integration to courses, we also explored results about e-learning platform gamification. Recent systematic research shows few articles have addressed motivation and gamification in higher education [8]. However, there is recent research by Reyssier et al. [9] that shows that gamification is (more) suitable to our target, which is the less motivated learners. The most efficient approach to ~~a~~ gamification would be one that is specifically tailored to the learner. Nevertheless, as detailed in section 3, we cannot alter every aspect of the course and design a fully adaptable SG. Therefore, we focused on the findings from Reyssier et al. that can be generalized to most of our targeted learners: avatars, badges, and progress bars are harmless gamification mechanics for most player types and can be used safely to enhance motivation.

As we wanted to go further to engage learners, we also wanted to explore bonuses and secondary objective mechanics. Indeed, in a wide study (n = 27000), Andersen et al. show that secondary objectives that support the primary goal of the game are consistently useful and very positive on the learning outcomes and motivation [10].

3 Serious Game *EscapeCell*

3.1 Objectives and Challenges of the Cell Biology Course

During the cell biology course, the lecturer introduces a large number of new terminology and complex phenomena that are not easy to grasp such as operation

photosynthesis, respiration and cell concentration. Yet, these are very important to understand since they set the foundations for the following classes. The course is led in a fairly classic way, with 16 hours of lectures, followed by several lab sessions. All the course material is available on a *Moodle* e-learning platform, and the teacher even added extra self-evaluation MCQ. However, students do not seem to find much interest in them. At the end of the course, the students take a final test. The large number of students and the limited number of teaching hours make it difficult to change this structure or even provide a personalized follow-up. The challenge is therefore to find a way to motivate students to work on their own, beyond classroom hours, and help them remember the terminology and better understand the biological phenomena.

3.2 **EscapeCell**

EscapeCell is composed of three elements: a set of mini-games to review the terminology and concepts for each chapter, a gamification module integrated into the e-learning platform that encourages the students to complete the mini-games and several references to the games in the course material and during the lecture. Let us describe each of these in detail.

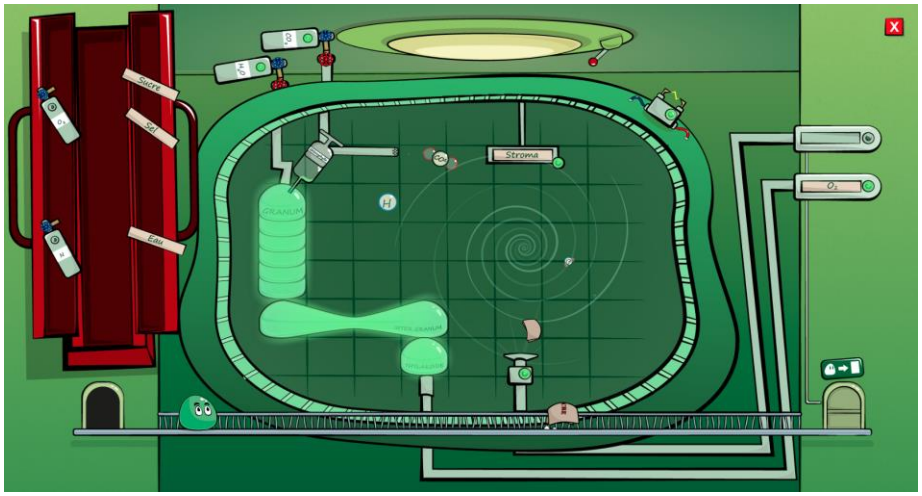

Fig. 1. Mini-game 1 - Operation photosynthesis

The course is comprises of an introductory chapter and five other chapters and one mini-game has been designed for each chapter. Thus, EscapeCell includes five mini-games, three of which have been developed.For example, the concepts in the chloroplast and plastids chapter were used to create the *mini-game 1*: *Operation Photosynthesis* (Figure 1). It is a **puzzle-type game** in which the students need to select the objects in the toolbox (left of the screen), that represent the elements in the chloroplast and correctly place them in the middle of the scene, to recreate the photosynthesis process. If the object is not positioned correctly, it flies back to its initial position in the toolbox. **A non-player character, called "Blob", provides**

explanations to help the students throughout their mission (*e.g.*, "it is too dark in here" to encourage students to switch on the light button that is necessary for photosynthesis). As students complete the scene, Blob moves forward on the bridge to materialize their progression. When the scene is complete, an animation shows the photosynthesis process which converts light into chemical energy that is then stored in organic compounds and releases gas. **Three bonus information modules are hidden in the game**. They provide extra information about the photosynthesis process. These modules can be unlocked by clicking on specific parts of the scene (*e.g.*, lever and battery on the top right of the first picture of Figure 1). Similar mini-games were created for chapters 2 and 3 (Figure 2). The mini-games for the last two chapters were designed but are not yet fully developed.

Fig. 2. Mini-game 2 - Mission respiration and Mini-game 3 - Vacuole commando

The look of the course space on the e-learning platform was completely transformed. Figure 3 shows how the artwork from the mini-games was used to illustrate the different sections of the course. When students click on the chapter related to chloroplasts and plastids (illustrated by a green Blob), for example, they have access to the slides used by the teacher during the lecture , the first mini-game in Figure 1, and the MCQ related to this chapter. We also developed a custom gamification module for the platform that shows if the students have completed the mini-games and the MCQs. This **completion meter is presented in the form of a plant** that gradually develops. A new branch grows each time the student completes a mini-game. On each branch**, a small flower appears for each bonus** information module the student has discovered, **and a leaf will sprout if the student completes the MCQ** related to the chapter. Students see this completion meter as a progress bar, an avatar and a set of badges, at all times, on the top right of their course space.

Finally, the teacher modified her course to integrate the game in three ways. First of all, she completely changed her slides by using the mini-game graphics to illustrate the elements in a plant cell and the biological phenomena. Second, she strongly encouraged the students to complete the mini-games and the MCQs at the beginning of each lecture. While undertaking this, she would also show the plant completion meters of the entire promotion of students on the board. Each student could see the plant associated with their name and compare it with others. This was intended to encourage students to work between lectures. Finally, the teacher also programmed a 2-hour "autonomous lab session" before the final exam, during which the students were asked to play or replay the mini-games and do the MCQs for each chapter.

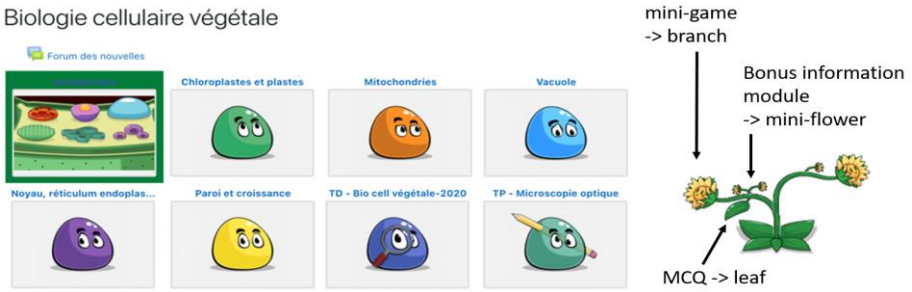

Fig. 3. Integration of the game to the e-learning platform

3.3 Design Method

The mini-games, the gamification module for the e-learning course and their integration in the lecture were designed during the *Ludifik'action* professional training session, provided by the university [11]. In addition to the two trainers, who specialize in SG design, the teacher was accompanied by a team of two educational engineers, a graphic designer, a multimedia developer, and an audiovisual artist who recorded the Blob's voice. The *Moodle* plugin was also developed by a research engineer. Several groups of students were involved in the design process by testing paper prototypes of the mini-games.

4 Experimentation

4.1 Hypothesis

The experimentation aims to measure if *EscapeCell* improved students' learning performances in the final exam. A second objective is to investigate the influence of specific game design elements such as Blob and bonus information modules. Based on the research objectives, we established the following hypotheses:

- H1: *EscapeCell* enhances students' performance in the final exam.
- H2: The presence of Blob, the non-player character, helps and guides students throughout the mini-games.
- H3: The bonus information modules, hidden in the mini-games, increase students' results in the final exam.

4.2 Experimental Protocol

This study follows the General Data Protection Regulation (GDPR), which serves as the legal reference for personal data protection in Europe. The data registration for this study was submitted to the Data Protection Officer at the University of Strasbourg.

To examine H1, we conducted a comparative study between this year's and last year's results of the final exam. It should be noted that the content of the course, the teacher, and the exam were identical in both years. The difference is that last year's students (n = 133) only followed the classic course before taking the final exam, whereas this year's students (n = 117) also engaged in the *EscapeCell* SG and Gamification. The mini-games could be played individually or in groups on computers or smartphones.

To examine H2 and H3, this year's students were asked to answer a set of questions after completing each mini-game. For each of the five following affirmations, they needed to indicate whether they agreed or not on a 5-point Likert scale:

- A1. The mini-game is easy to use.
- A2. The game design motivated me to play.
- A3. Blob helped and guided me.
- A4. The mini-game helped me better understand the course content.
- A5. The mini-game helped me better understand the biological phenomenon.

At the end of the semester course, the students were also asked to fill in a questionnaire that provided us with information on their profile (age, sex, gaming habits) and specifically measured their learning experience in SGs using a Learner Experience Questionnaire developed by Liu [12]., Several usage tracks were also retrieved from the e-learning platform, such as the number of times the students completed a mini-game and the number of bonus information modules they discovered. SPSS (Statistical Package for the Social Sciences) version 27 was used for data processing in this study.

5 Results of the Study

The usage tracks show that 88 out of 117 (around 75%) completed at least one mini-game and 66 (around 56%) completed all three mini-games. 40 students also played the mini-games several times. This is already a positive result, given the fact that the mini-games were not mandatory.

5.1 Results for H1: Effect of EscapeCell on the Final Exam Results

Table 1 presents a comparative analysis of the final exam results between the control group and the experimental group that used *EscapeCell*. The control group obtained a mean score of 13.65/20, with a standard deviation of 3.19, denoting a moderate spread of scores around this mean. On the other hand, the experimental group showed a higher mean score of 14.46/20. In addition, this group had a standard deviation of 2.6, indicating smaller differences in scores around the mean as compared to the control group. This lower standard deviation suggests less variability in the performance of the students who used *EscapeCell*.

Table 1. Comparison of students' final exam across the two groups

Group	n	Mean grade	Standard deviation
Control group	133	13.65	3.19
Experimental group	117	14.46	2.6

In order to analyze the significance of this difference, we examine at first the distribution of the data, then select the most suitable comparison test. Figure 4 shows that the scores of the two groups slightly deviate from a normal distribution and the Kolmogorov-Smirnovtest shows that the p-value of two groups is less than 0.05, which indicates the observed data didn't followa normal distribution [13]. We therefore apply the Mann-Whitney test, the result indicates p = 0.026, which is less than 0.05 and the difference between the means of the two groups is significant. Therefore, **we can confirm H1: *EscapeCell* has led to an improvement in student performance in the final exam in this study**.

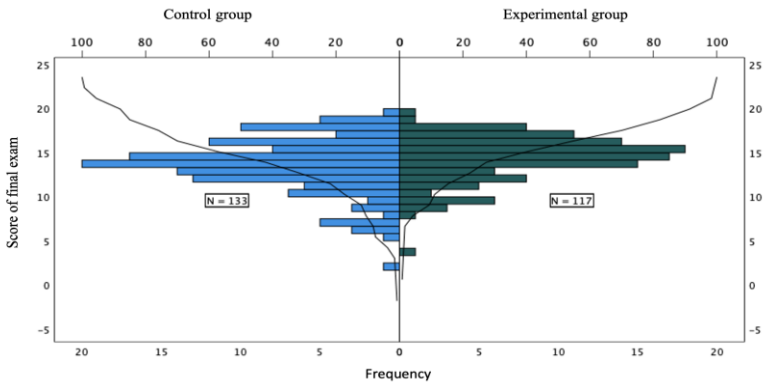

Fig. 4. Kolmogorov-Smirnov test for two independent groups

5.2 Results for H2: Usefulness of Blob

In terms of game design, we are interested in the role Blob plays in the game and if he acts as a facilitator in the students' gaming process. The results from the correlation analysis of the questionnaires indicate a positive correlation between Blob's perceived usefulness (affirmation A3) and the mini-games' perceived ease of use (affirmation A1). **The presence of Blob, therefore, seems to facilitate the use of the three mini-games**. However, as shown in Table 2, there are some notable differences among the mini-games. Blob seems especially useful and well-designed in the second and third mini-games and, in the third mini-game, Blob's perceived usefulness (affirmation A3) is even correlated to the fact that students understand the course content better (affirmation A4). This suggests that the presence and actions of Blob may have enhanced the usability of the game for students, making the gaming experience more intuitive and enjoyable. As such, Blob could facilitate student interaction with the game and could potentially contribute to improving learning outcomes. These results also

provide us with insight into how the mini-game 1 could be improved by taking an example of what Blob does in the mini-game 2 and 3.

Table 2. Impact of Blob in three mini-games.

A3. Blob usefulness	Mini-game 1	Mini-game 2	Mini-game 3
A1. Mini-game ease of use	0.349**	0.427**	0.525**
A2. Game design	0.243	0.349**	0.407**
A4. Comprehension course	0.161	0.199	0.290*
A5. Phenomena understanding	0.101	0.169	0.551

**The correlation is statistically significant at a 0.01 level.
*The correlation is statistically significant at a 0.05 level.

5.3 **Results for H3: Effects of the Bonus Information Modules on the Exam**

The number of bonus information modules discovered by students is positively correlated with the perceived ease of use (affirmation A1) of mini-game 2 ($rs = 0.297$, $p < 0.05$) and mini-game 3 ($rs = 0.380$, $p < 0.01$). Interestingly, students who unlocked more bonus information modules also achieved higher scores on the MCQ related to each chapter ($rs = 0.320$, $p < 0.01$). The results further indicate that the MCQ scores are significantly associated with the student's final exam grade ($rs = 0.296$, $p < 0.01$). **In other words, the more students discover bonuses, the better they are at the MCQ**. **Contrarily, there is no correlation between the number of bonuses a student receives and their final exam scores.**

When we look at the students' profiles, it appears that the frequency with which students play video games (gaming habits) has a positive influence on the number of bonuses they discover. Indeed, students who are casual to hard-core gamers demonstrate a higher propensity to unlock bonus in the mini-games. There is, however, no correlation between the frequency with which students play video games and their MCQ scores. This suggests that, although students may derive additional value from these mini-games, it does not necessarily guarantee a high performance in the final exam.

Table 3. Impact of Bonus Information Modules

Impact of bonus	Number of discovered bonuses
Gaming habits	0.220*
MCQ scores	0.320**
Scores of final exam	0.204
Perceived ease of use for Mini-game 1	0.125
Perceived ease of use for Mini-game 2	0.297*
Perceived ease of use for Mini-game 3	0.380**

**The correlation is statistically significant at the 0.01 level.
*The correlation is statistically significant at the 0.05 level.

5.4 Limitations

Even though this year's exam results are very encouraging for H1, this could be due to an overall better level of the students, a pre-test is required for further study. The teacher did notice that this year's promotion was "particularly motivated and pleasant". We could argue that their pleasantness and motivation could be due to *EscapeCell* and the fact that the teacher visibly went out of her way to provide a motivating experience by setting it up. In addition, only 3 out of the 5 mini-games were finalized this year, so the final exam results could be even better with all 5 games. However, this hypothesis remains to be validated next year.

The statistics concerning the effectiveness of the game mechanics (Blob and bonus information modules) are exploratory. They mostly rely on the answers on the Likert scale, provided by the students, to the 5 affirmations right after each game. However, these affirmations could have induced a confirmation bias. In addition, participation in the *EscapeCell* is voluntary, and only 66 out of 117 students answered these questionnaires. Further experimentation should be led to confirm those hypotheses by comparing *EscapeCell* with and without these game elements.

6 Conclusion

In this study, the integration of *EscapeCell* (composed of several mini SGs and a gamification module) can enhances the students' performance in the final exam. This result could be attributed to two circumstances. Firstly, this improvement could be due to the supplementary work undertaken by students in the experimental group (who used *EscapeCell),* compared to those in the control group. Indeed, these students had the opportunity to apply their course knowledge within the game, which further consolidated their understanding. Secondly, translating course content into a game-based context might have enhanced the students' engagement and interest, leading to a more proactive learning approach. This was the initial objective of the teacher. The engaging and fun nature of the game could have helped students, who may have not been attentive during traditional classroom sessions, to actively participate. Moreover, the non-player character, called Blob, who assists to players, facilitates their procession through the mini-games. The presence of this guide making the game more accessible and engaging, especially for those who may be new to gaming. Besides, the hidden bonus information modules introduce an aspect of rewards (progress bar). They motivate students to dive deeper into the game, thereby increasing their interactions and engagement with it. This could potentially lead to a more comprehensive understanding and internalization of the educational content presented within the game. However, the number of bonuses the students unlocked does not correlate with their final exam scores. *EscapeCell,* therefore, serves as a valuable supplement to conventional instruction. It provides a complementary teaching method to enhance understanding of the course material. These inferences are based solely on this study, and further research is needed to confirm them.

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