FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Histopólio - Gamification for the teaching of Animal Histology

André Miguel Soares Gomes



Master's in Informatics and Computing Engineering

Supervisor: António Fernando Vasconcelos Cunha Castro Coelho

Co-supervisor: Ricardo Jorge Pereira Córdova Marcos

July 31, 2022

© André Miguel Soares Gomes, 2022

Histopólio - Gamification for the teaching of Animal Histology

André Miguel Soares Gomes

Master's in Informatics and Computing Engineering

Approved by:

President: Alexandre Carvalho
Referee: Nuno Feixa Rodrigues
Supervisor: António Coelho

July 31, 2022

Resumo

A Histologia é uma unidade curricular presente em vários mestrados integrados, como Medicina e Medicina Veterinária. Nesta unidade curricular são estudados os 4 tecidos fundamentais, recorrendo frequentemente à interpretação de imagens. Apesar da presença de imagens, que teoricamente seriam apelativas, a atual geração de estudantes tende a apresentar uma baixa motivação e envolvimento nesta unidade curricular. Esta falta de motivação e envolvimento pode traduzir-se numa menor eficácia na aprendizagem dos estudantes.

A ludificação é uma estratégia que permite aumentar a motivação extrínseca e intrínseca. Assim sendo, o principal objetivo desta dissertação foi o desenvolvimento de uma plataforma de jogos digitais para ser utilizada nas aulas práticas de Histologia. Foi desenvolvido um jogo de tabuleiro que apresenta vários elementos de ludificação, como feedback através de pontos, troféus, leaderboards e avatares. Esta plataforma integra uma aplicação Web que serve de ponte de ligação entre o estudante e o jogo de tabuleiro, a partir da qual o estudante consegue efetuar a sua jogada e responder a quizzes, a partir do seu telemóvel ou computador pessoal.

Pretendeu-se que esta plataforma permitisse aumentar a motivação dos alunos de Histologia, assim como a socialização e interação entre os mesmos, melhorando assim o seu desempenho nesta unidade curricular e aumentando as suas competências interpessoais. Para medir os resultados da solução adotada, constituiram-se um grupo de controlo, composto pelas turmas sem ludificação, e um grupo de teste, composto pelas turmas com ludificação. Os resultados desta experiência foram positivos e promissores, revelando uma motivação extra dos estudantes associada à plataforma de jogos digitais e aos seus elementos de ludificação.

Tencionou-se, também, que o tabuleiro do Histopólio pudesse servir de modelo base a partir do qual os docentes conseguissem facilmente adaptar para outras unidades curriculares no contexto do ensino universitário. Para esse propósito, a aplicação Web disponibiliza também um back-office destinado a docentes com privilégios de administrador. Este back-office apresenta uma interface simples e intuitiva, permitindo aos docentes facilmente criarem, editarem e gerirem os seus tabuleiros, sem a necessidade de competências de programação.

Abstract

Histology is a course present in several integrated master's degrees, such as Medicine and Veterinary Medicine. In this course, the four fundamental tissues are studied, often using image interpretation. Despite the presence of images, which theoretically would be appealing, the current generation of students tends to present a low motivation and involvement in this course. This lack of motivation and involvement may translate into a lower effectiveness in student learning.

Gamification is a strategy that allows the increase of extrinsic and intrinsic motivation. Therefore, the main objective of this dissertation was to develop a digital gaming platform to be used in Histology practical classes. A board game was developed with several gamification elements, such as feedback through points, badges, leaderboards, and avatars. This platform integrates a Web application that serves as a remote control for the student to play with the board game. The students can make their moves and answer quizzes from their mobile phones or personal computers.

It was intended that this platform would increase the motivation of students of Histology, as well as the socialization and interaction among them, thus improving their performance in this course and increasing their interpersonal skills. To measure the results of the adopted solution, a control group, composed of classes without gamification, and a test group, composed of classes with gamification, were set up. The results of this experiment were positive and promising, showing more motivation from the students associated with the digital gaming platform and its gamification elements.

It was also intended that the Histopólio board could serve as a framework model from which professors could easily adapt to other courses in the context of university teaching. For this purpose, the Web application also provides a back-office for professors with administrator privileges. This back-office features a simple and intuitive interface, allowing faculty members to easily create, edit and manage their boards without any programming skills.

Acknowledgments

First of all, I would like to thank my supervisors, Professor António Coelho and Professor Ricardo Marcos, for giving me this opportunity and always being available to help me.

This journey would not have been possible without my family, especially my parents, my godparents, and Diana. Thank you for all the support and care that you have given me.

I would like to thank my friends who accompanied me during this journey. Without a doubt, everything was better with you.

I would especially like to thank Inês for always being by my side every day and giving me all the strength I needed to overcome any obstacle and complete this journey.

André Miguel Soares Gomes

Contents

1 Introduction **1**
- 1.1 Context . . . 1
  - 1.1.1 What is Histology? . . . 1
  - 1.1.2 The study of Histology . . . 1
  - 1.1.3 Intrinsic motivation and extrinsic motivation in the educational context . . . 2
  - 1.1.4 Gamification . . . 2
  - 1.1.5 Histopólio . . . 2
- 1.2 Motivation . . . 4
- 1.3 Objectives . . . 5
- 1.4 Document structure . . . 6

2 State of the art **7**
- 2.1 Gamification . . . 7
  - 2.1.1 Gamification in education . . . 8
- 2.2 Technologies for game development . . . 9
  - 2.2.1 Unity . . . 9
  - 2.2.2 Unreal Engine . . . 9
  - 2.2.3 Godot . . . 9
- 2.3 Technologies for the development of Web applications . . . 10
  - 2.3.1 React . . . 10
  - 2.3.2 Angular . . . 10
  - 2.3.3 Vue . . . 10
- 2.4 Related work . . . 11
  - 2.4.1 SPOT - serious game based on augmented reality for the prevention of melanoma . . . 11
  - 2.4.2 Histological challenge A digital book that is also a game . . . 11
  - 2.4.3 Gamified mobile application for Creative Introduction to Programming . . . 12
  - 2.4.4 Gamification in Science Education: Gamifying Learning of Microscopic Processes in the Laboratory . . . 12
  - 2.4.5 Blended Learning in Anatomy Teaching for Non-Medical Students: An Innovative Approach to the Health Professions Education . . . 14
  - 2.4.6 Kahoot! . . . 15

3 Solution **17**
- 3.1 Overview . . . 17
  - 3.1.1 Rules and flow of the game . . . 18
- 3.2 Definition of requirements . . . 29
  - 3.2.1 Functional requirements . . . 29

3.2.2 Non-functional requirements . . . 31
3.3 Software architecture . . . 32

4 Solution implementation **34**
4.1 Folder/file structure . . . 34
4.1.1 Backend . . . 34
4.1.2 Frontend . . . 35
4.1.3 Board game . . . 36
4.2 Database . . . 36
4.2.1 Structure . . . 36
4.2.2 Seeders . . . 40
4.3 API . . . 41
4.3.1 Authentication endpoints . . . 41
4.3.2 Game endpoints . . . 41
4.4 WebSocket communication . . . 42
4.4.1 WebSocket server . . . 43
4.4.2 WebSocket clients . . . 43
4.4.3 Fault tolerance . . . 44
4.5 User interface . . . 45
4.5.1 Web application . . . 45
4.5.2 Board game . . . 58

5 Evaluation **64**
5.1 Evaluation by the students . . . 64
5.2 Evaluation by the experts . . . 68

6 Conclusions and Future Work **71**
6.1 Reflection on the evaluation results . . . 71
6.2 Goals satisfaction . . . 73
6.3 Future Work . . . 73

References **75**

A Real experiment with the students **79**

B User interface **81**

C Students' questionnaires **84**
C.1 Questionnaire given to the control group . . . 84
C.1.1 Results . . . 85
C.1.2 Comments and suggestions . . . 86
C.2 Questionnaire given to the test group . . . 86
C.2.1 Results . . . 87
C.2.2 Comments and suggestions . . . 88
C.3 Comparison between the results of the test group and the control group . . . 90

D Experts' questionnaire **94**
D.1 Results 94
D.2 Global evaluation 95
D.3 Negative points 98
D.4 Positive points 99
D.5 Suggested changes/comments 100
D.6 Comments on the Admin Back-office 102

List of Figures

1.1 Physical version of Histopólio . . . 3
1.2 Player with a badge . . . 4
1.3 Players overlapping in one corner of the board (between the position 9 and 11) . . 5

2.1 SPOT - game screens that demonstrate a narrative . . . 11
2.2 Histological Challenge - mobile and desktop views of the leaderboard interface . 12
2.3 Gamified mobile application - feedback observed in the minigame's final view . . 13
2.4 ELISA digital tool - challenge screen . . . 14
2.5 Web platform for anatomy teaching - narrative animation . . . 15
2.6 Kahoot! - immediate feedback . . . 16

3.1 Example of a board game view (Game Board view) during a real scenario, with 13 students . . . 17
3.2 Example of a view from the Web application (Edit Board view) displayed on a desktop . . . 18
3.3 Example of two views from the Web application (Player Menu view and Game Controller view) displayed on a mobile device . . . 19
3.4 Join Menu view displayed in the board game (left) and Game Controller view from the Web application after the player joined the gaming session (right) . . . 20
3.5 Board game displaying the board with the players at the start (left) and Game Controller view from the Web application ready for the player to roll the dice (right) 21
3.6 The different types of tiles on the board game . . . 21
3.7 Board game displaying the board with the player in a Group Property tile (left) and Game Controller view from the Web application showing the question with the image and possible answers (right) . . . 22
3.8 Demonstration of the Group Property tile . . . 22
3.9 Board game displaying the board with the drawn Senate Decisions card in front (left) and Game Controller view from the Web application showing the button to continue (right) . . . 23
3.10 Demonstration of the Senate Decisions tile . . . 23
3.11 Board game displaying the board with the player in a Pay tile (left) and Game Controller view from the Web application showing the question with the possible answers (right) . . . 23
3.12 Demonstration of the Pay tile . . . 24
3.13 Board game displaying the board with the drawn Train card in front (left) and Game Controller view from the Web application showing the button to watch the given content (right) . . . 24
3.14 Demonstration of the Train Station tile . . . 24

3.15 Board game displaying the board with the drawn Chance card in front (left) and Game Controller view from the Web application showing the button to continue (right) . . . 25
3.16 Demonstration of the Chance tile . . . 25
3.17 Board game displaying the board with the player in the Library tile (left) and Game Controller view from the Web application showing the question with the possible answers (right) . . . 26
3.18 Demonstration of the Library tile . . . 26
3.19 Board game displaying the board with the player in the Students Association tile (left) and Game Controller view from the Web application showing the question with the image and possible answers (right) . . . 26
3.20 Demonstration of the Students Association tile . . . 27
3.21 Board game displaying the board with the player in a Go To Library tile (left) and Game Controller view from the Web application showing the question with the possible answers (right) . . . 27
3.22 Demonstration of the Go To Library tile . . . 27
3.23 Board game displaying the board with the player in a Go tile (left) and Game Controller view from the Web application showing the received points and the button to continue (right) . . . 28
3.24 Demonstration of the Go tile . . . 28
3.25 Game Controller view from the Web application before (left) and after (right) clicking the buy badges button . . . 29
3.26 Board game displaying the board and the player with their badge . . . 30
3.27 Diagram of the actors and functional requirements . . . 31
3.28 Diagram of the non-functional requirements . . . 32
3.29 Architecture of the solution . . . 33

4.1 Login view (desktop and mobile) . . . 46
4.2 Signup view (desktop and mobile) . . . 46
4.3 Player Menu view (desktop and mobile) . . . 47
4.4 Edit Profile view (desktop and mobile) . . . 47
4.5 Rules view (desktop and mobile) . . . 48
4.6 Enter Game Session view (desktop and mobile) . . . 48
4.7 Game Controller view (desktop and mobile) . . . 49
4.8 Admin Back-office Menu view . . . 50
4.9 New Board view . . . 50
4.10 Board view . . . 51
4.11 Edit Save view (taken from a real scenario with practical class 3) . . . 52
4.12 Edit Board view . . . 53
4.13 Edit Questions view . . . 53
4.14 New Question view . . . 54
4.15 Edit Question view . . . 54
4.16 Edit Deck Cards view . . . 55
4.17 New Deck Card view . . . 56
4.18 Edit Deck Card view . . . 56
4.19 Edit Train Cards view . . . 57
4.20 New Train Card view . . . 57
4.21 Edit Train Card view . . . 58
4.22 New Badge view . . . 59

4.23 Edit Badge view . . . 59
4.24 Login Menu view . . . 60
4.25 Login Menu view . . . 60
4.26 Board Menu view . . . 61
4.27 Saves Menu view . . . 62
4.28 Join Menu view (taken from a real scenario with practical class 4) . . . 62
4.29 Game Board view . . . 63

5.1 Mean of the scores given by the students to the questionnaires' statements (Control group's students versus Test group's students) . . . 66

A.1 Join Menu view of the board game projected in a real scenario with the students of the practical class 3 . . . 79
A.2 Game Board view of the board game projected in a real scenario with the students of the practical class 3 . . . 80

B.1 The different elements of the Game Controller view . . . 81
B.2 Edit Board full view . . . 82
B.3 Rules full view . . . 83

C.1 Sex of the students from the control group . . . 85
C.2 Mean of the scores given by the students of the control group to the questionnaire's statements (Female students versus Male students) . . . 86
C.3 Comments and suggestions given by some students of the control group . . . 87
C.4 Sex of the students from the test group . . . 89
C.5 Mean of the scores given by the students of the test group to the questionnaire's statements (Female students versus Male students) . . . 89
C.6 Comments and suggestions given by some students of the test group . . . 90
C.7 Mean of the scores given by the students to the questionnaires' statements (Control group's students versus Test group's students) . . . 91
C.8 Mean of the scores given by the female students to the questionnaires' statements (Control group's female students versus Test group's female students) . . . 92
C.9 Mean of the scores given by the male students to the questionnaires' statements (Control group's male students versus Test group's male students) . . . 93

D.1 Evaluations given by the experts to the first statement of the questionnaire . . . 95
D.2 Evaluations given by the experts to the second statement of the questionnaire . . . 95
D.3 Evaluations given by the experts to the third statement of the questionnaire . . . 96
D.4 Evaluations given by the experts to the fourth statement of the questionnaire . . . 96
D.5 Evaluations given by the experts to the fifth statement of the questionnaire . . . 97
D.6 Global evaluation given by the experts . . . 98
D.7 Negative points given by the experts . . . 99
D.8 Positive points given by the experts . . . 100
D.9 Suggested changes and comments given by the experts . . . 101
D.10 Comments on the Admin Back-office given by the experts . . . 102

List of Tables

2.1 Percentage of people who play regularly and occasionally by age 7

4.1 Folder/file description of the backend 34
4.2 Folder/file description of the frontend 35
4.3 Folder/file description of the board game 36
4.4 Database's models 37
4.5 Badge model's structure 37
4.6 Board model's structure 38
4.7 Card model's structure 38
4.8 Player model's structure 38
4.9 Question model's structure 39
4.10 Save model's structure 39
4.11 Tile model's structure 40
4.12 User model's structure 40
4.13 API's authentication endpoints 41
4.14 API's game endpoints 41

5.1 Mean of the scores given by the students of the control group and test group to the questionnaires' statements 65
5.2 Scores given by the experts to the questionnaire's statements 68

C.1 Mean of the scores given by the students of the control group to the questionnaire's statements 85
C.2 Mean of the scores given by the students of the test group to the questionnaire's statements 87
C.3 Mean of the scores given by the students of the control group and test group to the questionnaires' statements 90
C.4 Mean of the scores given by the female students of the control group and test group to the questionnaires' statements 92
C.5 Mean of the scores given by the male students of the control group and test group to the questionnaires' statements 93

D.1 Scores given by the experts to the questionnaire's statements 94

Abbreviations and Symbols

AHE	Animal Histology and Embryology
ELISA	Enzyme-linked immunosorbent assay
FMUP	Faculty of Medicine of the University of Porto
GE	Game engine
ICBAS-UP	School of Medicine and Biomedical Sciences of the University of Porto
IMVM	Integrated Masters in Veterinary Medicine
QR	Quick Response
TCP	Transmission Control Protocol

Chapter 1

Introduction

The main objective of this dissertation is to increase the motivation of Histology students by introducing a digital gaming platform in the practical classes of this course. It is intended that this platform increases, in addition to motivation, the interaction and socialization among participating students and their learning ability and academic achievement.

1.1 Context

1.1.1 What is Histology?

Histology is a branch of Biology that studies the tissues of plants and animals. The main aim of this science is to investigate how cells are organized as tissues at all structural levels and how they function. Four fundamental tissues make up the organs of animals: the epithelial, connective, muscular, and nervous tissues. Knowledge of the normal appearance and function of these tissues is essential for the identification of changes in them, which are then addressed in Pathology [33, 34]. Additionally, this knowledge is essential to understand better the functioning of organs (Physiology) and their location and arrangement (Anatomy).

1.1.2 The study of Histology

Histology is present in various integrated master's degrees, such as Medicine, Veterinary Medicine, and Biology. Following the traditional method, histology teaching is carried out by lecturers' presentations followed by observations under the microscope by the students. For the new generations of students, this teaching method results in a low level of extrinsic motivation. Students suffer low motivation even though the study of this course is very image-based, which theoretically would be appealing, and despite the efforts of the lecturers to increase motivation, for example, through continuous assessment in classes.

The low motivation felt by students translates into less involvement in the course. In fact, according to surveys carried out among students of Animal Histology and Embryology (AHE) I of the Integrated Masters in Veterinary Medicine (IMVM) of the School of Medicine and Biomedical

Sciences of the University of Porto (ICBAS-UP), it is possible to identify that low involvement is an existing problem and is felt by the students. In the last pedagogical surveys, students reported, on average, an involvement of 4.88 out of 7.

1.1.3 Intrinsic motivation and extrinsic motivation in the educational context

Intrinsic motivation is related to the satisfaction associated with the activity itself, without the existence of external rewards. An intrinsically motivated person is driven by the entertainment or challenge posed by the activity or their need for personal fulfillment and self-determination. This type of motivation is not enhanced by results, rewards, or external pressures and is a highly effective driving force [27, 36, 39].

In contrast, extrinsic motivation is influenced by the environment and external factors. An extrinsically motivated person is motivated by outcomes external to the activity itself, such as rewards or some instrumental value [39].

1.1.4 Gamification

Students of the current generation are regular users of new technologies, such as mobile phones and computers, from a very young age. Combining these technologies with teaching and studying can be very advantageous [23]. It allows the creation of experiences that are familiar to students, such as games, but which are new and innovative in the classroom context. Gamification can be an important and advantageous tool for teachers, who can combine traditional teaching methods with new, complementary, and creative methods [23].

Gamification is a process that results from incorporating games or gamification elements, commonly present in games, into a task in order to promote the motivation of participants [31]. In education, teachers can use gamification as a strategy to introduce intrinsic motivation and increase extrinsic motivation, thereby improving student achievement. Moreover, gamification in the classroom allows students to integrate and interact with each other better.

1.1.5 Histopólio

Histopólio is a board game, based on the Monopoly game, where the tiles and the cards are related to the subject of Histology and the university context. Histopólio already exists in a physical version (Figure 1.1) and was developed by Professor Ricardo Marcos from ICBAS-UP.

Each tile on the board has a specific set of questions or cards associated with it and a number of points, which will be awarded to the player if they get the question right or do the given task.

The question cards have a QR code printed on them so that the student can access the question and answer from their mobile phone. On the back of each question card, there is another QR code to help the student answer the question, at the expense of halving the original points. To promote interaction and teamwork between the classmates, the player can also ask for the help of another colleague to answer the question together and thus divide the points.

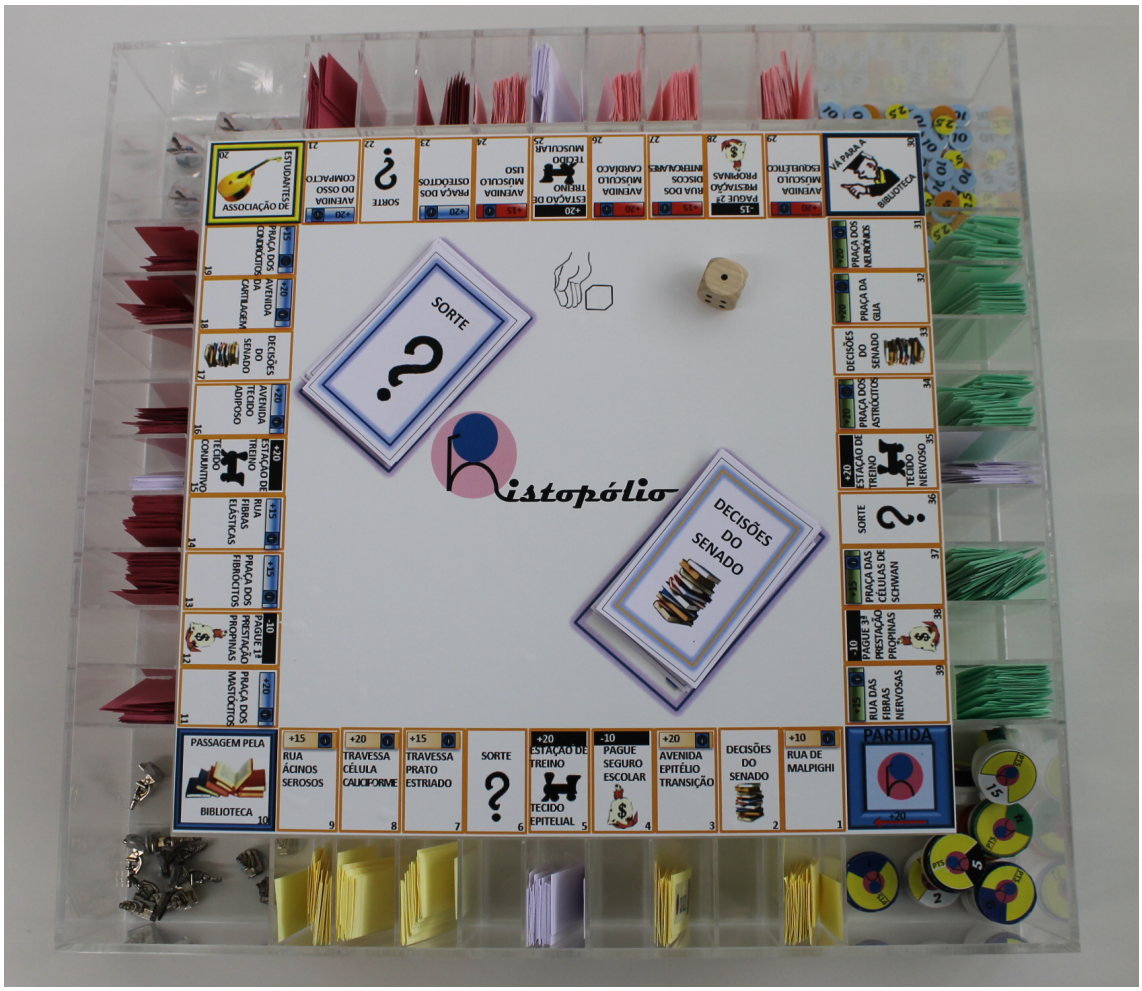


Figure 1.1: Physical version of Histopólio

In addition to the questions, there are three types of cards with different activities. The Chance cards allow players to earn points, advance positions, or play again, among other activities. As for the Senate Decisions cards, which replace the traditional Monopoly Community Chest cards, these introduce tasks to players, such as presenting a part of the class or narrating video elements, in exchange for points. Finally, the Train cards are given to the player when they land on a Train Station tile. These cards have links to short videos with drawing elements that resume the specific fundamental tissue of that row.

The game also has badges (Figure 1.2), which can be acquired in exchange for points and allow the player to multiply the points received by a factor each time they earn points.

The main disadvantage of the physical version compared to the digital one is the possibility of cheating by the students, who must be observed to make sure that the rules are followed. Moving the game to the digital format reduces this possibility, as the game engine (GE) ensures that all rules are followed. Furthermore, when several students occupy the same positions, especially in corners of the game (for example, between positions 9 and 11), they tend to overlap, making it difficult to appraise their actual position (Figure 1.3).



Figure 1.2: Player with a badge

The game's physical version is pretended to be used in the practical classes of AHE I, taught by Professor Ricardo Marcos, while the digital gaming platform is under development. This should allow the students to compare the physical model with the digital model.

1.2 Motivation

Considering that Histology is an important science that allows the identification of tissues and their changes throughout the disease process and in response to treatments, students must be able to learn and retain the contents taught in the Histology course. Knowing that many students have low levels of engagement in the course, it is necessary to seek new methods and strategies, in addition to traditional teaching approaches, to increase their motivation.

The introduction of a gamification strategy in the classroom context is an innovative idea that can help combat low student engagement and motivation rates and consequently improve learning ability.

The choice of this theme for the dissertation is motivated by a personal interest in the area of health and in digital games and by the possibility of combining both for the benefit of students in terms of learning and involvement in the Histology course. Furthermore, the digital gaming platform developed will allow professors to easily create more game boards designed specifically

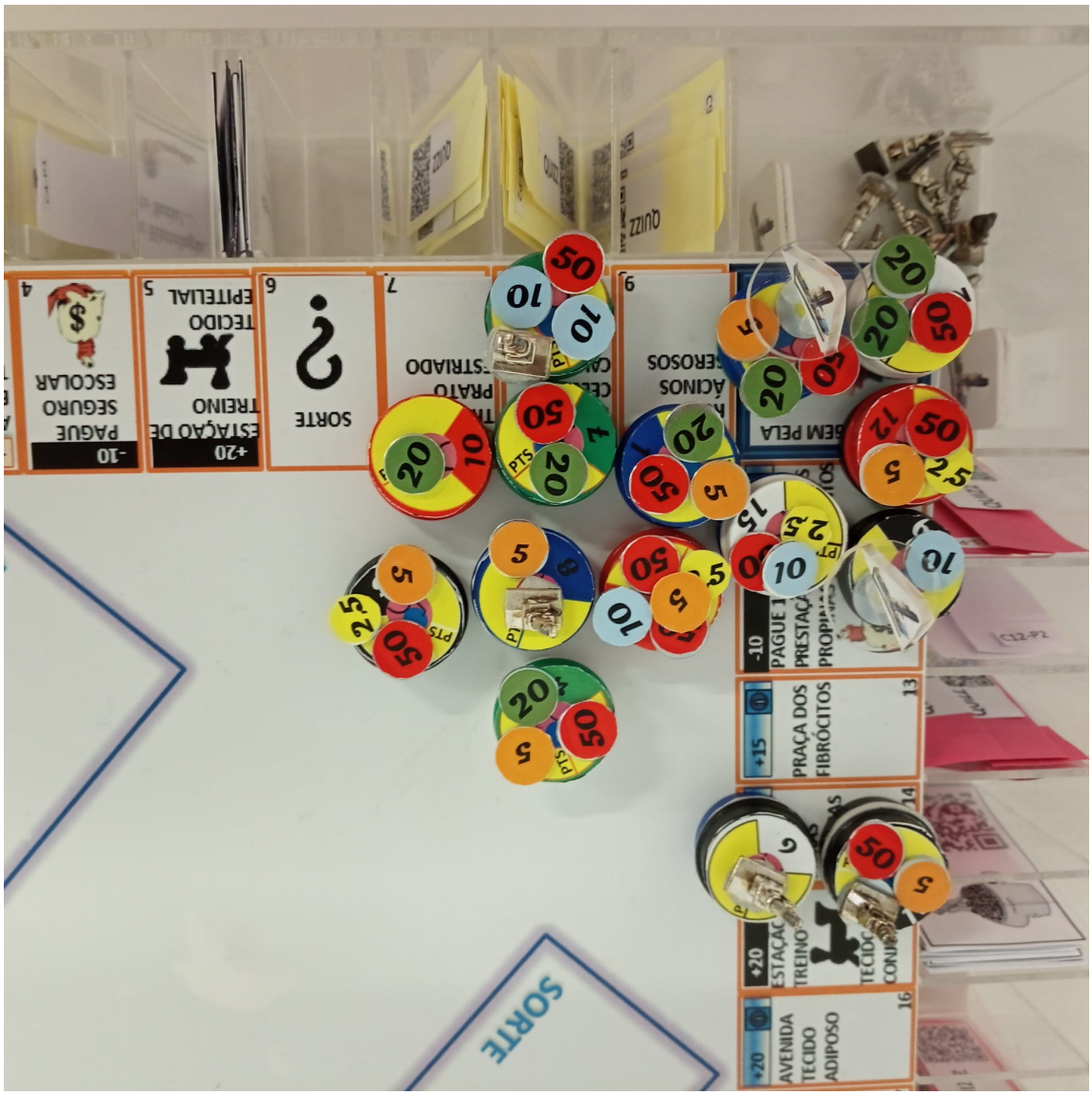


Figure 1.3: Players overlapping in one corner of the board (between the position 9 and 11)

for other courses, thus positively influencing many more students within the academic environment of the University of Porto.

1.3 Objectives

The dissertation's main objective is to develop a flexible digital gaming platform, containing the Histopólio game board, to be used in Histology practical classes. It is intended that the Histopólio game board serves as a base framework that can be easily adapted by professors who want to use gamification in the context of other courses.

Besides the board game, the digital gaming platform integrates a Web application. The Web application must allow each student to roll the dice, answer questions, and do tasks that influence

their score in the game from their smartphone or personal computer. The student's device and this Web application are important tools for the student to feel more integrated and motivated while participating in the game. Furthermore, the Web application should also allow professors with admin access to manage all their created boards and students in an Admin Back-office.

Finally, it is intended to evaluate the results of gamification through questionnaires conducted on two groups of students: a test group (with gamification) and a control group (without gamification). The students surveyed are from the AHE I classes of the IMVM of the ICBAS-UP. Another evaluation with professors of Histology is intended to further validate the digital gaming platform.

1.4 Document structure

The document is divided into six chapters.

In chapter 1, an introduction to the project is presented. The context in which the dissertation is set is analyzed, and the motivations that are the reason for its elaboration are described. After that, the main objectives are outlined, and the document's structure is presented.

In chapter 2, the state of the art is analyzed, and several concepts related to the project are presented. Some technologies used for the development of games and Web applications are explored, and several related projects are presented.

In chapter 3, a high-level analysis of the solution is made, including an overview, as well as a description of the functional and non-functional requirements and the software architecture.

Following, in chapter 4, the implemented solution is analyzed, including the folder/file structure, the database, the API, and the WebSocket communication. Additionally, the user interface is also presented.

Next, in chapter 5, the information regarding the tests performed with the students and the experts is presented, and the results are analyzed.

Finally, in chapter 6, the conclusions of the project developed are presented, including a reflection on the evaluation results and the satisfaction of the goals. Additionally, some future improvements and features are debated.

All references are provided at the end of the document, followed by the appendixes.

Chapter 2

State of the art

In this chapter, the strategy of gamification and its results, particularly in the context of education, will be analyzed. Technologies for the development of games and Web applications will also be discussed and reviewed.

Subsequently, some projects related to gamification in the field of education will be mentioned and presented.

2.1 Gamification

The development and growth of the video games industry have been remarkable in recent decades. It is one of the few industries that have had an extremely positive impact due to the pandemic, showing a 23% growth in 2020 compared to the previous year [35, 50]. This rapid growth has made video games a mainstream entertainment medium, especially popular among young people (Table 2.1) [6, 44].

Table 2.1: Percentage of people who play regularly and occasionally by age [6]

Age	Plays regularly	Plays occasionally	Total
18-29	29%	31%	60%
30-49	28%	25%	53%
50-64	15%	17%	31%
65+	11%	13%	24%

The concept of gamification emerged in 2010 and is defined as the application of elements associated with games and game design technics in non-game contexts. It is a strategy whose goal is to promote the participation and involvement of people, seen here as players [8, 44]. Gamification is a practice that has been widely explored in marketing, where gamification elements, such as reward systems, are used to engage and retain the customer [19, 52]. Beyond marketing, its application has been extended to the areas of health, environment, institutional services, and education [44].

Gamification increases extrinsic motivation by introducing gamification elements (such as points, badges, and leaderboards) that promote healthy competition or provide rewards for the player. If applied correctly, this strategy can also introduce intrinsic motivation by transforming previously tedious and tiring tasks into an activity as entertaining as playing a game.

2.1.1 Gamification in education

Considering the rapid growth of the video game industry, whose most significant users are young people, it is expected that gamification in the context of education can have a positive impact on students, if applied correctly. In fact, gamification has a unique potential in education, as this new generation of students is very familiar with the mechanics of video games and gamification elements, besides being avid consumers of new technologies. Successful cases of gamification in education, although outside the school and university context, include the Khan Academy and Codecademy. These online services present videos and exercises to users, who can check their progress through points and badges systems [4].

The most commonly adopted gamification elements in the different areas of study are levels, badges, points systems, and leaderboards [4, 54]. These elements elicit different effects on participants' behavior. Elements like points and leaderboards promote healthy competition among peers, provoking motivation in users to be better than others. In contrast, elements such as levels promote self-assessment by the individual as they offer a way to quantify their progress and work, allowing verification by the user and motivating them to improve with each attempt. Elements such as badges, which usually serve as a visual representation of objectives, combine these two effects [40].

The use of leaderboards as a gamification element is often controversial, as it may be argued that users who find themselves in the last places will feel demotivated. However, studies on the use of leaderboards in gamification contexts have found no significant adverse effects on motivation [4, 30]. In fact, students identified leaderboards, among all the elements, as the most engaging due to the introduction of a competitive environment, creating a higher motivation to learn. Furthermore, leaderboards promote greater interaction and socialization of students through competition and comparison of scores [54]. Despite the possible competition, games in the education context are frequently collaborative and all players win by learning. These games lack the typical win-lose features of gaming.

Several studies have shown that incorporating gamification elements, such as badges or leaderboards, into teaching effectively increases students' motivation and thus improves their learning experience, engagement, and performance [54]. Some critics argue that these elements only create extrinsic motivation, i.e., students complete tasks only to receive badges or points and not for the satisfaction of acquiring new knowledge. However, many authors argue that gamification contributes to both extrinsic and intrinsic motivation. The principles and elements used in games are naturally enjoyable and fun for students, increasing task-related intrinsic motivation [1, 22, 54]. Furthermore, the integration of gamification into the students' grading system may lead to an improvement of learning outcomes [54].

Furthermore, the interaction and socialization of students can also be enriched by introducing certain gamification elements. As mentioned above, points and leaderboards are some of the most commonly used elements that promote healthy competition between colleagues and, consequently, their interaction. Other elements, such as virtual goods and gifts that users can share between them, contribute to a greater sense of community among students [40, 54].

2.2 Technologies for game development

Game developers usually resort to Game Engines (GE) when creating a game. A GE is a software that offers a set of tools and features that help game developers build their games professionally and efficiently, while hiding the low-level details of various tasks that make up a video game [2, 43, 47].

Some of the most popular GEs are described below.

2.2.1 Unity

Unity is a GE and integrated development environment used primarily for creating games. The first version was released in 2005 with the goal of creating an affordable GE with professional tools for amateur game developers [16, 17]. Furthermore, the current version is compatible with many target platforms, including desktop, mobile, console, and virtual reality platforms [16]. Game developers can use this GE to create 2D and 3D games. Some examples of games developed with Unity are Fall Guys, Cuphead, and Pokemon GO [18].

2.2.2 Unreal Engine

Unreal Engine is a GE developed by Epic Games that emerged in 1998 [24]. This GE is considered more complex to learn, with students finding learning more frustrating. Despite this, Unreal Engine can create more professional results with greater ease [9]. This GE can be used for creating 2D and 3D games. Some examples of games developed with the Unreal Engine are Ark: Survival Evolved, Borderlands 3, and Fortnite [10].

2.2.3 Godot

Godot is an open-source GE released under the MIT license. This GE distinguishes itself from most other GEs on the market as it is entirely free and any project belongs 100% to the creator. Moreover, the open-source nature of Godot also allows developers to modify the GE and add features as needed [5]. Game developers can use this GE to create 2D and 3D games [7]. Some examples of games developed with Godot are Ex Zodiac, Until Then, and Resolutiion [26].

2.3 Technologies for the development of Web applications

A Web application is an application that is built using Web technologies and is invoked with a Web browser over the Internet. Since it became available to the public in 1994, the Internet has become a platform of choice for many increasingly sophisticated and innovative Web applications. Web applications are different from more traditional Websites, because they are more dynamic and allow the user to accomplish tasks. In contrast, Websites are designed for the consumption of static information [21, 48].

Recently, many libraries and frameworks have been created to help the development of Web applications. Below, three of the most popular libraries and frameworks are presented.

2.3.1 React

React is a JavaScript library developed by Facebook in 2011 and made open-source in 2013. It is used to create interfaces for the Web in a more interactive way, making it easier to update the view when data changes. Furthermore, the view can be split into smaller components in order to create a more complex interface [41, 51].

2.3.2 Angular

Angular is a JavaScript framework created in 2008 by two Google employees, with the purpose of simplifying Web application development, mainly for Web designers with little knowledge of Web development [15, 51]. Soon after, Angular became open-source and available to people outside Google [41].

Angular was one of the first frameworks for single-page application development and offers developers features such as bi-directional data binding. One of its main advantages over competitors is its accessible nature [51].

2.3.3 Vue

Vue is a JavaScript framework developed in 2014 by Evan You, a former Google employee [51]. While a Google employee, Evan worked a lot with Angular and felt that using this framework was too heavy for some instances, so he created a lighter framework with the features he liked best from Angular. That same year Evan shared his project on GitHub, and Vue became open-source [41, 51].

Vue is regularly described as a progressive framework that can be used to develop interfaces for the Web. Although it is not strictly associated with the Model-View-ViewModel pattern, its principles were partially inspired by this pattern. One of the most considerable merits of this framework is its scalability, as developers can use it for both small projects and large single-page applications [51].

2.4 Related work

It is presented below some projects and applications related to gamification in the context of education. Some of these projects were made available by Professor António Coelho and Professor Ricardo Marcos, and are from the area of health sciences.

2.4.1 SPOT - serious game based on augmented reality for the prevention of melanoma

SPOT is a serious game that aims to prevent melanoma and integrates augmented reality elements. A serious game is a game where the primary purpose is not entertainment, but the transmission of educational content and problem-solving [12, 45]. The main goal of this serious game is to change people's behavior so that they take more account and regularly perform skin self-examinations, which are necessary for the identification of melanoma. The game has several gamification elements, such as badges, a narrative (Figure 2.1), virtual currency, player progression, and high scores, among others [12].



Figure 2.1: SPOT - game screens that demonstrate a narrative [12]

The project's outcome was a success. The tests performed verified a positive increase in the effectiveness of the participants' self-examinations and the likelihood of performing self-examinations in the following months. This increase indicates a greater awareness among users of an important issue such as melanoma prevention. Through gamification, participants could learn and successfully perform skin self-exams in an enjoyable and fun way [12].

2.4.2 Histological challenge A digital book that is also a game

The Histological Challenge is an online platform with gamification elements to aid the teaching of the Histology course. The main gamification elements present are narrative, leaderboards (Figure

2.2), and a system of levels, or "chapters", as the author refers. Furthermore, this platform can be adapted to other areas of education by uploading CSV files to change the content to be taught [3].

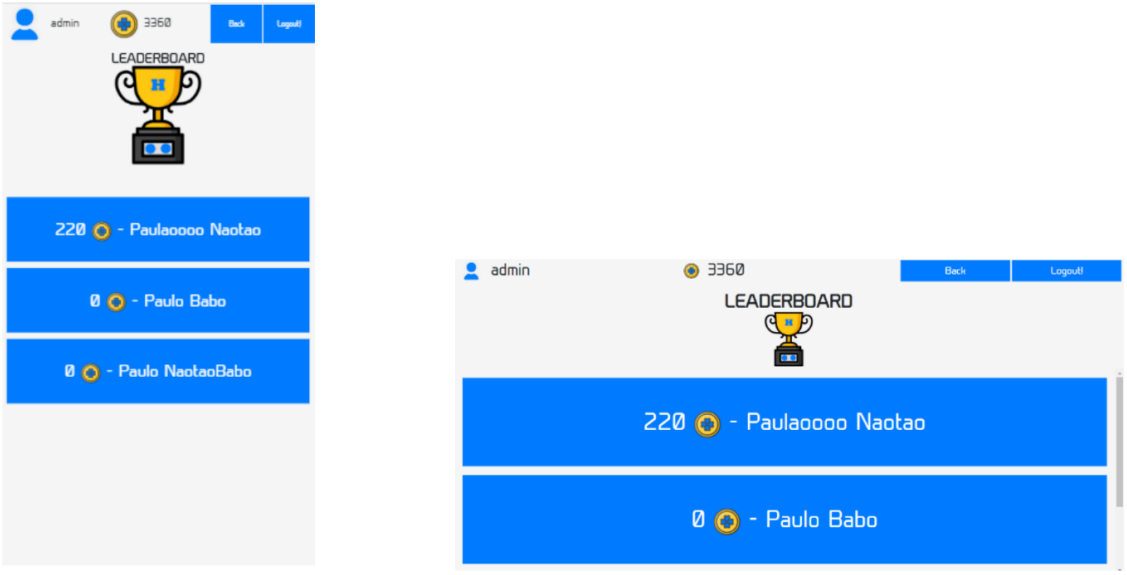


Figure 2.2: Histological Challenge - mobile and desktop views of the leaderboard interface [3]

The feedback received by students was positive, although there was only one small test involving ten students in a single session [3].

2.4.3 Gamified mobile application for Creative Introduction to Programming

Given the problems associated with teaching programming in the digital media area, often due to the difficulties experienced in thinking in a computational way, an augmented book was idealized. This project consisted in developing this augmented book that combines the paper book with a Web application, available for mobile and computer. The Web application allows the transposition from paper to digital support. Additionally, the project also integrates gamification elements, such as player progression, points system, level unlocking, leaderboards, and feedback (Figure 2.3) [13].

The results on the usability of the application were positive, but with room for improvement, mainly in terms of resources used and design [13].

2.4.4 Gamification in Science Education: Gamifying Learning of Microscopic Processes in the Laboratory

This project consisted in developing a learning tool for visualizing enzyme-linked immunosorbent assays (ELISAs) in a digital laboratory. In the traditional teaching method, it is impossible to observe by microscope the process of these assays, so students only find out the success or failure of the assay at the end of the experiment, with little chance of identifying what went wrong in case of failure. This tool tackles this problem by allowing visualization throughout the steps of

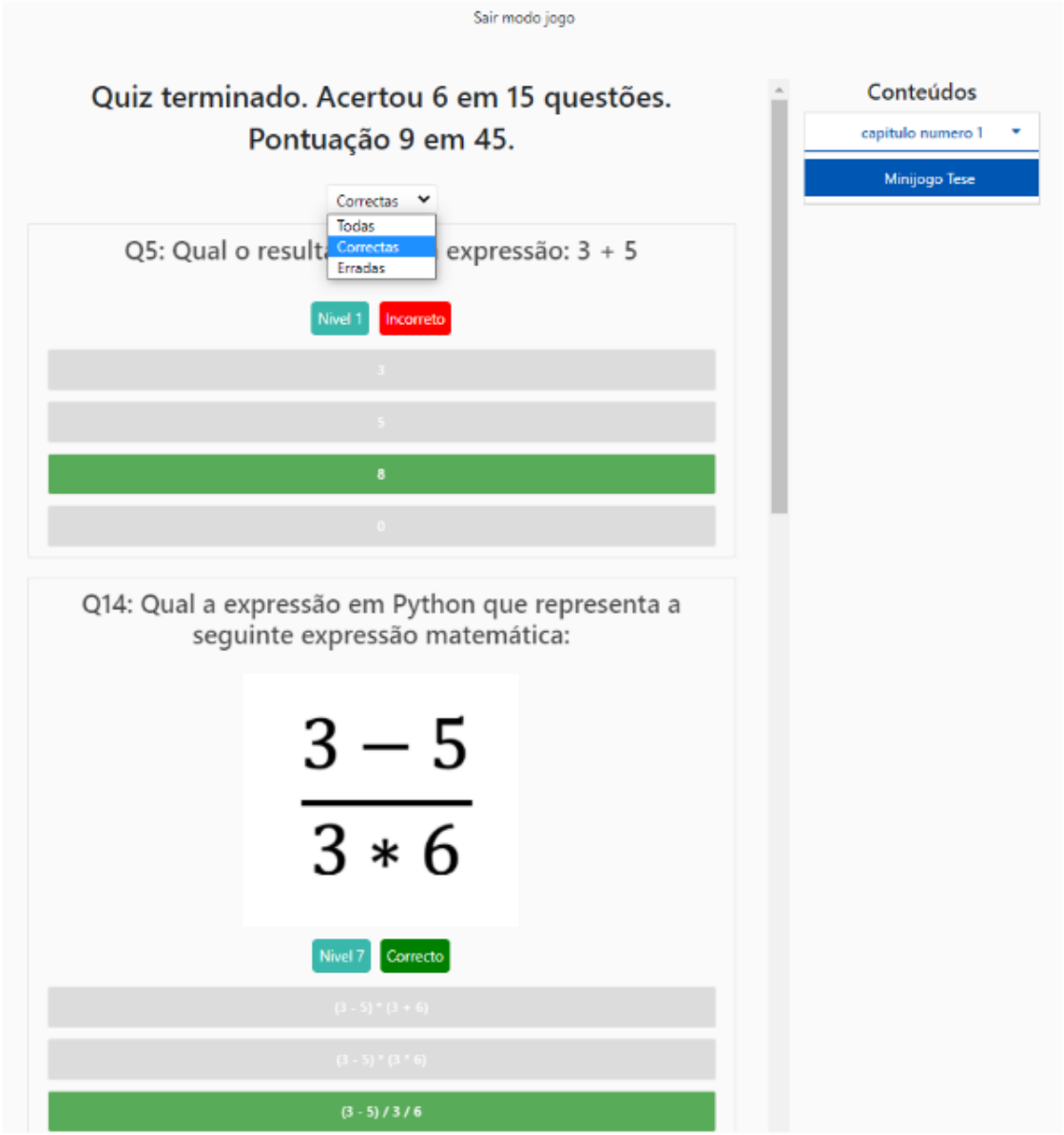


Figure 2.3: Gamified mobile application - feedback observed in the minigame's final view [13]

the ELISA process and by providing instant feedback on the application of different reagents. In addition to having a game-like design, the tool contains challenges as a gamification element (Figure 2.4) to provoke greater motivation among students [14].

The feedback from students who used the tool during the lessons was positive, with 66% saying the tool is 'useful' or 'very useful'. Furthermore, 90% of students responded in the surveys that they enjoyed learning with the help of the tool, indicating that the gamification elements were well applied [14].

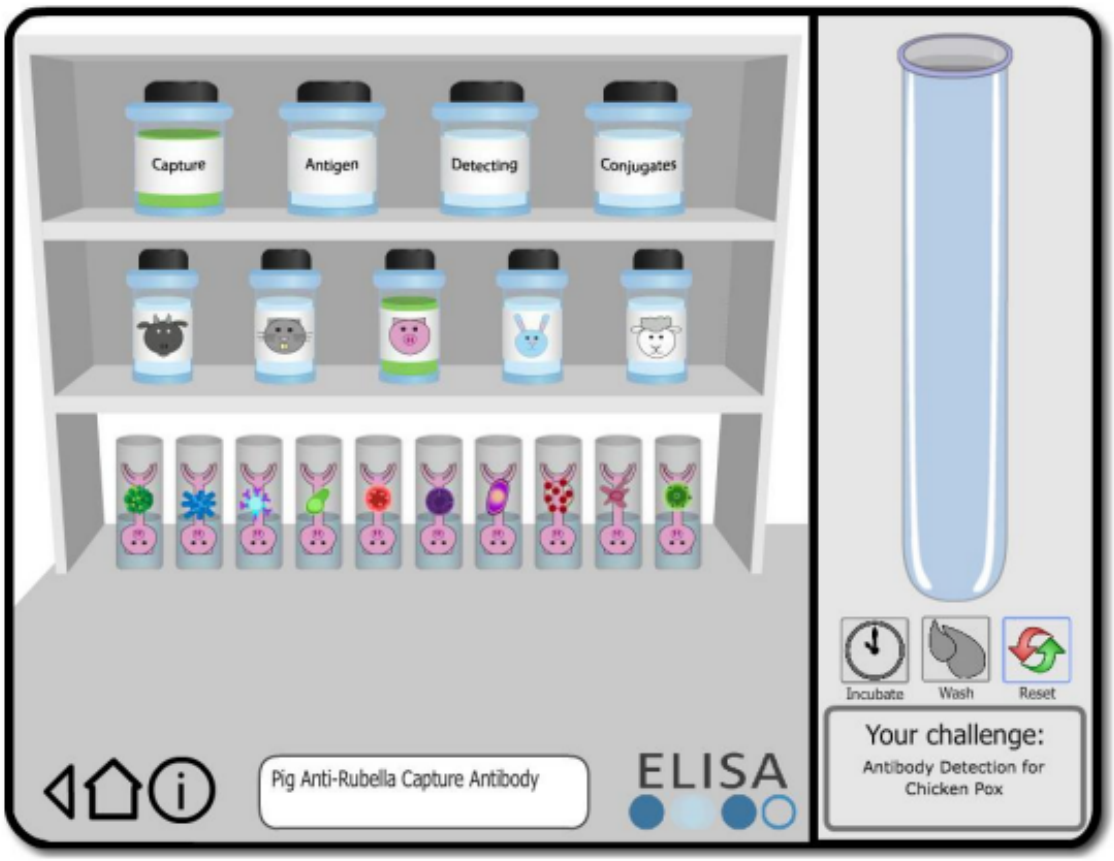


Figure 2.4: ELISA digital tool - challenge screen [14]

2.4.5 Blended Learning in Anatomy Teaching for Non-Medical Students: An Innovative Approach to the Health Professions Education

This project consisted of the development of a Web platform for non-medical students to learn anatomy. These students face limitations of access to resources designed explicitly for medicine degrees. This Web platform was designed to tackle these limitations, offering solutions that meet the specific needs of non-medical students. Some solutions provided by this tool are illustrations and 360-degree spatial simulations. Moreover, to increase the motivation of these students, the Web platform incorporates several gamification elements, such as a narrative (Figure 2.5), quizzes with different difficulty levels, points, leaderboards, and badges [32].

This teaching method was perceived positively by most students. The majority of students agreed that the course presented content in a straightforward and easy-to-navigate way. Meanwhile, 66% found this tool helpful, and 85% gave positive feedback regarding the gamified quiz [32].



Figure 2.5: Web platform for anatomy teaching - narrative animation [32]

2.4.6 Kahoot!

Kahoot! is a gamification platform used to assess students' knowledge through quizzes, with the purpose of introducing a different activity into traditional lessons. After its launch in 2013, Kahoot! has become one of the largest gamification platforms [49]. Besides offering immediate feedback on each question (Figure 2.6), this platform contains gamification elements, such as points and leaderboards. It also allows users to create their own quizzes and export results at the end of each session for performance analysis. Kahoot! requires the use of two devices, where one device displays the answers and access code, and the other is used to answer the questions. Many users can connect simultaneously to answer the questions and compete with each other [13].

Nowadays, Kahoot! is widely used in education, from elementary school to high school and university levels [42, 49]. Several studies indicate that this tool can positively affect learning ability, interaction, and socialization between students, as well as students' anxiety and motivation [49].

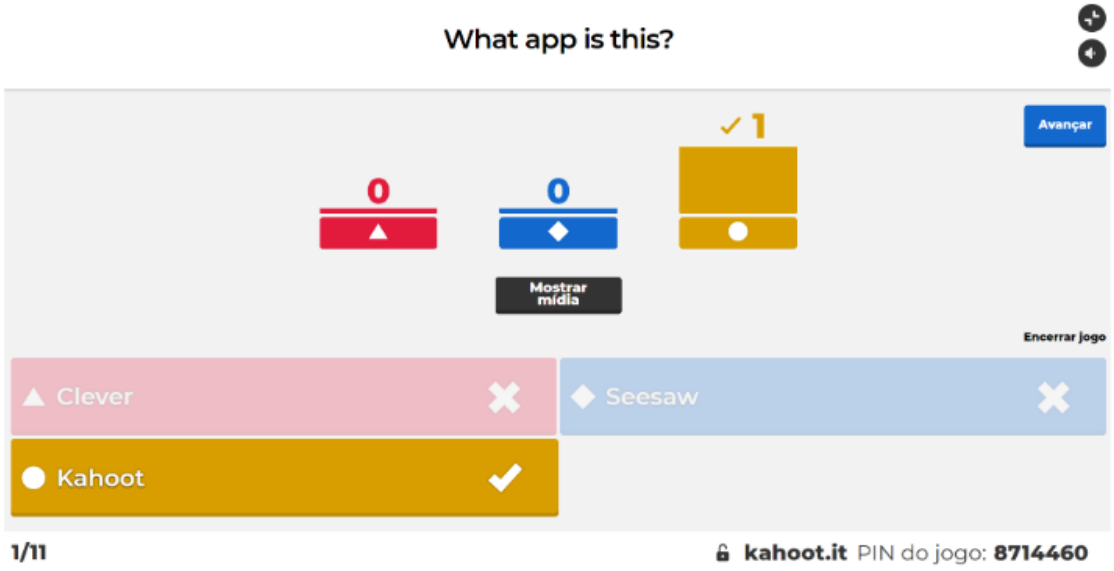


Figure 2.6: Kahoot! - immediate feedback [13]

Chapter 3

Solution

In this chapter, a high-level analysis of the solution is made, starting with an overview, followed by the definition of functional and non-functional requirements and the software architecture.

3.1 Overview

The proposed solution consists of a digital gaming platform, through the conjunction of a board game developed in Unity and a Web application.

The board game is intended to be displayed simultaneously for all the students, with the help of a large screen or projector (Appendix A). It will present, besides other information, the game board and all the players' positions (Figure 3.1).



Figure 3.1: Example of a board game view (Game Board view) during a real scenario, with 13 students

The Web application can be used on desktop (Figure 3.2) or mobile devices (Figure 3.3). It is intended to be used by the players as a controller for the digital game, where they can roll the dice and do personal tasks, such as answering questions. Besides that, the Web application will allow professors with admin access to create and edit boards and to visualize and edit players' scores, positions, turns, and other information.

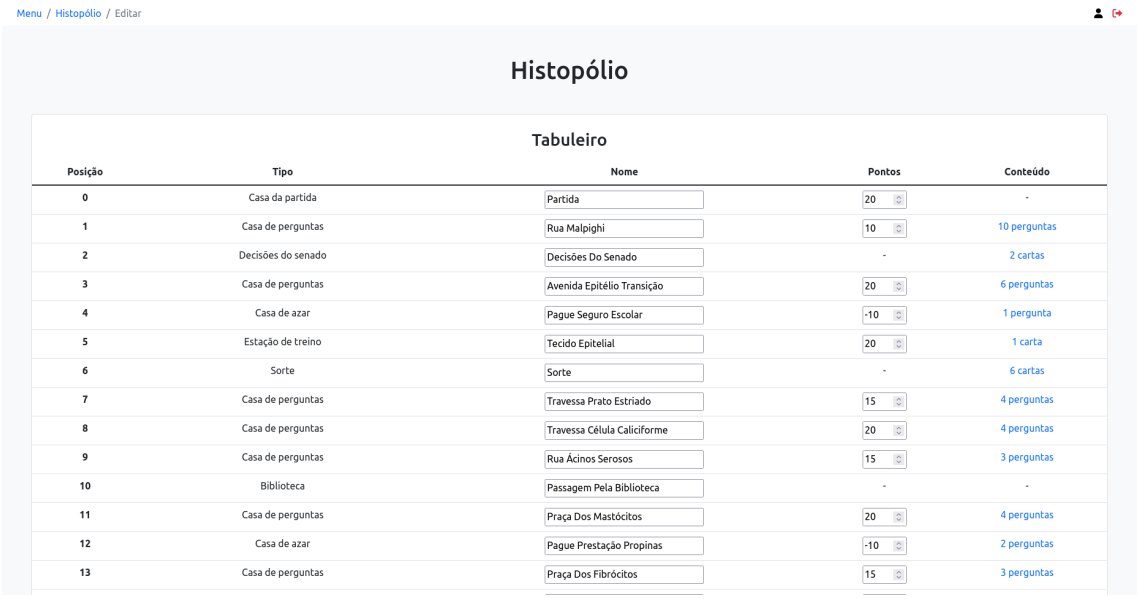


Figure 3.2: Example of a view from the Web application (Edit Board view) displayed on a desktop

This solution was designed to increase students' motivation in the AHE I course of the IMVM of ICBAS-UP. Although the current digital gaming platform only contemplates the game board and materials from that course, new game boards can be created and modified with completely different tile names, points, questions, cards, and badges. This versatility was also one of the main goals, as it allows teachers without any programming skills to create games for other subjects in the context of university education, through a simple and intuitive user interface.

3.1.1 Rules and flow of the game

This section provides a description of how the board game works and its rules, including an analysis of the game's flow.

This digital gaming platform is intended to be used exclusively during classes. Since that is the case, each class will have a different game session, where players must join to play the board game. The players' scores, positions, and other data will be saved and carried throughout all the different game sessions. The players will start each game session with the same scores and positions on the board as they ended up in the previous game session, ensuring a continuity of the board game. If it is the first time a student is playing in the active game board, they will start on the GO tile.

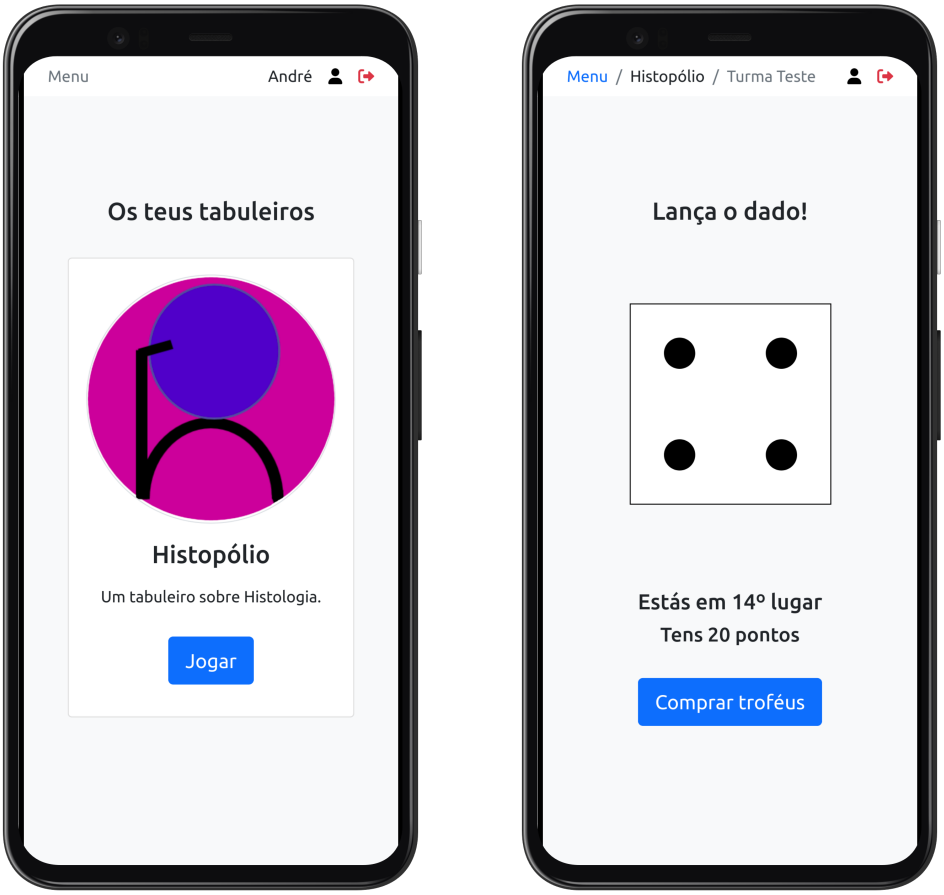


Figure 3.3: Example of two views from the Web application (Player Menu view and Game Controller view) displayed on a mobile device

In the AHE I course of ICBAS-UP, the students used the digital gaming platform in their practical classes.

3.1.1.1 Joining the game session

Players can join the game session when the board game shows the Join Menu screen. To do so, players must authenticate themselves in the Web application and go to the Game Controller, after selecting the corresponding game board. If it is the first time playing in the active save, the player must enter the session code presented on the Join Menu screen in order to join the session. The session code is a randomly generated number between 1000 and 9999 and is unique for the session. Once joined, the player's avatar will be displayed in the Join Menu view of the board game (Figure 3.4).

After the game session has started, the board with all the players in their respective positions is displayed. If it is the first time playing on the active game board, the player will start in the Go tile (position 0).

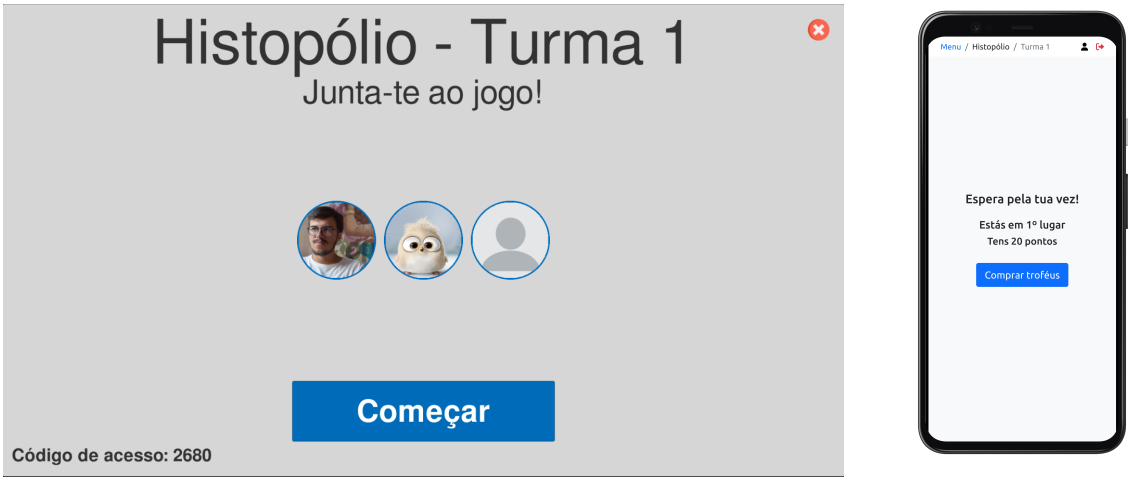


Figure 3.4: Join Menu view displayed in the board game (left) and Game Controller view from the Web application after the player joined the gaming session (right)

3.1.1.2 Turns system

This board game is a turned-based game, where the player with the least turns played will always go next. This strategy prioritizes the players who have played fewer turns, allowing students who missed some class to catch up to other players who were always present. If a player has many fewer turns than any other active player, they will play multiple turns in a row until they catch up with the rest of the players. If all players have the same number of turns, they will play by the order in which they joined the game session.

3.1.1.3 Rolling the dice

If the current player has not finished the board yet, their turn starts with the dice roll. The current player's Game Controller in the Web application displays the dice, which the player can click to roll (Figure 3.5).

After rolling the dice, the player will see on the game board their avatar moving the same number of positions as the number they rolled. After arriving at the destination tile, the player will have to do a specific task, depending on the type of tile (Figure 3.6) they have landed on.

In the Histopólio board, since it is designed to teach the four fundamental tissues, the theme of each row is assigned to a specific tissue (epithelial, connective, muscular, or nervous tissue). Furthermore, the topics covered in this game board's tiles follow the outline and sequence of the lessons covered in the practical classes.

3.1.1.4 The Group Property tile

This type of tile is the most common in the game, as it can be found all across the board. When a player lands in a tile of this type, they will need to answer a multiple-choice question from that tile in order to receive the corresponding points (Figure 3.7).

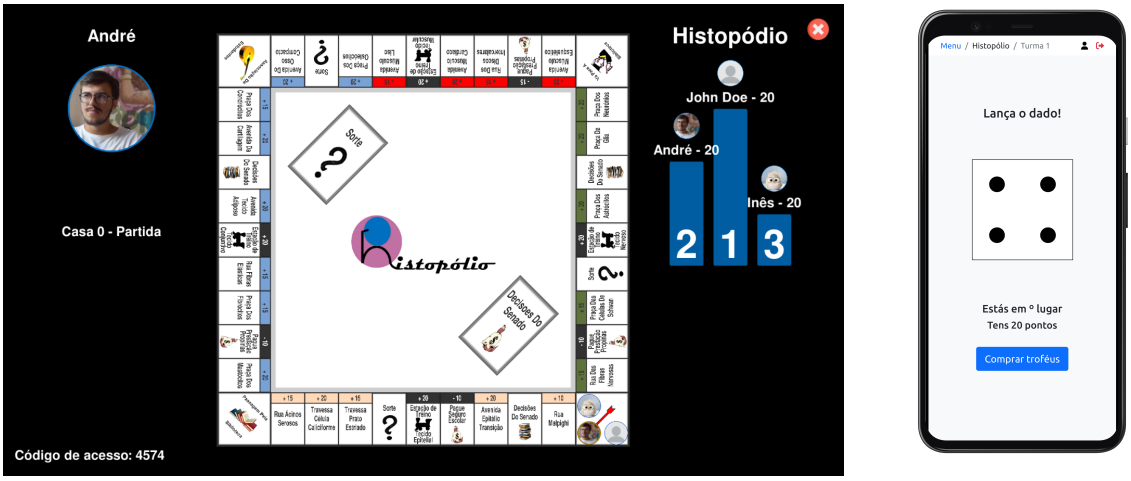


Figure 3.5: Board game displaying the board with the players at the start (left) and Game Controller view from the Web application ready for the player to roll the dice (right)



Figure 3.6: The different types of tiles on the board game

A Quick Response (QR) code that links to a video demonstrating the Group Property tile is shown in Figure 3.8.

In the Histopólio board, these tiles are named after Histology terms, and the questions are Histology-related.

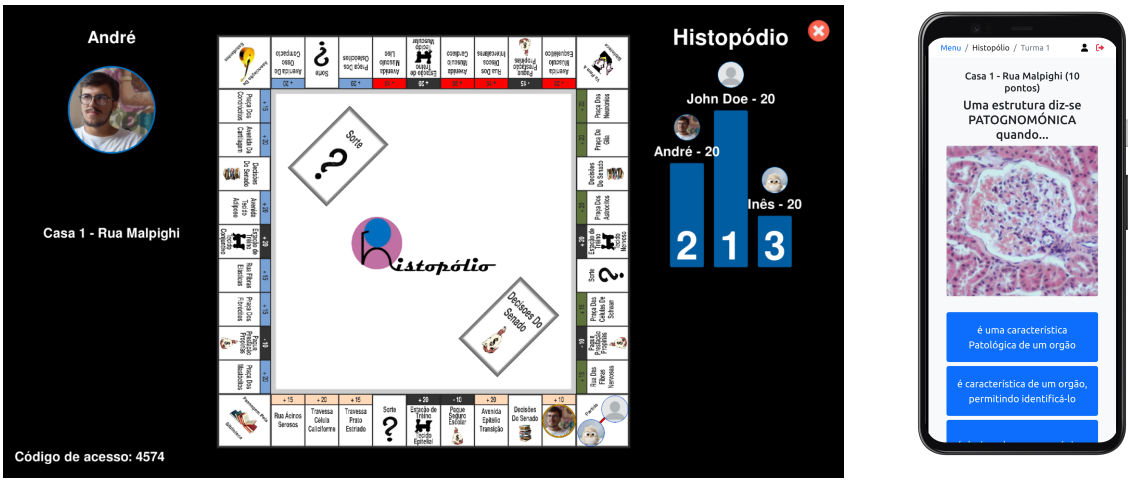


Figure 3.7: Board game displaying the board with the player in a Group Property tile (left) and Game Controller view from the Web application showing the question with the image and possible answers (right)

Figure 3.8: Demonstration of the Group Property tile

3.1.1.5 The Senate Decisions tile

When a player lands in a tile of this type, a random card from the Senate Decisions deck will be drawn and displayed on the board game screen, as shown in Figure 3.9. Depending on the action associated with the card, the player might receive points and then move a given number of spaces, move to a given tile, or stay in the same place. A Senate Decisions card is usually associated with a more demanding task that the student will later deliver after the game session.

A QR code that links to a video demonstrating the Senate Decisions tile is shown in Figure 3.10.

In the Histopólio board, these tiles give Histology-related tasks to the players.

3.1.1.6 The Pay tile

If a player lands in a Pay tile, they will need to answer a multiple-choice question to avoid losing points (Figure 3.11). If the player answers the question wrongly, they will lose the corresponding points.

A QR code that links to a video demonstrating the Pay tile is shown in Figure 3.12.

In the Histopólio board, the questions from the Pay tiles are Histology-related and are usually more accessible than the questions from the Group Property tiles.

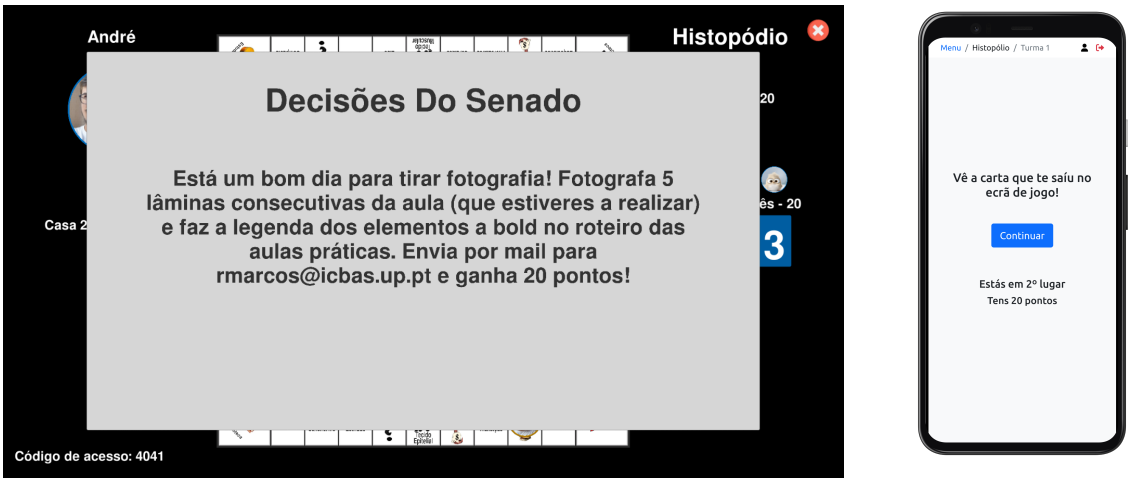


Figure 3.9: Board game displaying the board with the drawn Senate Decisions card in front (left) and Game Controller view from the Web application showing the button to continue (right)

Figure 3.10: Demonstration of the Senate Decisions tile



Figure 3.11: Board game displaying the board with the player in a Pay tile (left) and Game Controller view from the Web application showing the question with the possible answers (right)

3.1.1.7 The Train Station tile

When a player arrives at a Train Station tile, a random card from the tile will be drawn, and the player will be given some specific content to watch, like a YouTube video (Figure 3.13). Once the player clicks to see the content, they will be awarded the corresponding number of points.

Figure 3.12: Demonstration of the Pay tile

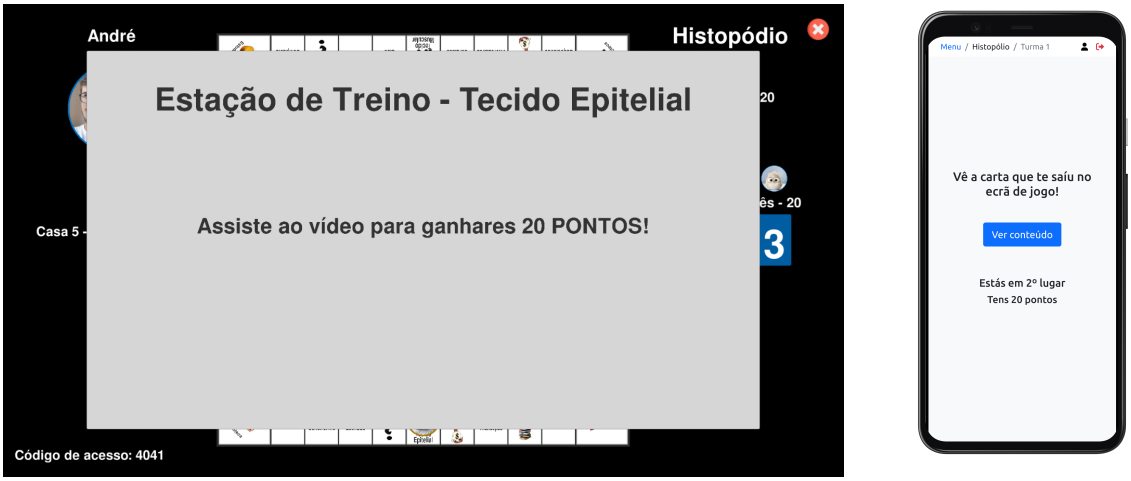


Figure 3.13: Board game displaying the board with the drawn Train card in front (left) and Game Controller view from the Web application showing the button to watch the given content (right)

A QR code that links to a video demonstrating the Train Station tile is shown in Figure 3.14.

Figure 3.14: Demonstration of the Train Station tile

In the Histopólio board, these tiles are named after the four fundamental tissues, and the students are given small videos of less than 5 minutes with the tile's topic to watch.

3.1.1.8 The Chance tile

If a player lands in a tile of this type, a random card from the Chance deck will be drawn and displayed on the board game screen, as shown in Figure 3.15. Depending on the action associated with the card, the player might receive points and then move a given number of positions, move to a given tile, or stay in the same place. A Chance card is usually associated with lucky bonuses, like instant points and moving the player.

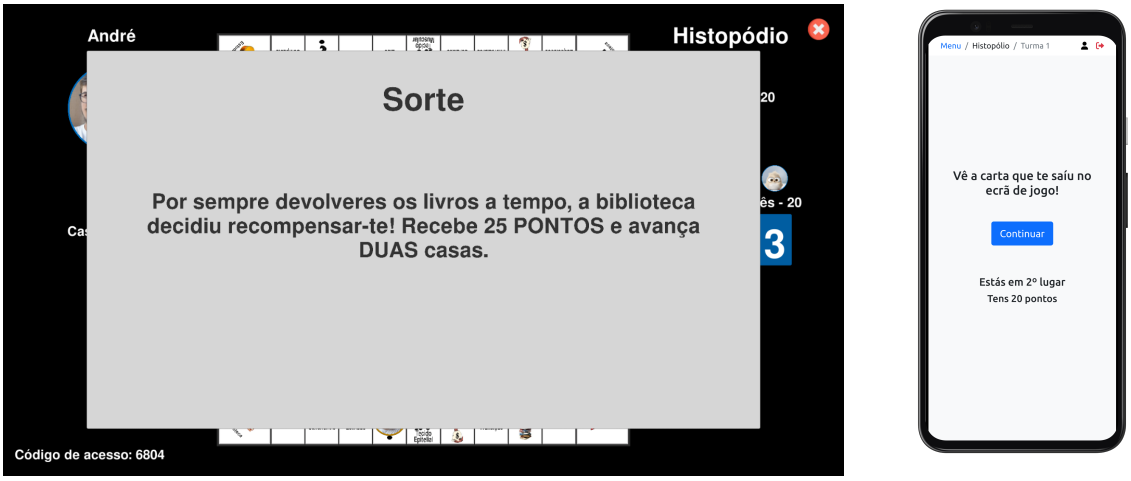


Figure 3.15: Board game displaying the board with the drawn Chance card in front (left) and Game Controller view from the Web application showing the button to continue (right)

A QR code that links to a video demonstrating the Chance tile is shown in Figure 3.16.

Figure 3.16: Demonstration of the Chance tile

3.1.1.9 The Library tile

There is only one tile of this type on the board, located at position 10. When a player lands in this tile, they will have to answer one random multiple-choice question from a tile of the previous row (Figure 3.17). If the player answers correctly, they will receive the corresponding points.

A QR code that links to a video demonstrating the Library tile is shown in Figure 3.18.

3.1.1.10 The Students Association tile

There is only one tile of this type on the board, located at position 20. With a similar behavior to the Library tile, when a player lands in this tile, they will have to answer one random multiple-choice question from a tile of the previous row (Figure 3.19). If the player answers the question correctly, they will be awarded the corresponding points.

A QR code that links to a video demonstrating the Students Association tile is shown in Figure 3.20.

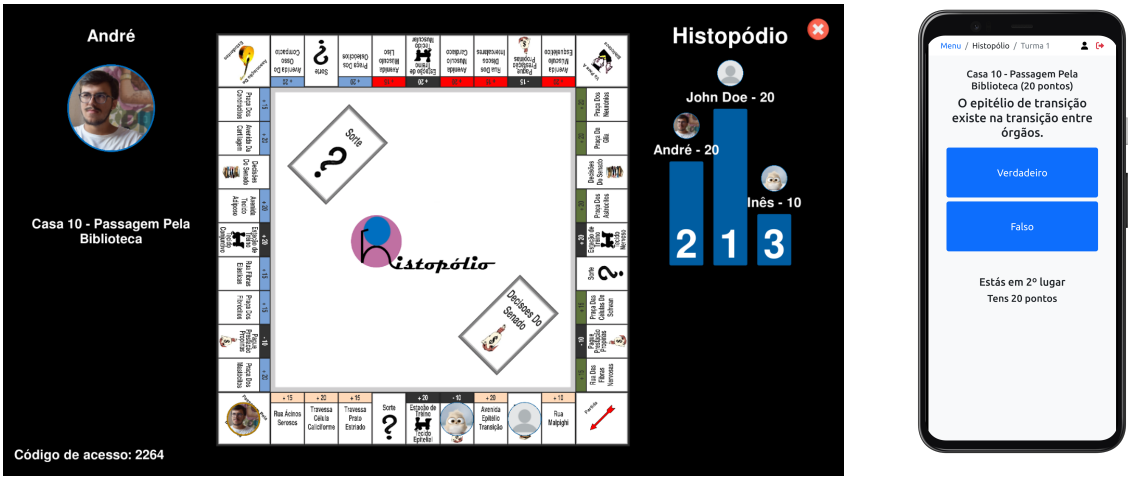


Figure 3.17: Board game displaying the board with the player in the Library tile (left) and Game Controller view from the Web application showing the question with the possible answers (right)

Figure 3.18: Demonstration of the Library tile

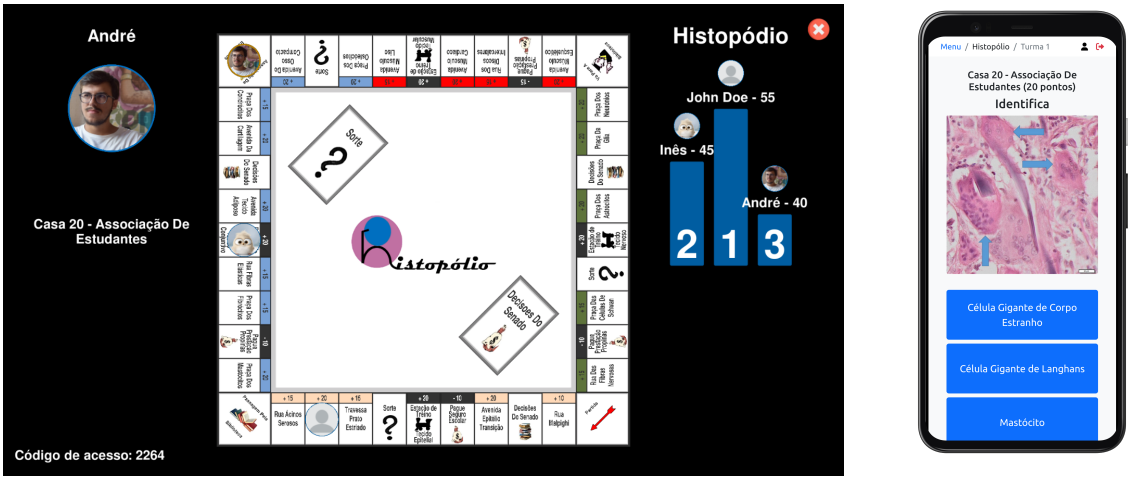


Figure 3.19: Board game displaying the board with the player in the Students Association tile (left) and Game Controller view from the Web application showing the question with the image and possible answers (right)

3.1.1.11 The Go To Library tile

There is only one tile of this type on the board, located at position 30. If a player arrives at this tile, they will have to answer one random multiple-choice question from any previous Pay tile to

Figure 3.20: Demonstration of the Students Association tile

avoid going back to the Library tile (Figure 3.21). If the player answers correctly, they will stay in the current tile.



Figure 3.21: Board game displaying the board with the player in a Go To Library tile (left) and Game Controller view from the Web application showing the question with the possible answers (right)

A QR code that links to a video demonstrating the Go To Library tile is shown in Figure 3.22.

Figure 3.22: Demonstration of the Go To Library tile

3.1.1.12 The Go tile

There is only one tile of this type on the board, located at position 0. This is the tile from which players start on the game board. Furthermore, when a player reaches this tile for the second time, they finish the board and receive the corresponding points (Figure 3.23).

A QR code that links to a video demonstrating the Go tile is shown in Figure 3.24.

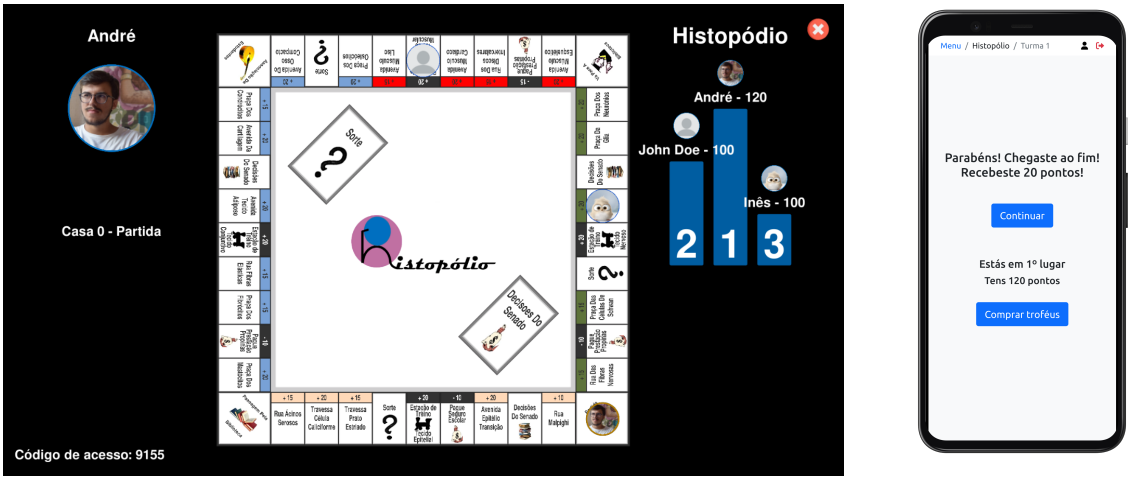


Figure 3.23: Board game displaying the board with the player in a Go tile (left) and Game Controller view from the Web application showing the received points and the button to continue (right)

Figure 3.24: Demonstration of the Go tile

3.1.1.13 Purchasing a badge

A player can buy badges on four occasions: before the start of the game session, before the start of their turn, before rolling the dice, and immediately before finishing their turn. To do so, the player must click on the buy badges button to access all the available badges, as shown in Figure 3.25.

If the player has the necessary points and decides to purchase a badge, an icon of the badge will appear next to the player in the board game, as shown in Figure 3.26, and the player will lose the points corresponding to the cost of the badge. However, from that moment onward, all the points the player receives from the board game will be multiplied by a specific multiplication factor given by the badge. If the player has multiple badges, the board game will only consider the highest multiplication factor when awarding the player with points.

3.1.1.14 Finishing the game board

As mentioned previously, when a player reaches the Go tile for the second time, they will finish the game board. From that moment onward, the player will stay in that tile for the rest of the game. Whenever it is their turn to play, instead of rolling the dice, the player will answer a random multiple-choice question from the entire board. If they answer correctly, they will earn the corresponding points from the Go tile.

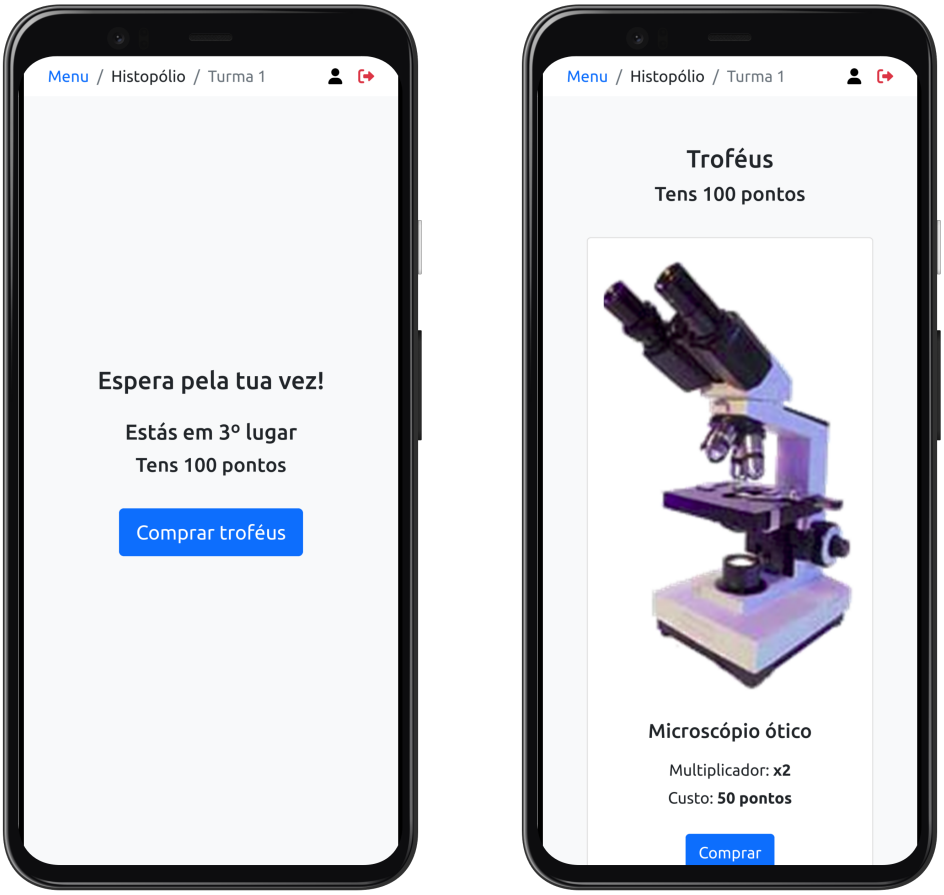


Figure 3.25: Game Controller view from the Web application before (left) and after (right) clicking the buy badges button

3.2 Definition of requirements

The solution should provide specific functionalities, described by the functional requirements, and include general software characteristics, defined by the non-functional requirements.

3.2.1 Functional requirements

The digital gaming platform should include the following functional requirements:

- Log in to an existing account.
- Create a new account.
- Log out of the account.
- Edit the profile.
- Select a game board to play.



Figure 3.26: Board game displaying the board and the player with their badge

  - Enter with an access code.

- Visualize personal points, ranks, and badges, from different game boards.
- Create a new game board.
- Edit an existing game board.
  - Edit tiles' names and points.
  - Add, edit, and delete questions.
  - Add, edit, and delete cards.
  - Add, edit, and delete badges.
- Visualize and edit players' points, positions, total questions answered, and correct answers, from different game boards and saves.
- Start a new game session.
  - Load a save.
  - Create a new save for the game board.
  - Remove inactive players from the session.

The actors and functional requirements are represented in the diagram displayed in Figure 3.27.

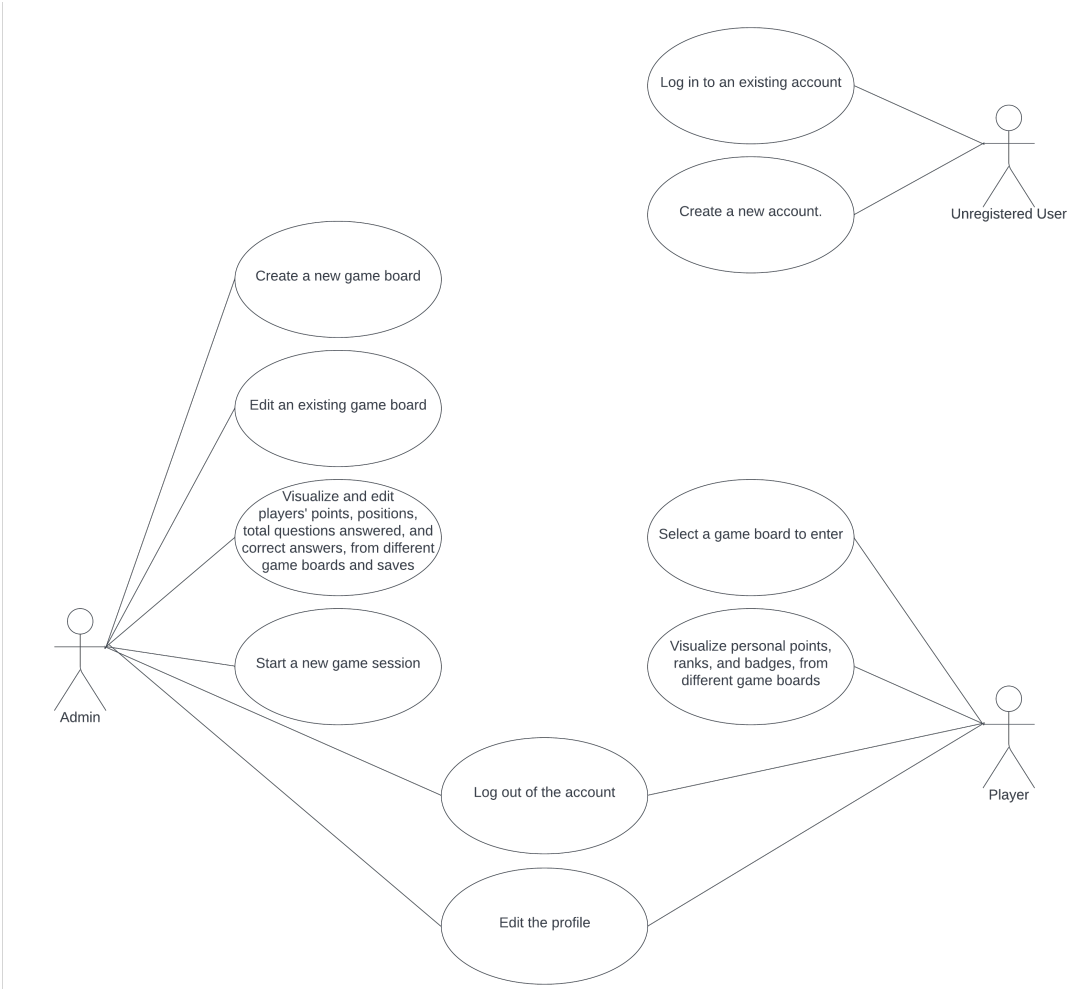


Figure 3.27: Diagram of the actors and functional requirements

3.2.2 Non-functional requirements

The digital gaming platform should have the following non-functional requirements:

- Have encrypted passwords.
- Require easy maintenance.
- Be scalable.
- Be accessible anytime and anywhere.
- Be easy to use and intuitive.
- The board game should be available for the main desktop operating systems.
- The Web application should be responsive and work on all devices, from smartphones to desktops.

The non-functional requirements can be observed in the diagram displayed in Figure 3.28.

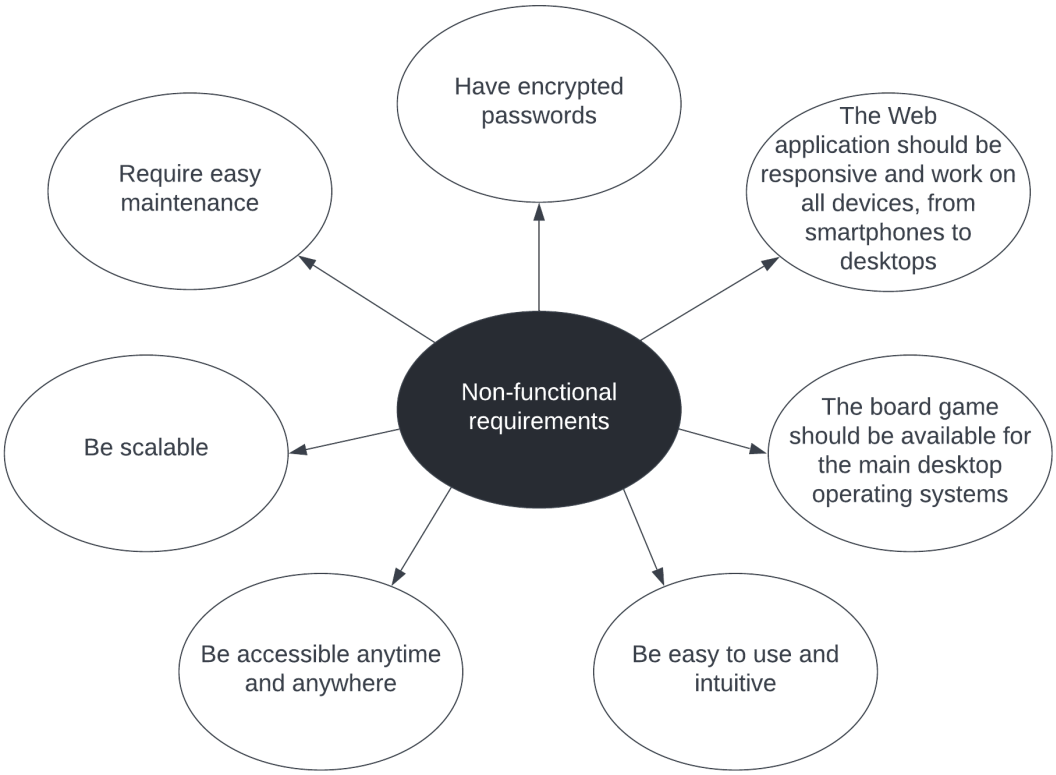


Figure 3.28: Diagram of the non-functional requirements

3.3 Software architecture

The solution comprises three modules: the board game, the backend, and the frontend (Figure 3.29). The backend and frontend are hosted on the Heroku platform, available at https://histopolio-app-backend.herokuapp.com/ and https://histopolio-app.herokuapp.com respectively (base URLs).

The backend is composed of a database, an API, and a WebSocket server. The database is responsible for storing all the users' data, including user credentials and scores, and all the boards' data (tiles, questions, and cards). The API and WebSocket server are connected to the database and are responsible for the communication with it. The backend also includes scripts that populate the database with an admin, a player, and the Histopólio board.

The frontend platform includes all the pages and routes available for the different users and can be divided into the following modules: Authentication, Admin Back-office, Player Area, and Game Controller. The first three modules use the backend's API routes to communicate with the database, gathering and sending the required information. Since the Game Controller module requires real-time notifications from the backend to inform the player of game updates and tasks, this module relies on WebSocket communication. This protocol allows for bidirectional messages over a single Transmission Control Protocol (TCP) connection between the frontend and the backend [37].

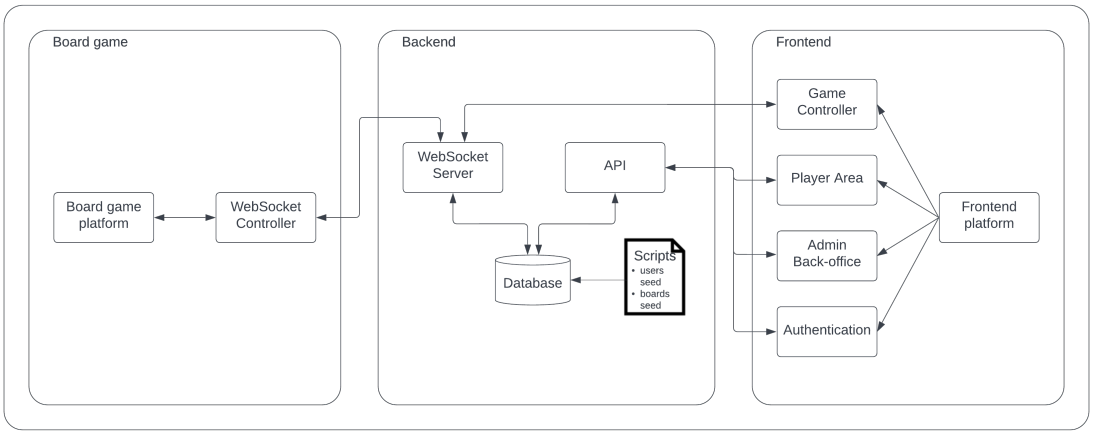


Figure 3.29: Architecture of the solution

The board game imposes the rules and mechanics of the game, besides displaying the board and players. This module also relies on WebSocket communication since it requires real-time updates from the backend, with information sent by the players. The WebSocket is also used to fetch and load board-related data from the backend and to send updates and other information.

Chapter 4

Solution implementation

In this chapter, an in-depth analysis of the solution implementation is made, starting with the folder/file structure description, followed by the specification of the database structure and seeders, and an analysis of the API and WebSocket communication. Finally, the user interface is presented and described.

4.1 Folder/file structure

Since the solution is divided into three modules, each has its own folder/file structure. The organization and meaning of the folders and files of these modules are described in the following sections.

4.1.1 Backend

The backend module contains all the files necessary to set up the database and its models, the API and its routes, the WebSocket server, and the management of active games and players. It also contains the scripts that populate the database. The module's folder/file structure can be consulted in Table 4.1.

Table 4.1: Folder/file description of the backend

Folder/file	**Description**
src/	Folder with all the source files required to run the backend.
src/controllers/	Folder that contains all the controllers required to process requests and messages.
src/controllers/auth-ctrl.js	File that processes authentication requests.
src/controllers/game-ctrl.js	File that manages all the active games and players and processes game-related requests and messages.
src/db/	Folder with all the scripts to populate the database.
src/models/	Folder that includes all the models for the database.

src/routes/	Folder that contains the routes of the API.
src/routes/auth.js	File that contains the routes of the API for authentication.
src/routes/game.js	File that contains the routes of the API to get game information and send updates.
index.js	File that contains the set-up of the backend server.
package.json	File that contains the project's dependencies and basic information.
package-lock.json	File that keeps track of the exact version of each installed package.
Procfile	File that contains the commands to run on the Heroku platform.

4.1.2 Frontend

The frontend module contains all the files necessary for user interaction with the Web application and its four modules: the Admin Back-office, the Authentication, the Player Area, and the Game Controller. This module's folder/file structure can be observed in Table 4.2.

Table 4.2: Folder/file description of the frontend

Folder/file	**Description**
public/	Folder with all images and the icons of the frontend.
src/	Folder that contains all the source code of the frontend.
src/app/	Folder that contains all components, pages, routes, and logic of the frontend.
src/app/api	Folder that contains all backend API routes.
src/app/components	Folder with components used by the frontend pages.
src/app/navigation	Folder that contains all the routes of the frontend.
src/app/pages	Folder that contains all individual pages of the frontend.
src/index.js	File responsible for rendering all the frontend.
src/Styles.css	File with all the custom CSS of the frontend.
package.json	File that contains the project's dependencies and basic information.
package-lock.json	File that keeps track of the exact version of each installed package.
react.config.js	File that includes the set-up of the environment variables.
README.md	File that includes a description of the project and how to set it up.

4.1.3 Board game

The board game module contains all the files needed for user interaction, displaying the game board and players, and imposing all the rules and game mechanics. This module's folder/file structure is described in Table 4.3.

Table 4.3: Folder/file description of the board game

Folder/file	**Description**
Assets/	Folder with all the assets required by the board game.
Assets/BeardyGridLayoutGroup/	Folder that contains the files of the package BeardyGrid-LayoutGroup used in the board game.
Assets/Fonts/	Folder that includes external fonts used in the board game.
Assets/NuGet/	Folder that contains the files of the package NuGet used in the board game.
Assets/Packages/	Folder with packages used in the board game.
Assets/Plugins/	Folder that contains the plugins used in the board game.
Assets/Prefabs/	Folder with all the prefabs created and used in the board game.
Assets/Scenes/	Folder that includes the scene used in the board game.
Assets/Scripts/	Folder that contains all the scripts that impose the rules and mechanics of the board game.
Assets/Sprites/	Folder that contains all the sprites used in the board game.
Packages/	Folder that includes the project's dependencies and basic information.
ProjectSettings/	Folder that defines the project's settings.

4.2 Database

The database used for the digital gaming platform is a MongoDB database, a simple, flexible, and highly scalable database. Mongoose, an Object Data Modeling library for MongoDB, was used to create the schemas and models that define the documents' structures of the database.

4.2.1 Structure

The database structure was designed taking into account all the needs and requests of the system, namely authentication, game boards, and saves.

The User model was created to keep track of registered users' information, including login credentials, names, and avatars. It also stores an admin token for admin users, necessary to access the Admin Back-office and admin functionalities.

The Board and Tile models contain information about the boards, while the Question, Card, and Badge models contain information regarding boards' questions, cards, and badges.

The Save and Player models connect the users with the game boards. A single game board can have multiple saves with multiple players. Meanwhile, a user can be included in one save per game board, each with a different personal score, position, and other player-related information.

A brief description of each model is provided in Table 4.4.

Table 4.4: Database's models

Model	**Description**
Badge	Contains information about the badge, including the name, multiplier, and cost.
Board	Contains information about the board, including the name and the description.
Card	Contains information about the card, including the type of the card and the points it gives.
Player	Contains information about the player, including the score, its position on the game board, and the number of questions answered.
Question	Contains information about the question, including the question itself and the possible answers.
Save	Contains information about the save, namely the board associated and the name of the save.
Tile	Contains information about the tile, including its type, name, and position on the game board.
User	Contains information about the user, including their credentials, name, and avatar.

The following tables provide a representation of the structure of each model:

- Badge model

Table 4.5: Badge model's structure

Field	**Type**	**Required**	**Description**
boardId	ObjectId	Yes	Id of the board associated with the badge.
name	String	Yes	Name of the badge.
multiplier	Number	Yes	Factor by which the points will be multiplied.
cost	Number	Yes	Cost in points of purchasing the badge.
image	String	Yes	URL of the badge's image.

- Board model

Table 4.6: Board model's structure

Field	**Type**	**Required**	**Description**
adminId	ObjectId	Yes	Id of the user that created the board.
name	String	Yes	Name of the game board.
description	String	No	Brief description of the game board.
image	String	Yes	URL of the board's logo.

- Card model

Table 4.7: Card model's structure

Field	**Type**	**Required**	**Description**
type	String	Yes	Type of the card (Deck or Train card).
subtype	String	No	Subtype of the card, if the card is of "Deck" type (Chance or Senate Decisions card).
boardId	ObjectId	No	Id of the board associated with the card (necessary for Deck cards).
tileId	ObjectId	No	Id of the tile associated with the card (necessary for Train cards).
points	Number	No	Number of points to receive immediately after drawing the card.
action	String	No	Type of action the player will do after drawing a Deck card (move a number of spaces or move to a specific tile).
actionValue	String	No	Complement for the "action" field with the number of spaces the player has to move or the tile position the player has to move into.
info	String	No	Description of the card.
content	String	No	URL of the content the player needs to watch after drawing a Train card.

- Player model

Table 4.8: Player model's structure

Field	**Type**	**Required**	**Description**

userId	ObjectId	Yes	Id of the user associated with the player.
saveId	ObjectId	Yes	Id of the save associated with the player.
points	Number	Yes	Player's score.
boardPosition	Number	Yes	Player's position on the game board.
turns	Number	Yes	Number of turns the player has played.
totalAnswers	Number	Yes	Total number of answers the player has given.
correctAnswers	Number	Yes	Number of correct answers the player has given.
badges	Array	Yes	Array of the ids of the badges the player has purchased.
finishedBoard	Boolean	Yes	The player has reached the Go tile and finished the board.

- Question model

Table 4.9: Question model's structure

Field	**Type**	**Required**	**Description**
tileId	ObjectId	Yes	Id of the tile associated with the question.
question	String	Yes	Question that will appear to the player.
image	String	No	URL of the image to be shown to the player, alongside the question.
answers	Array	Yes	Array of possible answers that will appear to the player.
correctAnswer	Number	Yes	Index that indicates the correct answer among the possible answers.

- Save model

Table 4.10: Save model's structure

Field	**Type**	**Required**	**Description**
boardId	ObjectId	Yes	Id of the board associated with the save.
name	String	Yes	Name of the save.

- Tile model

Table 4.11: Tile model's structure

Field	**Type**	**Required**	**Description**
boardId	ObjectId	Yes	Id of the board associated with the tile.
boardPosition	Number	Yes	Position of the tile on the game board.
name	String	Yes	Name of the tile.
type	String	Yes	Type of the tile (Go, Group property, Senate Decisions, Pay, Train station, Chance, Prison, Parking, or Go to prison tile).
position	Object	Yes	Spacial position of the tile (x, y, and z coordinates).
rotation	Object	Yes	Spacial rotation of the tile (x, y, z, and w values).
points	Number	No	Number of points the tile gives.
groupColor	Object	No	Color (r, g, b, and a values) of the tile's group section (only applicable for Group property tiles).

- User model

Table 4.12: User model's structure

Field	**Type**	**Required**	**Description**
name	String	Yes	Name of the user.
email	String	Yes	Email of the user.
password	String	Yes	Encrypted password of the user.
avatarUrl	String	Yes	URL of the avatar chosen by the user.
adminToken	String	No	Token that gives the user admin privileges.

4.2.2 Seeders

The root of the backend project contains a folder named "db" with several scripts that seed the database. These seeders are run automatically when the backend is run and are used for:

- Creating an admin user, if one does not exist.
- Creating a user without admin access, if one does not exist.
- Creating the Histopólio game board and all its questions, cards, and badges, if this board does not exist.

- Creating a save for the Histopólio game board, with a player associated, if one does not exist.

Besides creating and making the original Histopólio game board available to play, these seeders allow for testing every functionality the digital gaming platform has to offer.

4.3 API

The API is responsible for the communication with the database, providing the necessary endpoints for CRUD (Create, Read, Update, Delete) operations. With the API, the frontend module is able to gather all required information to present to the user. All requests and responses from the API endpoints are JSON encoded strings.

4.3.1 Authentication endpoints

The authentication endpoints allow users to register, log in, and edit their profiles. Once authenticated, the users will have access to different kinds of content, depending on their role (player or admin). The authentication endpoints are listed and described in Table 4.13.

Table 4.13: API's authentication endpoints

Endpoint	**HTTP**	**Description**
/api/auth/login	POST	Log in to an existing account.
/api/auth/signup	POST	Create a new account.
/api/auth/update_profile	PUT	Update the user's profile.

4.3.2 Game endpoints

The game endpoints provide all the game-related information necessary both for the Admin Backoffice and the Player Area. These endpoints also provide requests that allow users with admin access to update data related to the boards and players. The game endpoints are listed and described in Table 4.14.

Table 4.14: API's game endpoints

Endpoint	**HTTP**	**Description**
/api/game/data/boards	GET	Get all existing game boards.
/api/game/data/admin/:admin/boards/	GET	Get all game boards that an admin has created.
/api/game/data/board/:board	GET	Get all data regarding a game board, including tiles, questions, cards, and badges.
/api/game/data/board/new	POST	Create a new game board.
/api/game/data/board/update/	PUT	Update a board.

/api/game/data/board/tiles/update	PUT	Update all the tiles from a game board.
/api/game/data/:board/:tile/questions	GET	Get all questions from a tile of a board.
/api/game/data/question/:id	GET	Get all data from a question.
/api/game/data/questions/new	POST	Create a new question.
/api/game/data/question/update	PUT	Update a question.
/api/game/data/question/:id	DELETE	Delete a question.
/api/game/data/card/:id	GET	Get all data from a card.
/api/game/data/card/:id	DELETE	Delete a card.
/api/game/data/:board/deck_cards/:deck	GET	Get the board's cards from a deck (Senate Decisions or Chance).
/api/game/data/cards/deck/new	POST	Create a new Deck card.
/api/game/data/deck_card/update	PUT	Update a Deck card.
/api/game/data/:board/:tile/train_cards	GET	Get all Train cards from a tile of a board.
/api/game/data/cards/train_cards/new	POST	Create a new Train card.
/api/game/data/train_card/update	PUT	Update a Train card.
/api/game/data/:board/badges	GET	Get all the badges from a game board.
/api/game/data/badge/:id	GET	Get all data from a badge.
/api/game/data/badges/new	POST	Create a new badge.
/api/game/data/badge/update	PUT	Update a badge.
/api/game/data/badge/:id	DELETE	Delete a badge.
/api/game/data/:board/saves	GET	Get all saves from a game board.
/api/game/data/:board/saves/:save	GET	Get all players' data from a save.
/api/game/data/save/update	PUT	Update all players' data from a save.
/api/game/data/:board/players/:user_id	GET	Get the player data a user has with a board.
/api/game/data/players/new	POST	Create a new player for a user and register it in an active game board and save.

4.4 WebSocket communication

Since the board game is a real-time multiplayer game and since the players will be doing tasks from the Web application that have an immediate impact on the board game and require instant feedback, a real-time bidirectional form of communication is needed between the modules of the digital gaming platform. To solve this issue, the digital gaming platform uses WebSocket communication between the backend, the frontend's Game Controller, and the board game.

The messages sent between the modules are JSON encoded strings, with all containing a "type" field that identifies the type of the message. All modules use this field to organize and process received messages in different ways, depending on their type.

4.4.1 WebSocket server

The backend is responsible for initializing the WebSocket server and managing all the connections with the WebSocket clients. To manage the WebSocket clients, the backend has two maps, one for the frontend WebSockets and the other for the game board WebSockets. In the frontend WebSockets map, the key is the user id, and the value is the WebSocket object that is connected to the frontend where the user is authenticated. As for the game board WebSockets map, the key is also the user id, and the value is the WebSocket object that is connected to the board game where the user is authenticated. Whenever a message of type "identification" is received, the corresponding WebSocket object is added either to the frontend or board game WebSockets map, depending on the content of the identification message.

Upon receiving a message from a WebSocket connection, the backend is able to process the message based on its type and remaining content. Then, the backend is able to send the necessary messages to the right WebSocket clients, thanks to the WebSockets maps.

Moreover, Ping/Pong messages are used between the WebSocket server and all the WebSocket clients to verify which WebSocket connections are still alive. The backend sends a "ping" message every two seconds to all the WebSockets in the WebSockets maps and expects a "pong" message from each one before sending the next "ping" message. If a "pong" message is not received in that time interval, the backend closes the corresponding WebSocket connection and removes the WebSocket object from the map. On the one hand, if the closed WebSocket connection was a connection to the frontend, the backend will send a "remove player" message to the corresponding board game WebSocket. On the other hand, if the closed WebSocket connection was a connection to the board game, the backend will send a "game status" message to all the corresponding frontend WebSockets, which will allow the frontend to update the state of the Game Controller view.

4.4.2 WebSocket clients

Both the board game and the frontend modules can initiate a WebSocket connection with the WebSocket server. For the frontend, this connection is only initiated on the Game Controller view, whereas, in the board game, the connection is initiated immediately when the game is started. Each module processes different types of messages received in different ways and can only send messages to the backend.

In the frontend module, the messages received from the backend directly impact the state of the Game Controller view and what is being shown to the user. Different messages can update the view to show different elements, such as the dice or a question. Additionally, the frontend can send different types of messages to the backend, based on the user action, such as the number the user rolled on the dice or the answer the user selected.

As for the board game module, the messages received from the backend, depending on the type, allow for the board game to display the desired board and all the necessary components and influence the players' positions and scores. Moreover, the board game can send different types of messages to the backend, following the flow of the game, such as a question or a task for the user.

4.4.3 Fault tolerance

Since the digital gaming platform uses real-time communication between all the modules when a game session is active, each module should have a constant internet connection, which may not always be the case. To prevent the game session from becoming stuck or presenting other errors, the following fault-tolerance measures were initially implemented:

- Before sending each message, the backend checks if the WebSocket connection is still open, to avoid causing errors.
- Before sending each message, the board game checks if the WebSocket connection is still open. If not, it will first create a new WebSocket connection with the backend before sending the desired message.
- The backend will wait 6 seconds after the WebSocket connection with the board game is lost, before considering the game session indeed ended and clearing any related data.
- When the current player's frontend loses internet connection, eventually, the backend will realize, through the Ping/Pong messages system, that the player has left. The backend will then send a "remove player" message to the corresponding board game. Then, the board game will interpret this message and display a warning text and a button to remove the current player.
- When the current player's frontend is able once again to create a new WebSocket connection with the backend, the backend will send a "join message" message to the board game. Then the board game will stop displaying the warning text and the button to remove the current player.

After testing the digital gaming platform with one of the AHE I classes for the first time, some unexpected connection-related problems still occurred, which required the gaming session to be restarted on several occasions. In fact, the room where the students used the digital gaming platform had a poor internet reception, so some unforeseen problems were encountered. To further mitigate these problems, the following fault-tolerance measures were implemented or improved:

- If the WebSocket connection with a board game is not open, the backend pushes the messages directed to that board game to a queue. When the WebSocket connection with that board game is reestablished, the backend will send the queue's messages to the board game in their original order. The lack of this measure was the main reason why the game session got stuck on several occasions while testing with one of the classes, since some answers given by the players on the frontend were lost due to the WebSocket connection with the board game not being open. This message queue system fixes that problem.
- The time the backend will wait after the WebSocket connection with the board game is lost, before considering the game session indeed ended was increased to 60 seconds.

- The board game checks if the WebSocket connection with the backend is open on every frame. If not, it will create a new WebSocket connection.
- While the user is on the Game Controller view, the frontend will check every second if the WebSocket connection with the backend is open. If not, it will create a new WebSocket connection.

After all these measures were implemented, the subsequent game sessions with the AHE I classes did not face any connection problems, despite the still poor internet reception in the room.

4.5 User interface

In this section, the digital gaming platform is analyzed from the user's point of view. Since the gaming platform is composed of a Web application and a board game, each of these components presents a different graphic interface that will be described in this section.

4.5.1 Web application

The Web application's interface was developed using the React framework, combined with HTML, CSS, and Javascript elements. It was designed to be as simple and intuitive as possible, providing easy navigation and responsiveness to any screen size (desktop or mobile).

A navbar is present in top of all views, with the exception of the Login view (4.5.1.1) and the Signup view (4.5.1.2). This navbar contains, on the left-hand side, the view's breadcrumbs that allow the user to navigate back to previous views. Additionally, the navbar also contains on the right-hand side a button to redirect the user to the Edit Profile view (4.5.1.4) and a button to log out.

4.5.1.1 Login view

/login

When a user visits the Web application, they are first presented with the Login view, containing the login form. If the user already has an account, they can enter their account by filling the form with their credentials (email and password) and clicking the "Login" button. If the form is filled correctly, the user will gain access to either the Player Menu view (4.5.1.3) or the Admin Back-office Menu (4.5.1.8), depending on the user's role. If the user does not have an account, they can click on "Register here" option to change to the Signup view (4.5.1.2).

Every input field from this form is mandatory and has validations with custom error feedback.

4.5.1.2 Signup view

/signup

In this view, the Signup form is shown to the user. To create an account, the user must fill out this form and click on the button below. If the form is filled correctly, an account with no admin

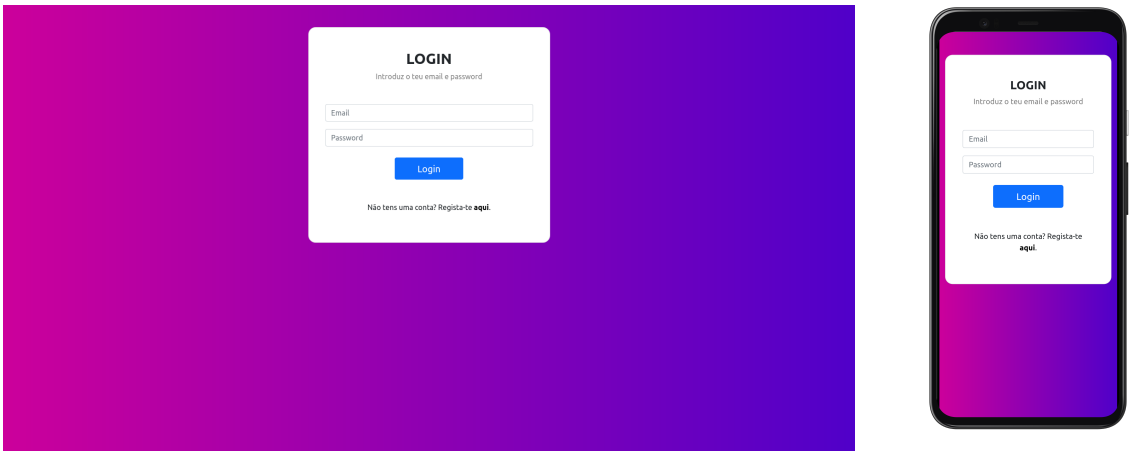


Figure 4.1: Login view (desktop and mobile)

access will be created, and the user will be redirected to the Player Menu view (4.5.1.3). If the user already has an account, they can click on "Log in here" option to change to the Login view (4.5.1.1).

This form contains validations with custom error feedback for every input field. Every input field of the form is mandatory, except for the "Link of the Avatar" field.

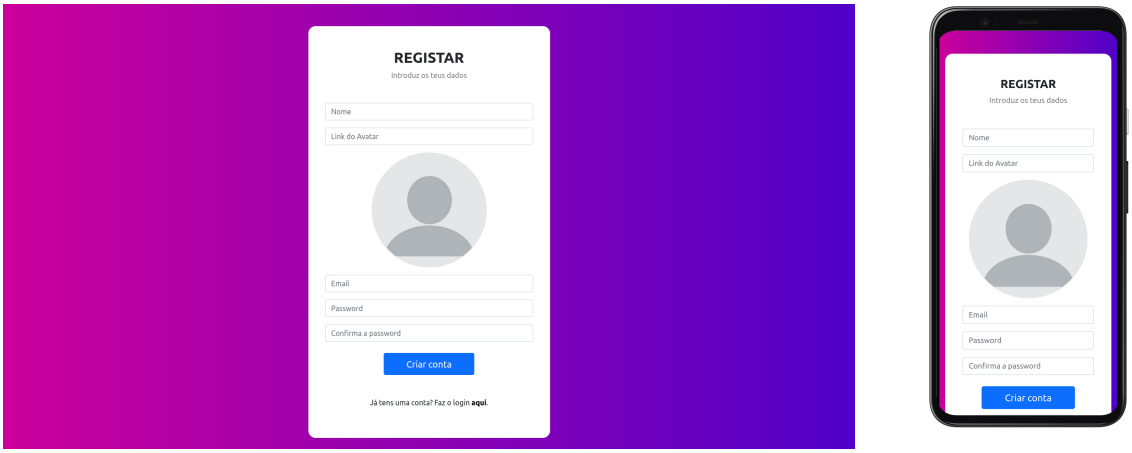


Figure 4.2: Signup view (desktop and mobile)

4.5.1.3 Player Menu view

/

In this view, all the available game boards the user can choose to play are listed. The user can select the board they want to play by clicking the "Play" button of the chosen game board. After clicking the button, if the user has already played on the selected game board before, they will be taken directly to the Game Controller view (4.5.1.7). Otherwise, the user will be redirected to the Enter Game Session view (4.5.1.6).

Below the available boards, a button that takes the user to the Rules view (4.5.1.5) is displayed.

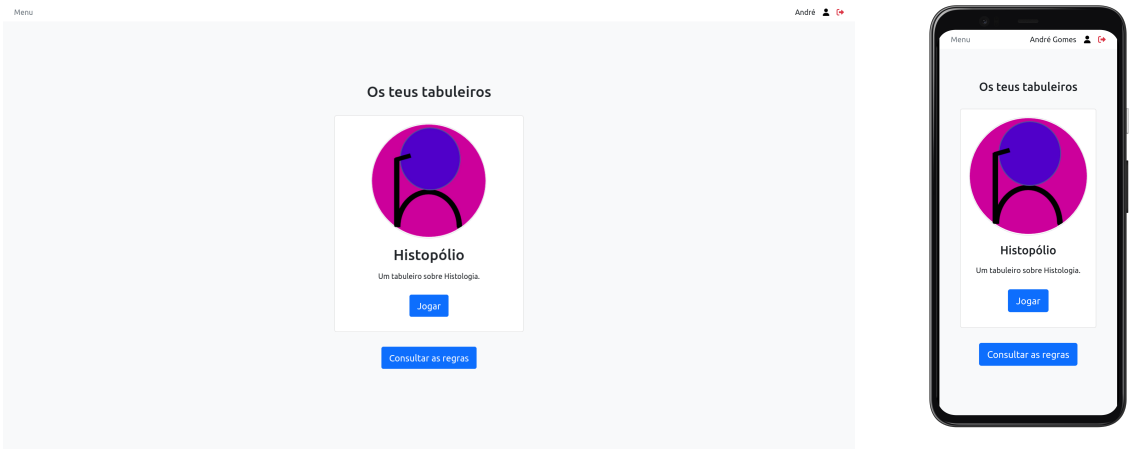


Figure 4.3: Player Menu view (desktop and mobile)

4.5.1.4 Edit Profile view

/profile/edit

This view is similar to the Signup view, as it presents an identical form without the password fields. The form is filled with the user's information, and all the fields can be edited as the user wishes. To save the changes, the user must click the button that is presented below the form. By clicking this button, the user will also be redirected to the Player Menu view (4.5.1.3) or the Admin Back-office view (4.5.1.8).

This form contains validations with custom error feedback for every input field. Every input field of the form is mandatory, except for the "Link of the Avatar" field.

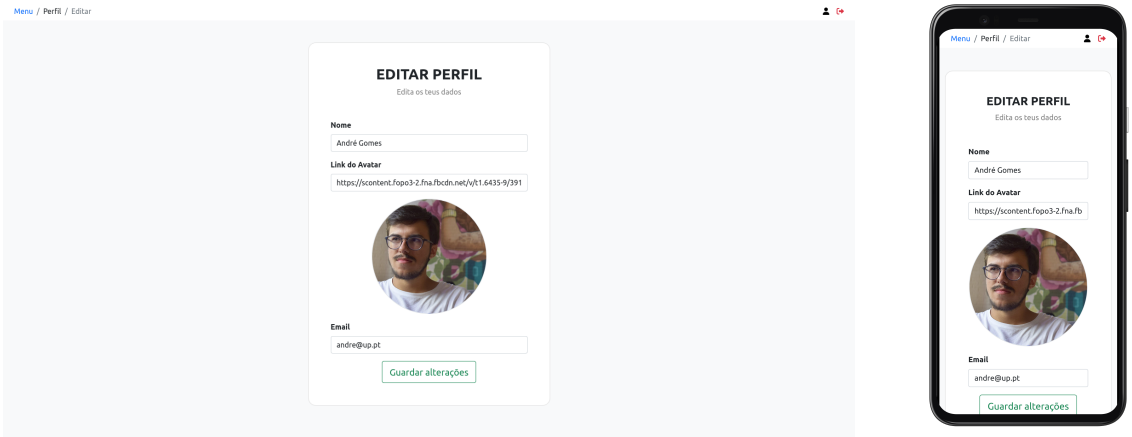


Figure 4.4: Edit Profile view (desktop and mobile)

4.5.1.5 Rules view

/rules

In this view, a summarized explanation of the game's rules is presented to the user. It is described how the turns system works, how a player's turn unfolds, and how the badges work.



Figure 4.5: Rules view (desktop and mobile) (full view in Appendix B)

4.5.1.6 Enter Game Session view

/:board/enter

In this view, the user is presented with the Enter Game form. This form consists of only one input field for the access code. Once entering the access code displayed in the board game and clicking the button below, a new player will be added to the active save of the game session, and the user will be taken to the Game Controller view (4.5.1.7).

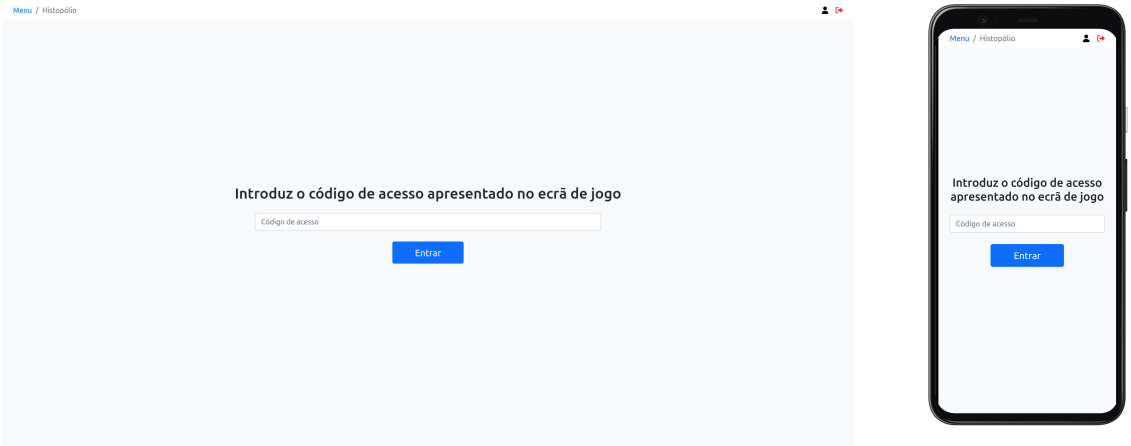


Figure 4.6: Enter Game Session view (desktop and mobile)

4.5.1.7 Game Controller view

/:board/play

In this view, the user is presented with all the different elements needed to interact with the board game. All the distinct elements the view can show are the following:

- The "wait for the game to start" message and the "buy badges" button.
- The "wait for your turn" message and the "buy badges" button.
- The dice and the "buy badges" button.
- A question and all its possible answers.
- The continue button with a feedback message.
- The "view content" button.
- The continue button with a feedback message and the "buy badges" button.

All these elements appear in different stages of a game session and a player's turn, and are explained in greater detail in section 3.1.1 and presented in Appendix B.

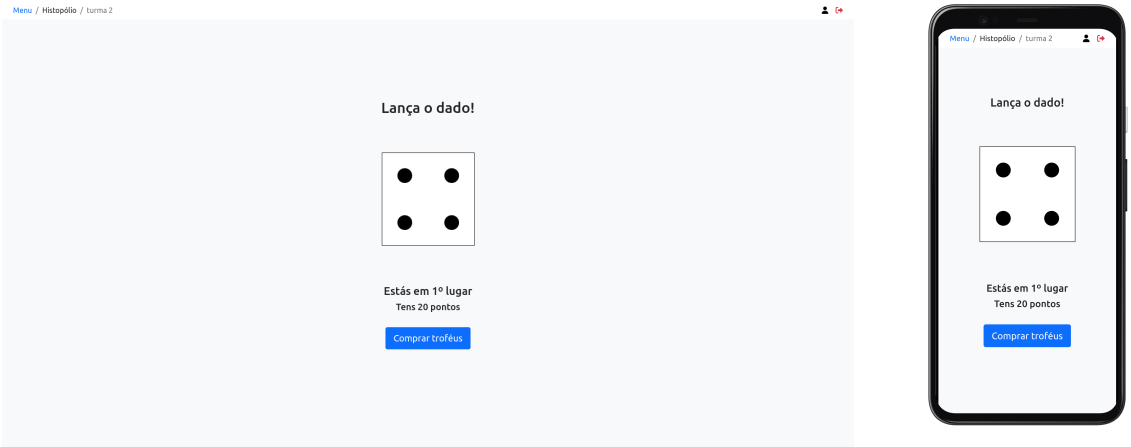


Figure 4.7: Game Controller view (desktop and mobile)

4.5.1.8 Admin Back-office Menu view

/admin

This view is only available for users with admin access. Similar to the Player Menu view (4.5.1.3), this view shows all the game boards created by the authenticated user. By clicking the button of one of the displayed boards, the user will be redirected to the Board view (4.5.1.10), where more details are presented. Below the game boards, a button that takes the user to the New Board view (4.5.1.9) is presented.

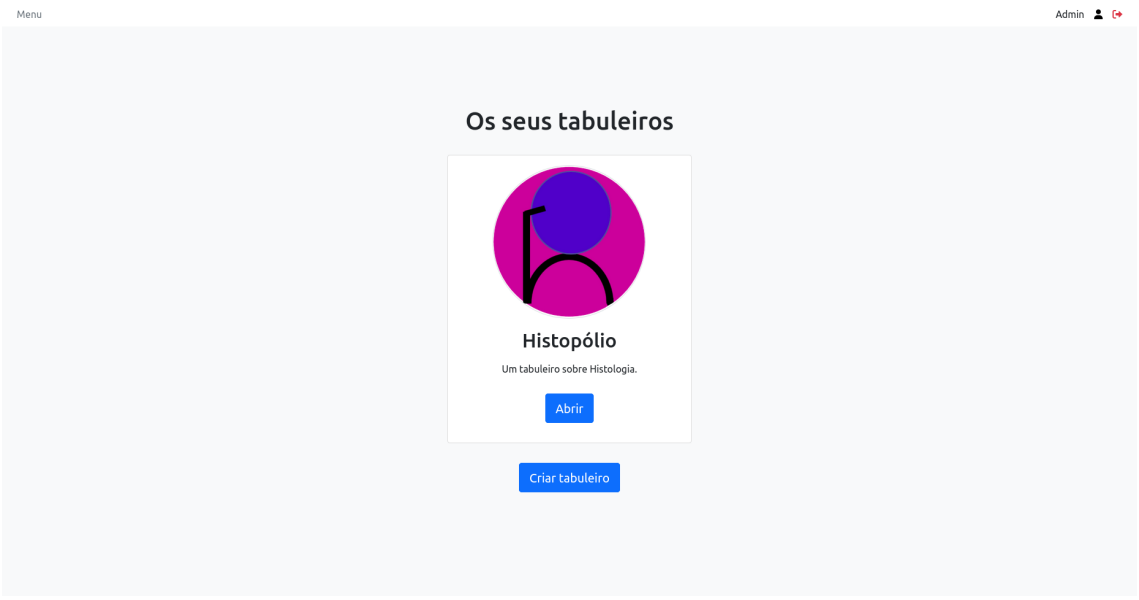


Figure 4.8: Admin Back-office Menu view

4.5.1.9 New Board view

/admin/boards/new

In this view, the Board form is shown to the user. The user is able to create a board with a given name, description, and image. To create a board, the user must fill out this form and click on the button below. If the form is filled correctly, a new board will be added to the digital gaming platform, and the user will be redirected to the Admin Back-office Menu view (4.5.1.8).

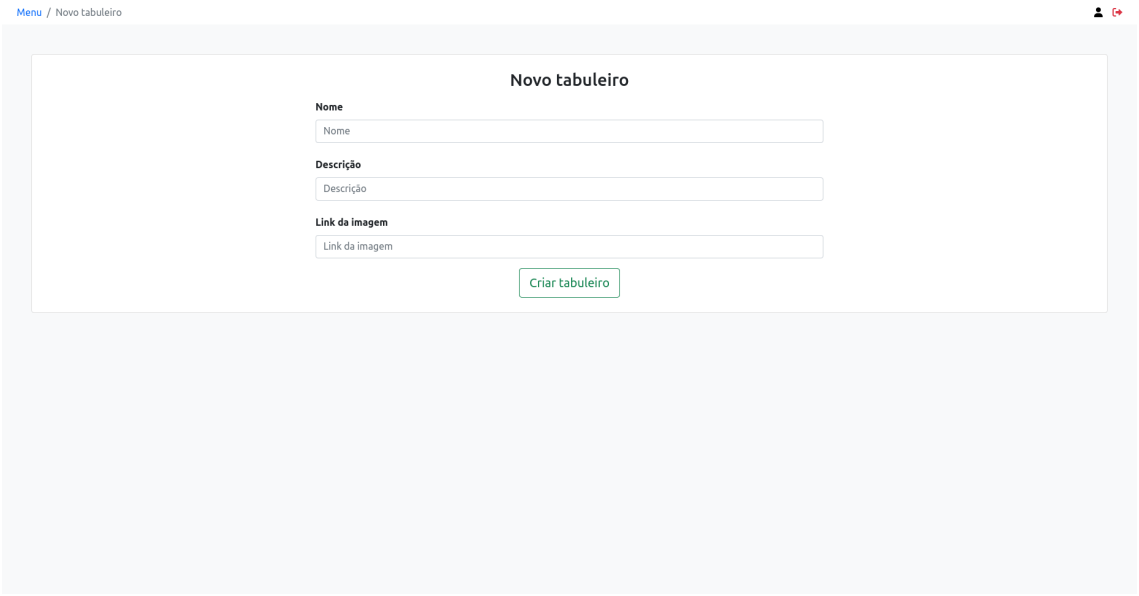


Figure 4.9: New Board view

4.5.1.10 Board view

/admin/:board

This view presents to the user a list of all the saves a board has. By clicking one of the saves, the user will be redirected to the Edit Save view (4.5.1.11). Below the list of saves, a button is shown that allows the user to go to the Edit Board view (4.5.1.12).

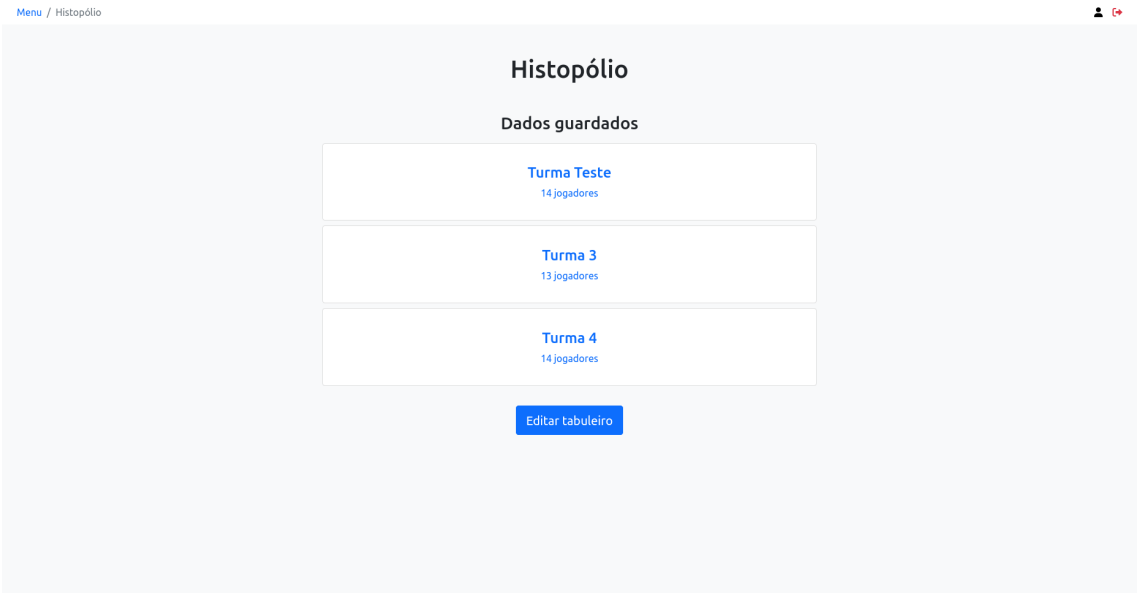


Figure 4.10: Board view

4.5.1.11 Edit Save view

/admin/:board/:save

In this view, the user is shown a table with all the players of a particular save of a board. For each player, it is displayed its name, email, board position, number of turns, score, number of answers, number of correct answers, and percentage of correct answers, which is calculated automatically. The user can edit any player's board position, number of turns, score, number of answers, and number of correct answers. To save the changes, the user must click on the button below the table.

4.5.1.12 Edit Board view

/admin/:board/edit

This view is divided into three sections: the tiles section, the badges section, and the other settings section.

The tiles section contains a table with information about all tiles of a board and their type, name, points, and content. The user can edit any tile's name and, depending on the type of tile, its points. The content column gives information about the number of questions or cards a tile



Figure 4.11: Edit Save view (taken from a real scenario with practical class 3)

has and a link to see all the questions or cards in more detail. By clicking the link, the user will be redirected to the Edit Questions view (4.5.1.13), Edit Deck Cards view(4.5.1.16), or Edit Train Cards view (4.5.1.19), depending on the type of the tile. To save any changes made to the tiles, the user must click on the button shown below the tiles table.

The badges section appears below the tiles section and presents a table with information about all badges of a board and their name, multiplier, and cost. Every table row contains a button that redirects the user to the Edit Badge view (4.5.1.23) and another button to delete the badge. Below this table, a button that takes the user to the New Badge view (4.5.1.22) is shown.

Finally, the other settings section is presented below the badges section. This section contains the Board form filled with the board data. The user can edit any of the form's fields and save the changes by clicking on the button below. If the form is filled correctly, the board will be successfully updated.

4.5.1.13 Edit Questions view

/admin/:board/:tile/questions

In this view, a table with all the questions of a tile and their correct answer is shown to the user. Every table row also contains a button to change to the Edit Question view (4.5.1.15) and a button to delete the question. Below this table, a button that redirects the user to the New Question view (4.5.1.14) is shown.

4.5.1.14 New Question view

/admin/:board/:tile/questions/new

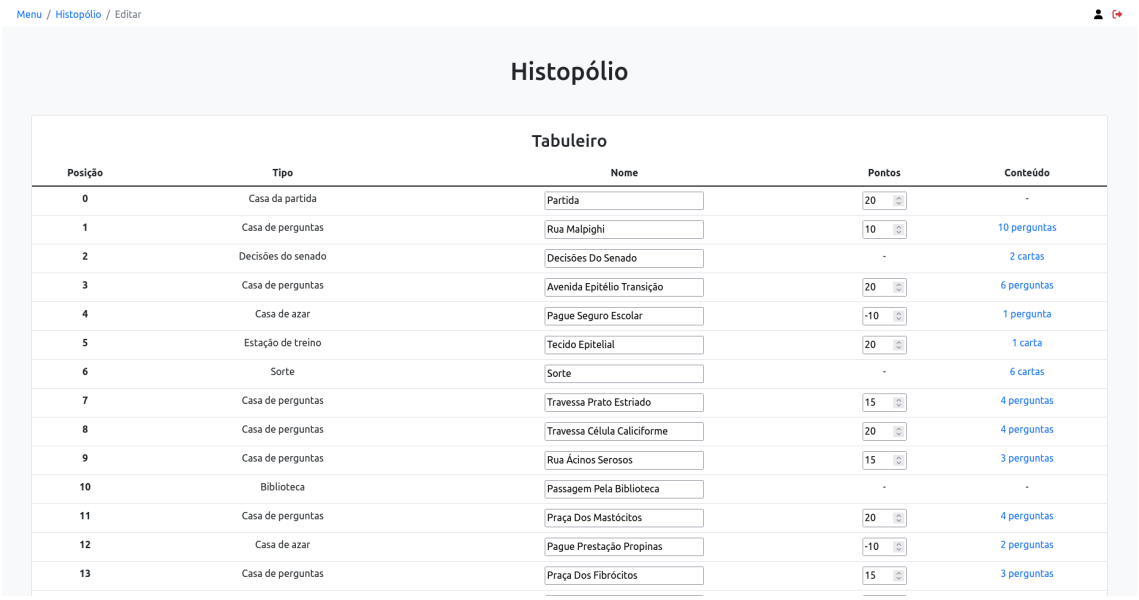


Figure 4.12: Edit Board view (full view in Appendix B)

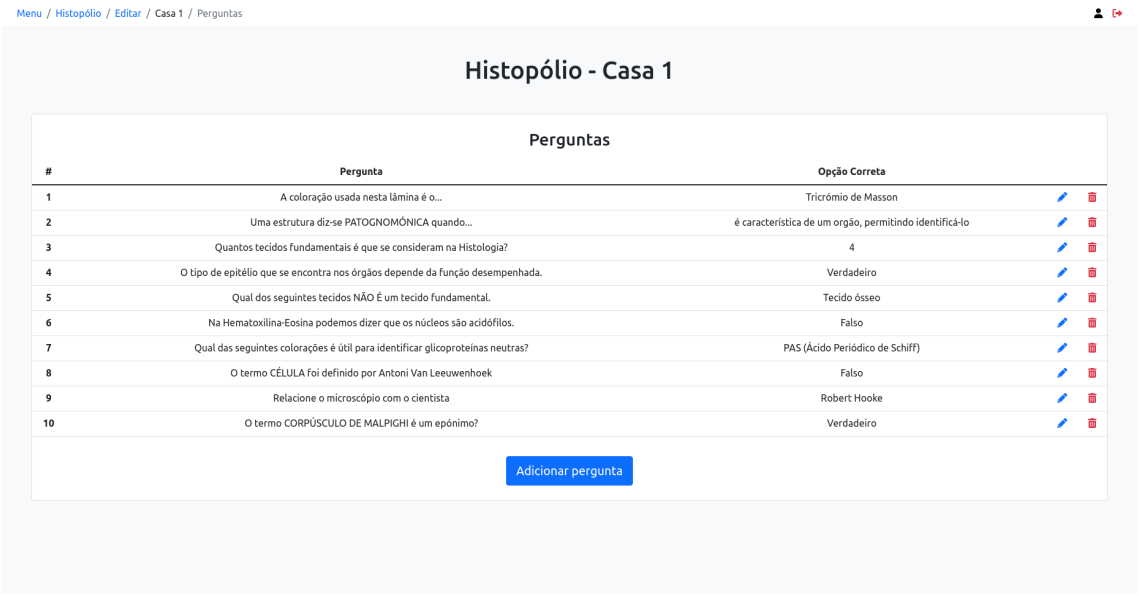


Figure 4.13: Edit Questions view

In this view, the Question form is shown to the user. The user is able to create a question with an image and add up to ten possible answers. To create a question, the user must fill out this form and click on the button below. If the form is filled correctly, a new question will be added to the tile, and the user will be redirected to the Edit Questions view (4.5.1.13).

4.5.1.15 Edit Question view

/admin/:board/:tile/question/:id/edit

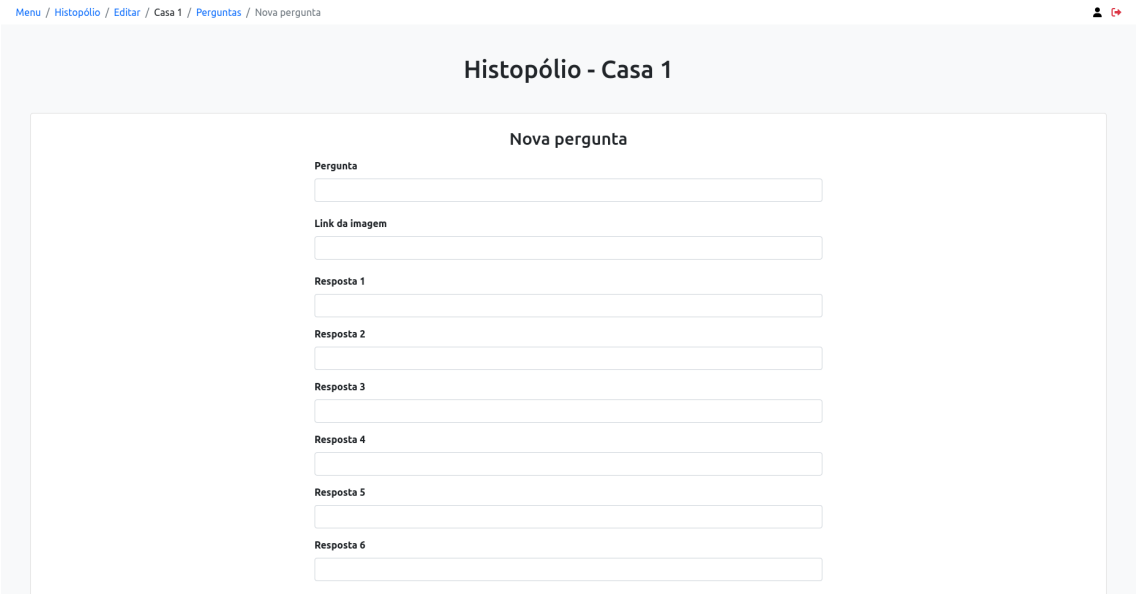


Figure 4.14: New Question view

In this view, the Question form filled with a question's data is shown to the user. The user can edit any of the form's fields and click on the button below to save the changes. If the form is filled correctly, the question will be updated, and the user will be redirected to the Edit Questions view (4.5.1.13).

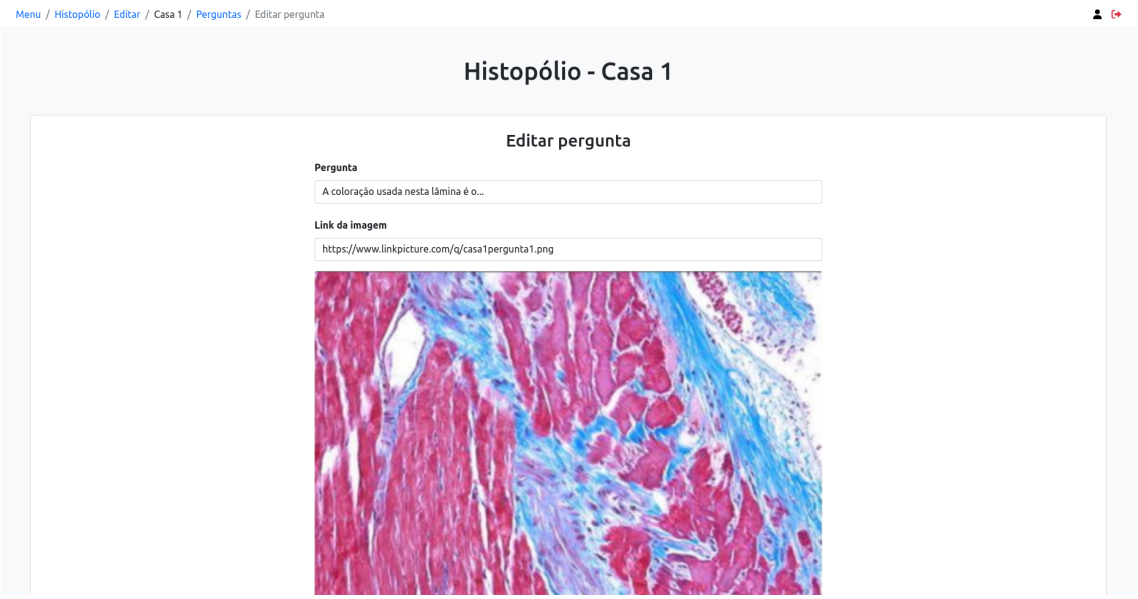


Figure 4.15: Edit Question view

4.5.1.16 Edit Deck Cards view

/admin/:board/deck_cards/:deck

In this view, a table with all the cards of a board's deck (Senate Decisions or Chance) is presented to the user. Each table row also contains the card's description, immediate points, and action, as well as a button that redirects the user to the Edit Deck Card view (4.5.1.18) and another button to delete the card. Below this table, a button to navigate the user to the New Deck Card view (4.5.1.17) is shown.

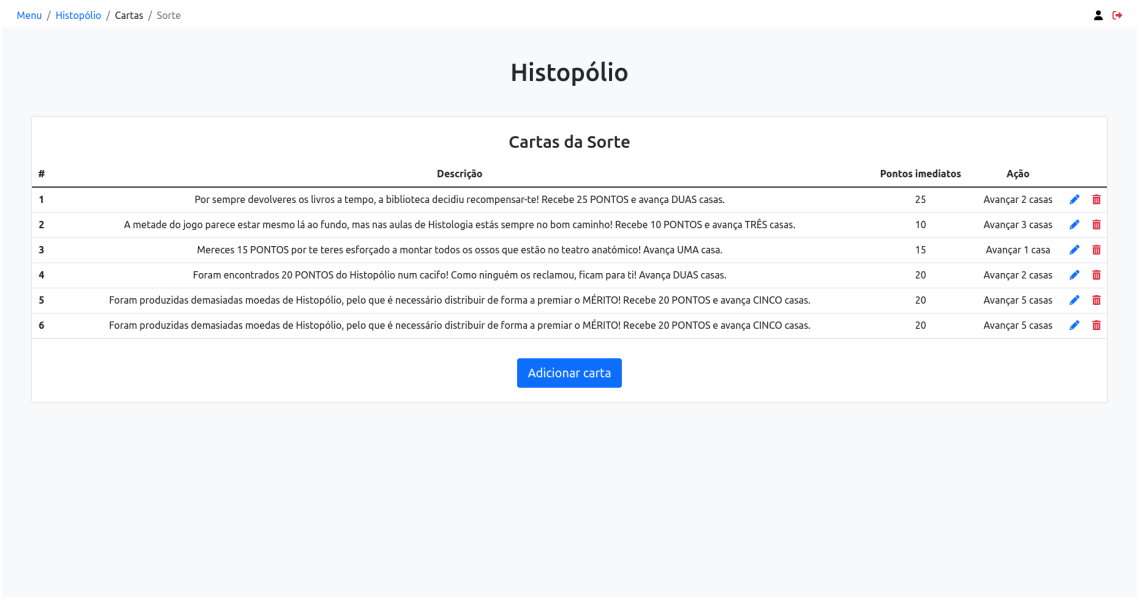


Figure 4.16: Edit Deck Cards view

4.5.1.17 New Deck Card view

/admin/:board/cards/deck/new

In this view, the Deck Card form is presented to the user. The user can select the deck of the card, add a description, and specify the number of points and the action of the card. To add a new Deck card, the user must fill out this form and click on the button below. If the form is filled correctly, a new Deck card will be added to the board, and the user will be redirected to the Edit Deck Cards view (4.5.1.16).

4.5.1.18 Edit Deck Card view

/admin/:board/cards/deck/:id/edit

In this view, the Deck Card form filled with a Deck card's data is shown to the user. The user can edit any of the form's fields and save the changes by clicking on the button below. If the form is filled correctly, the card will be successfully updated, and the user will be redirected to the Edit Deck Cards view (4.5.1.16).

4.5.1.19 Edit Train Cards view

/admin/:board/:tile/train_cards

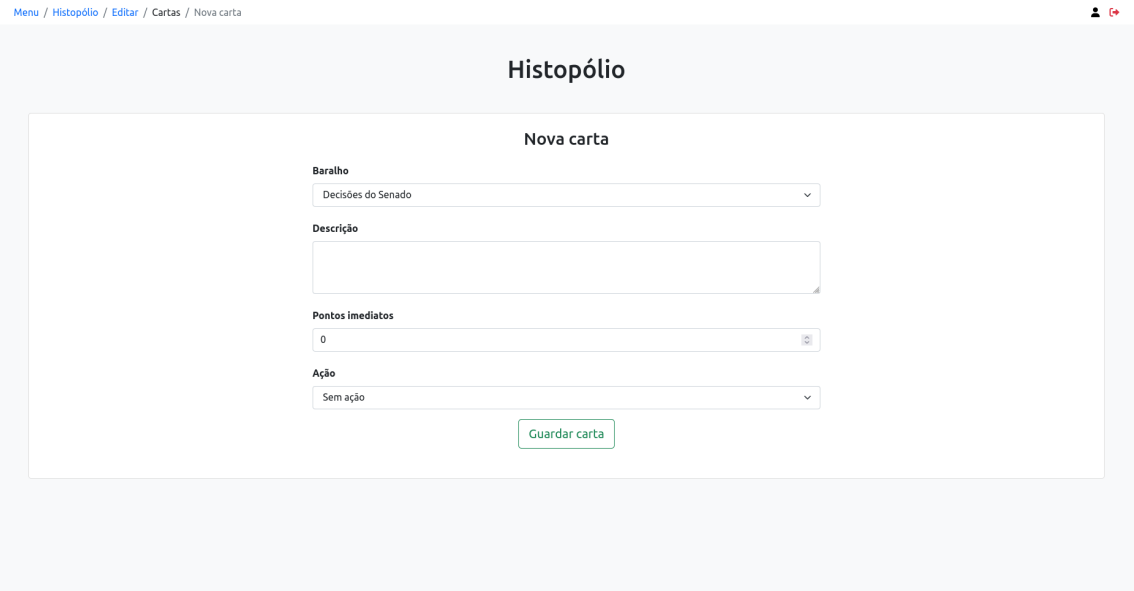


Figure 4.17: New Deck Card view

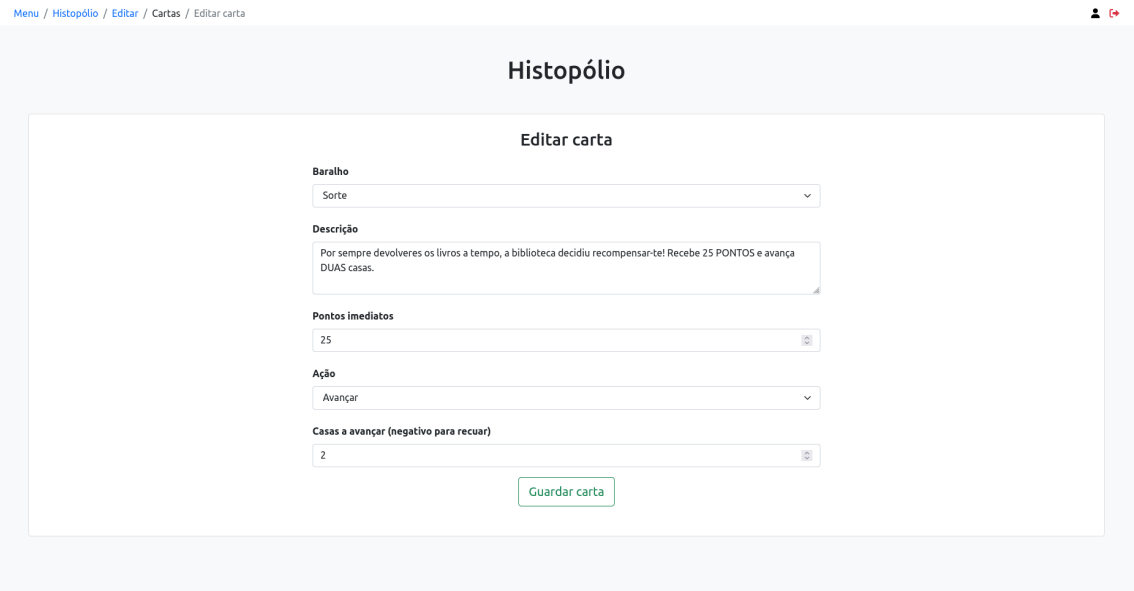


Figure 4.18: Edit Deck Card view

In this view, it is presented to the user a table with all the cards of a Train Station tile and their description and content. Additionally, all the rows have a button that takes the user to the Edit Train Card view (4.5.1.21) and another button to delete the card. Below this table, a button that redirects the user to the New Train Card view (4.5.1.20) is shown.

4.5.1.20 New Train Card view

/admin/:board/:tile/train_cards/new



Figure 4.19: Edit Train Cards view

In this view, the user is presented with the Train Card form. The user can write a description and provide a link for the card's content. To create a new Train card, the user must fill out this form and click the button below. If the form is filled correctly, a new Train card will be added to the tile, and the user will be taken back to the Edit Train Cards view (4.5.1.19).

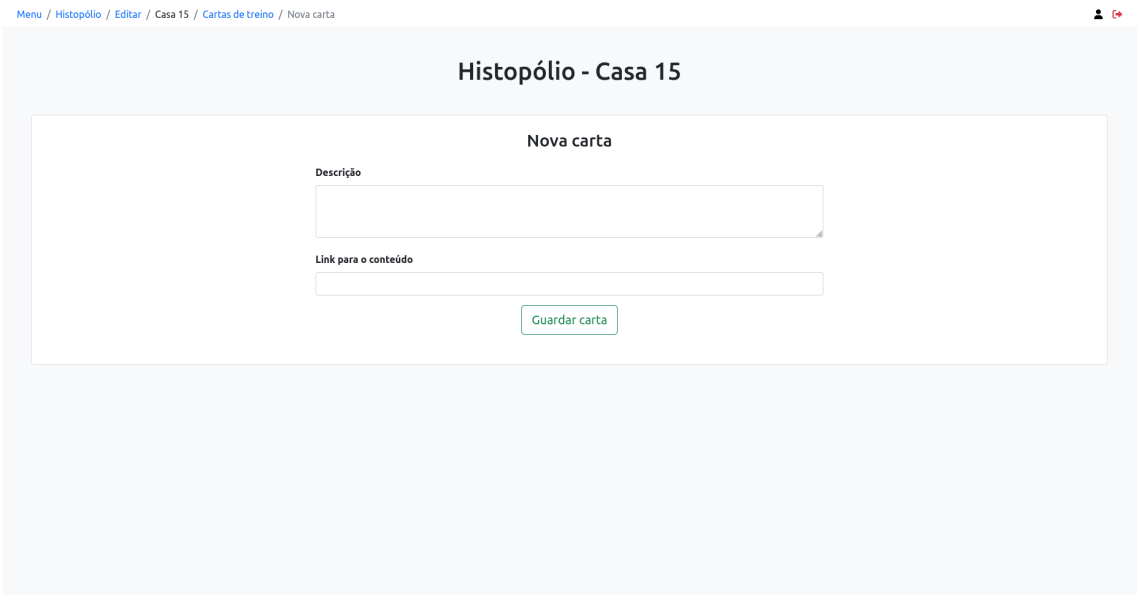


Figure 4.20: New Train Card view

4.5.1.21 Edit Train Card view

/admin/:board/:tile/train_cards/:id/edit

In this view, the Train Card form filled with a Train card's data is shown to the user. The user is able to edit any of the form's fields and save the changes by clicking on the button below. If the form is filled correctly, the card will be successfully updated, and the user will be redirected to the Edit Train Cards view (4.5.1.19).

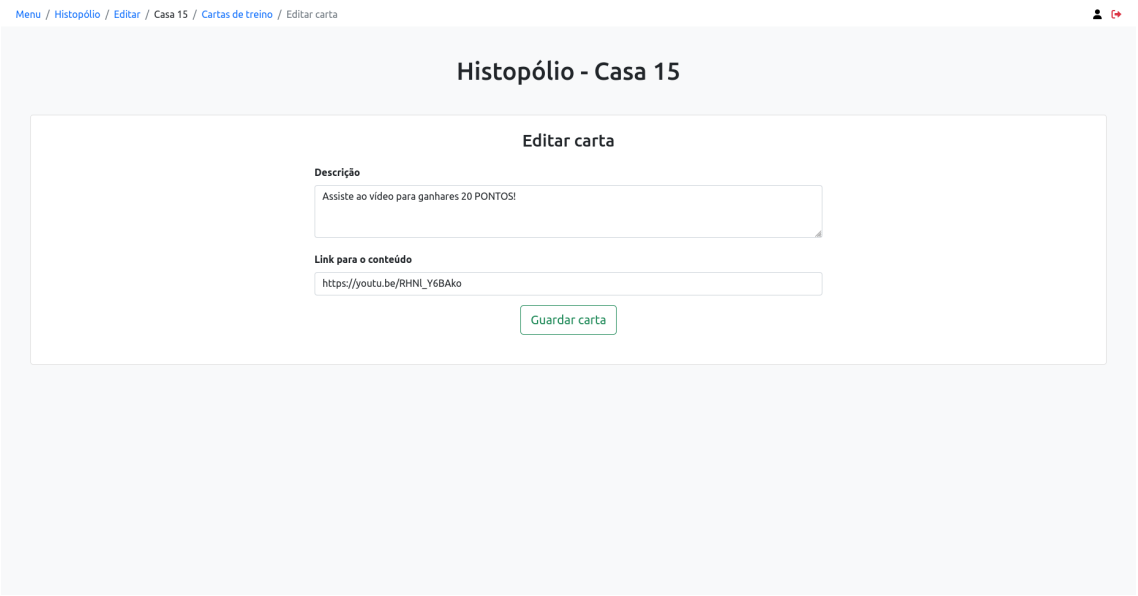


Figure 4.21: Edit Train Card view

4.5.1.22 New Badge view

/admin/:board/badges/new

In this view, the Badge form is shown to the user. The user can write the badge's name, add a link to an image, and specify the badge's multiplier and cost. To add a new badge, the user must fill out this form and click the button below. If the form is filled correctly, a new badge will be created and added to the board, and the user will be redirected to the Edit Board view (4.5.1.12).

4.5.1.23 Edit Badge view

/admin/:board/badge/:id/edit

In this view, the Badge form filled with a badge's data is presented to the user. The user is able to edit any of the form's fields and save the changes by clicking on the button below the form. If the form is filled correctly, the badge will be updated, and the user will be taken back to the Edit Board view (4.5.1.12).

4.5.2 Board game

Like the game itself, the board game's interface was developed using the Unity engine. It was designed to be as simple and intuitive as possible and provide easy navigation using buttons.

A button to close the game is presented in the top-right corner of all views.

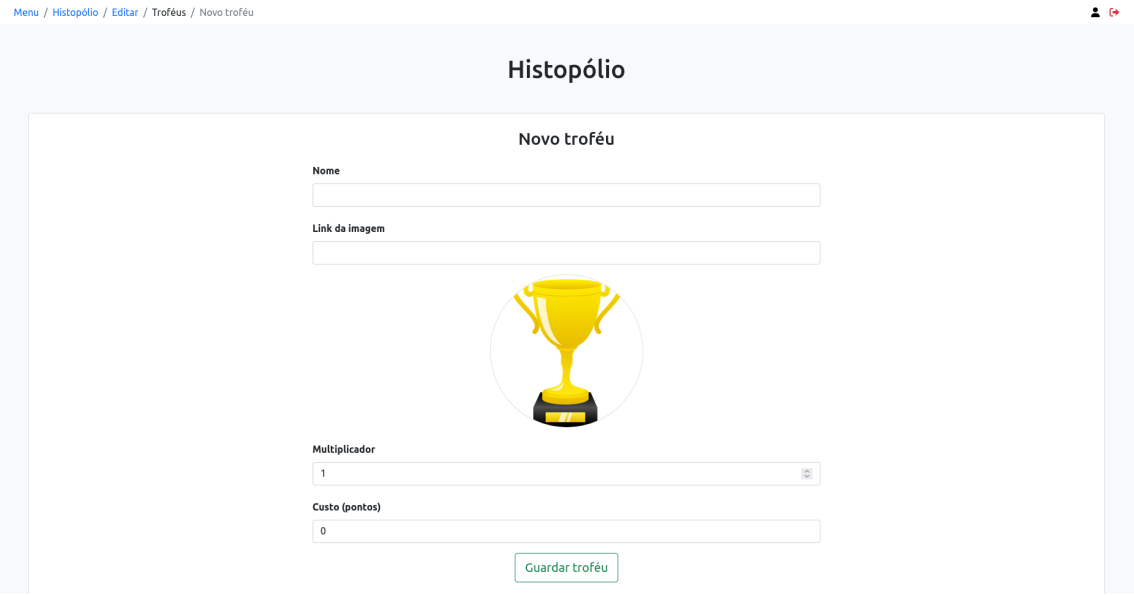


Figure 4.22: New Badge view

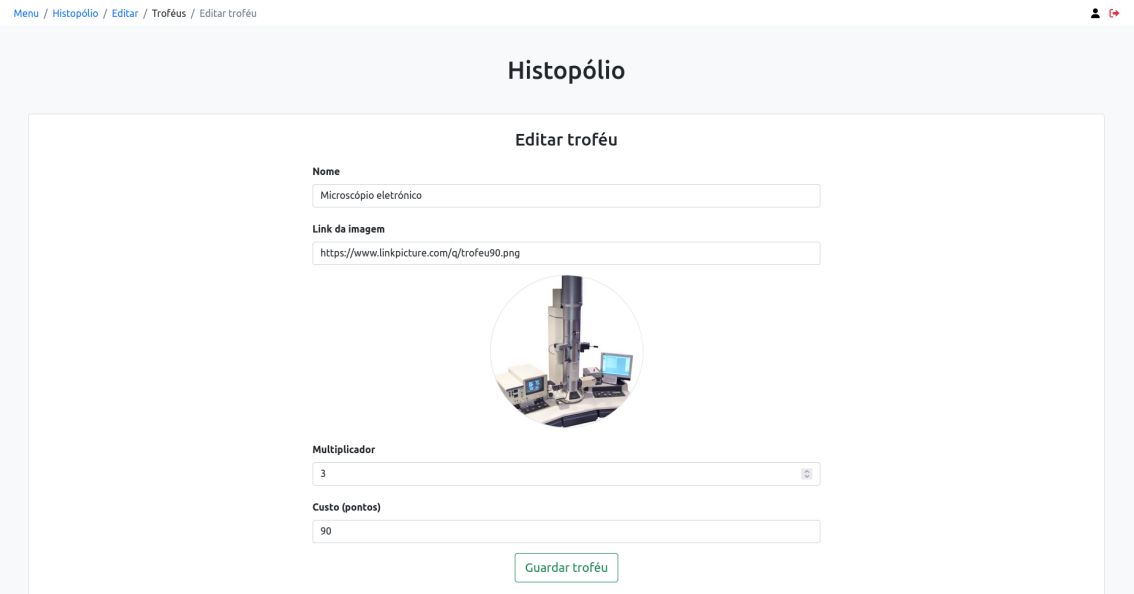


Figure 4.23: Edit Badge view

4.5.2.1 Login Menu view

When a user runs the board game, they are first presented with the Login menu view, containing the Login form. To access all the features of the board game, the user must fill the form with the credentials of an existing account with admin privileges and click the button below. If the form is filled correctly and the authentication is successful, the user will be taken to the Boards Menu view (4.5.2.2).

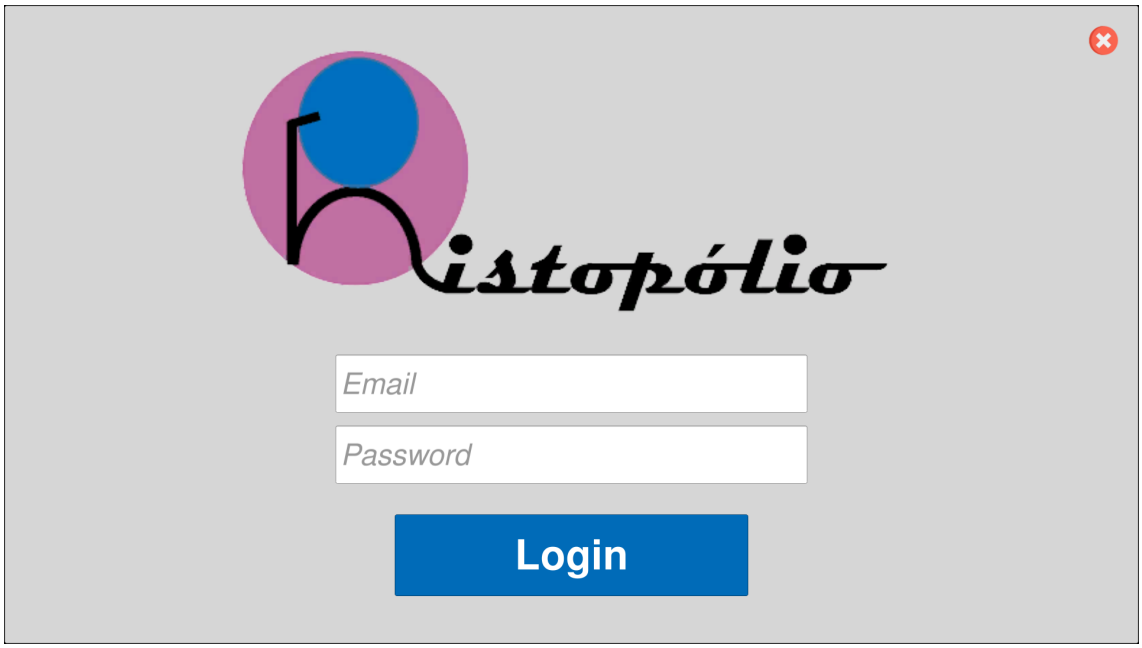


Figure 4.24: Login Menu view

4.5.2.2 Boards Menu view

In this view, the user is presented with a scrollable list of all the game boards they created. After the user clicks the board they selected to play, they will be taken to the Board Menu view (4.5.2.3).

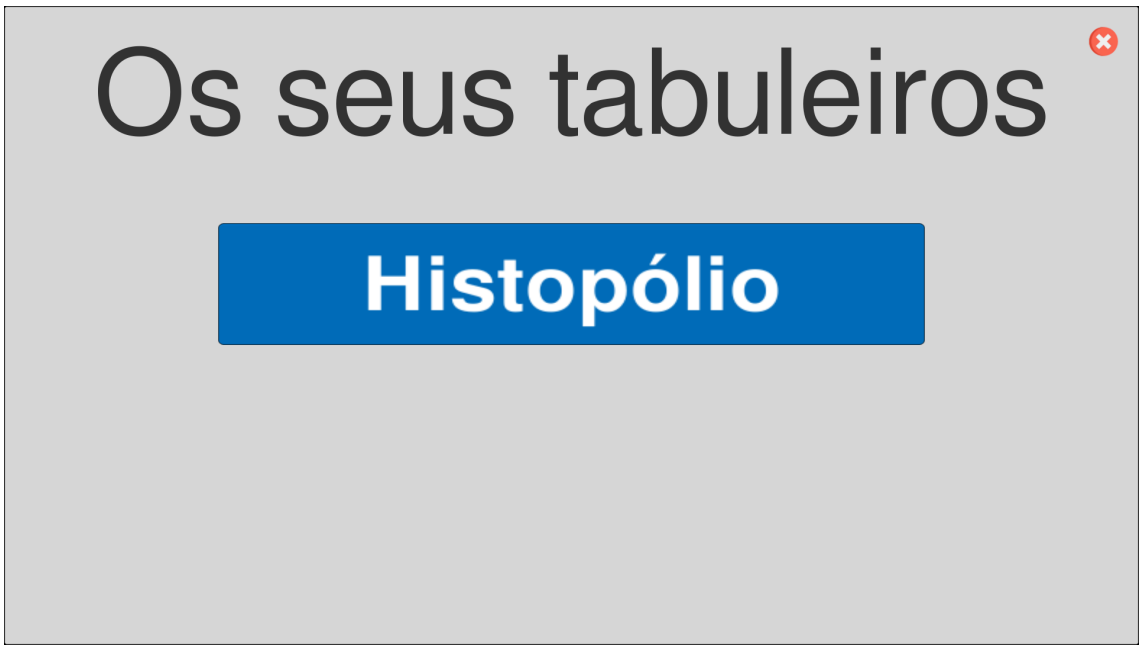


Figure 4.25: Login Menu view

4.5.2.3 Board Menu view

In this view, a simple menu with two buttons is shown to the user. The user can load a save, by clicking the first button, or create a new one, by clicking the button below. If the user presses the first button, they will be taken to the Saves Menu view (4.5.2.4), while clicking the second button will open a field to specify the save's name and then navigate the user to the Join Menu view (4.5.2.5).



Figure 4.26: Board Menu view

4.5.2.4 Saves Menu view

In this view, a scrollable list with all the chosen board's saves is shown to the user. The user can select any save by clicking on it, being afterward taken to the Join Menu view (4.5.2.5).

4.5.2.5 Join Menu view

In this view, it is presented all the avatars of players that have joined the active game session. Additionally, the access code new players use to enter the game session and register in the active save is shown in the bottom left corner. When all the players have joined, the user can click on the button shown at the bottom of the view to go to the Game Board view (4.5.2.6).

4.5.2.6 Game Board view

In this view, the game board is presented with the avatars of all the players in their respective positions. Furthermore, the left side of the view shows the current player's name, avatar, and badges and the name of the tile where the player is positioned. On the bottom left corner, the



Figure 4.27: Saves Menu view



Figure 4.28: Join Menu view (taken from a real scenario with practical class 4)

access code to join the game session is shown. Moreover, the right side of the view displays a podium with the avatars, names, and scores of the top three players with the most points in the active save.

Additionally, when the current player is not active, a button to remove the player is displayed in the bottom right corner of the view.



Figure 4.29: Game Board view

Chapter 5

Evaluation

Once the digital gaming platform was implemented, two evaluations were carried out, one with the students of AHE I of the IMVM of the ICBAS-UP and another with three professors (experts) of Histology from the Faculty of Medicine of the University of Porto (FMUP) and the ICBAS-UP.

5.1 Evaluation by the students

Before introducing the digital gaming platform in the practical classes of AHE I of the IMVM of ICBAS-UP, the design and development of this platform was supported by a focus group. This focus group consisted of six former AHE I students (2 males and 4 females) who were able to test the implementation of the digital gaming platform at different stages of development. Two sessions were performed in which these students were able to give valuable feedback and suggestions from both a student's and a player's perspectives, which positively influenced the development and final implementation of the digital gaming platform.

The digital gaming platform containing the Histopólio board was tested in the last two practical classes of AHE I of the IMVM of ICBAS-UP. To better test and compare the results of this experiment, only two of the four classes of this course used the digital gaming platform, effectively dividing the students of this course into two groups: the control group (28 students, 23 females and 5 males) without gamification and the test group (26 students, 20 females and 6 males) with gamification. In the test group, the digital gaming platform replaced the mini-evaluations that were given to the control group and were used as a form of continuous evaluation representing 20% of the final grade (this is the traditional setting, which has been applied in previous years). In the Histopólio test group, the percentage of correct answers to the board game questions was used to define the continuous evaluation grade. It is opportune to mention that the digital gaming platform was only implemented at the end of the semester, meaning that the students of the test group played with the physical version of the Histopólio board game during the rest of the semester. In each practical class, every student had only one turn to play, except for those who missed the previous class. In those lectures where the digital gaming platform was used, the board game was projected to the entire class (Appendix A) during the second half of each class. After

the students joined the game session using their smartphones or tablets, they continued doing their normal class activities until it was their turn to play. After playing their turn, they would resume their class activities.

To evaluate the results of this experiment, two similar questionnaires (Appendix C) were made and given to each student of the two groups in their last practical class. Whereas the questionnaire given to the control group had questions related to the mini-evaluation elements, the questionnaire given to the test group had identical questions related to the gamification elements. These questionnaires were designed to allow a direct comparison between the mini-evaluation and gamification approaches. It is worth mentioning that these questionnaires were adapted from a recently published and validated questionnaire used for assessing the motivation of gamification strategies [29]. Both questionnaires contained 16 statements, and students were able to evaluate each using a Likert 5-level scale, between 1 (Strongly Disagree) and 5 (Strongly Agree). The questionnaire was answered anonymously by students. Besides collecting the students' opinions on those 16 statements, their age and gender information was also collected. Additionally, each questionnaire had a blank space to gather specific comments or suggestions.

A statistical analysis was performed using a statistics software (www.statskingdom.com). After checking if the data followed a normal distribution, a non-parametric test (Two Sample Mann-Whitney U Test) was used to compare the answers to the questionnaires between the control and test groups. Since gender differences could exist [6, 25], a separate analysis was performed for the male and female populations.

The following Table and Figure 5.1 illustrate the mean scores given by the students of the control group and test group to each of the statements:

Table 5.1: Mean of the scores given by the students of the control group and test group to the questionnaires' statements (*despite not registering significant differences between the total students of the two groups, significant differences were noted between the female students of the two groups)

Statement	**Control group's mean scores**	**Test group's mean scores**	**Significant differences**
1 (Enjoyed)	3.79	4.54	Yes p = 0.0005
2 (Would repeat)	3.89	4.62	Yes p = 0.0097
3 (Motivated)	3.54	4.35	Yes p = 0.0018
4 (Increased knowledge)	4.25	4.19	No
5 (Interest)	3.67	4.04	No (p = 0.086)*
6 (Check knowledge)	4.25	4.00	No
7 (Identify weaknesses)	3.96	3.96	No

8 (Understand subjects)	4.14	3.96	No
9 (Learn more)	3.64	4.00	No (p = 0.083)*
10 (Connect classmates)	3.70	4.23	Yes p = 0.015
11 (Learn from colleagues)	3.71	4.31	Yes p = 0.025
12 (Found elements fun)	3.07	4.73	Yes p = 0.0001
13 (Test/Game elements)	3.43	4.35	Yes p = 0.001
14 (Not aware of surroundings)	3.21	2.88	No
15 (Capable)	3.86	4.08	No
16 (Comforting)	3.46	4.00	Yes p = 0.03

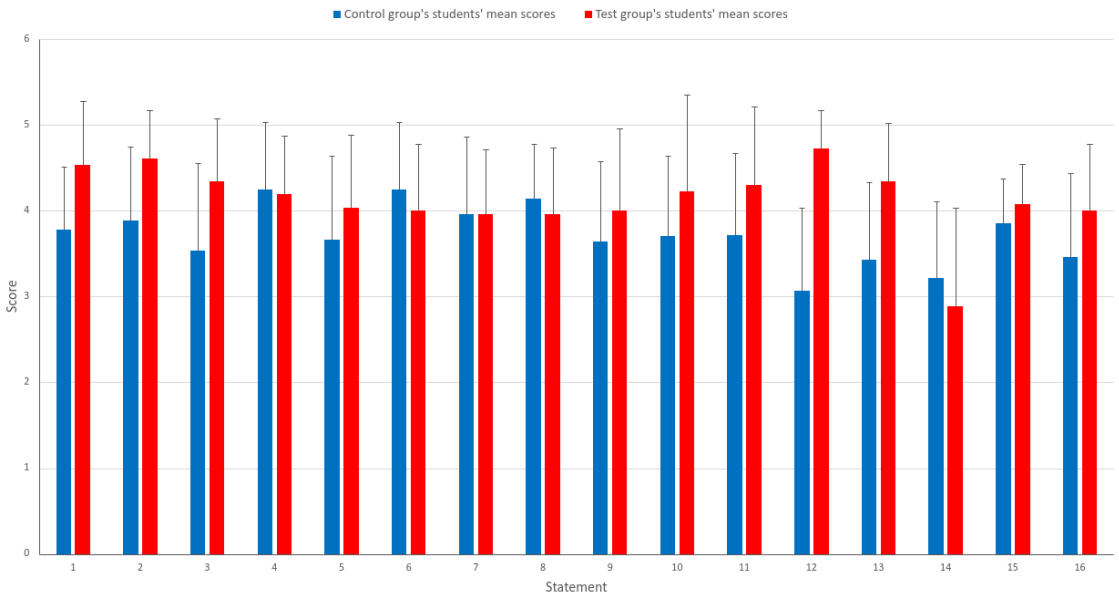


Figure 5.1: Mean of the scores given by the students to the questionnaires' statements (Control group's students versus Test group's students)

As can be observed in Table 5.1 and Figure 5.1, the results of this experiment were positive and presented good forecasts for the gamification approach and the digital gaming platform. Significant differences existed in several answers to the questionnaires, namely in their enjoyment, motivation, and engagement. In contrast, no differences existed in the amount of knowledge and cross-checking/testing abilities.

Students enjoyed the gamification strategy significantly more than the mini-evaluations (4.54 ± 0.75 versus 3.79 ± 0.72, respectively) and would be much more willing to repeat these activities (4.62 ± 0.56) than the mini-evaluations (3.89 ± 0.86). Furthermore, students playing the game reported a significantly higher motivation (4.35 ± 0.73) than those performing the mini-evaluations (3.54 ± 1.02) ($p < 0.002$). Interestingly, this difference was more pronounced in female students, who also reported that their interest in the subject increased with the gaming strategy (4.25 ± 0.77 versus 3.64 ± 0.93; $p < 0.02$). Male students reported no differences in their interest.

As expected, students reported that the game elements were much more fun than the mini-evaluations (4.73 ± 0.44 versus 3.07 ± 0.96, $p < 0.001$) and that they felt engaged, since the game had elements that motivated them to continue playing (4.35 ± 0.68 versus 3.43 ± 0.90, $p < 0.001$) with activities that they considered valuable (4 ± 0.78 versus 3.46 ± 0.98, $p < 0.05$). Notably, male and female differences were reported, besides the abovementioned difference in interest. In fact, female students reported that they learned more with gamification activities than in traditional classes (4.2 ± 1.12 versus 3.61 ± 0.98, $p < 0.05$), while male students reported no differences. Likewise, teamwork was different across gender, since female students reported they were much more able to connect with their colleagues to learn within the gaming framework than in the classic lectures (4.2 ± 1.12 versus 3.64 ± 0.98), whereas no differences existed for male students.

It is well acknowledged that gender differences exist in gaming, since boys and male adolescents spend significantly more time playing video games [6, 25]. In this view, the results were surprising since it would be expected a priori that male students would be fonder of this gamification strategy. However, it should be kept in mind that these gender differences are nowadays becoming less pronounced [25] and that they depend on the used devices, since there is a male trend towards consoles and similar male/female use for smartphones [25]. It is worth noting that this experiment's male population was much smaller than the female population (11 total male students vs. 43 total female students), so it is uncertain if this gender difference is real or may be due to an undersized sampling bias.

On the downside, and considering the specific comments left by students of the test group, some considered their form of evaluation less appropriate than that of the control group (one student specifically stated that the gamification approach was not the best as a form of evaluation). This was mainly due to the fact that the board game always involves some chance. To mitigate this problem, professors could allow each player to play more turns throughout the semester, particularly towards the end of the semester. This strategy would decrease the effects of the chance involved, especially after all the students arrive at the GO tile. After arriving there, the only way for a player to win points would be to answer random questions from the entire board. Alternatively, the professor could use the digital gaming platform as a tool to practice and test students' knowledge, and not for evaluation purposes.

In addition to these evaluations, some students from both groups left comments regarding their experiences. These comments and suggestions are presented in Appendix C. On the one hand, two students from the control group left comments stating that they wanted to play the Histopólio board game, which is a good indicator that students from that group would indeed replace their

mini-evaluations with the gamification approach. On the other hand, several students from the test group left different suggestions, including new features they would like to see in the digital gaming platform, as well as positive comments regarding the whole experience. All these suggestions and comments are valuable feedback that will be considered in future work and development of the digital gaming platform.

Finally, it is opportune to mention that no differences existed in the final grades between the students of the control group (classes 1 and 2) and the test group (classes 3 and 4).

5.2 Evaluation by the experts

The digital gaming platform was later presented to another professor of AHE I from the ICBAS and two professors of Histology from the FMUP. All the professors created an account, joined a game session, and played several turns. After finishing the game session, the professors were able to see the interface and features of the Admin Back-office.

A questionnaire (Appendix D) was later provided to each professor. This questionnaire was different from the previous two given to the students, and contained only 5 statements, which the professors were able to evaluate each using a Likert 5-level scale, between 1 (Strongly Disagree) and 5 (Strongly Agree). In addition to these 5 statements, each questionnaire had open questions to gather the participants' global evaluation, negative and positive points, suggestions, and comments regarding the Admin Back-office.

The following table displays the scores given by all participants to the questionnaire's statements:

Table 5.2: Scores given by the experts to the questionnaire's statements

Statement	**Participant 1**	**Participant 2**	**Participant 3**
1 (increase motivation)	5	4	5
2 (useful in class)	5	4	5
3 (easy to integrate in class)	4	5	4
4 (back-office is simple and interactive)	5	4	5
5 (easy to edit game board in back-office)	5	4	5

The results from this experiment were positive and promising. All the professors agreed or strongly agreed that the digital gaming platform would increase students' motivation, would be

useful for the class activities, and could be easily integrated with other class activities. Additionally, the professors agreed or strongly agreed that the Admin Back-office presents an interactive and straightforward interface, where it is easy to edit a game board.

Regarding the global evaluation, the professors agreed that the digital gaming platform is suitable for the current university population and can positively influence students' participation in class. Additionally, one professor pointed out that this platform could be an important tool in remote classes, where it is harder to attract the students' attention. Another professor pointed out that these kinds of activities are a good way of assessing students without the stress usually associated with exams.

As for the negative aspects of the digital gaming platform, the professors left the following remarks:

- Participant 1:
  - "No downsides, as long as the room where it is played has a good internet connection."
- Participant 2:
  - "Limitation of playing in large classes."
  - "Difficulty in having questions with the same degree of difficulty for all students due to chance associated with the game."
- Participant 3:
  - "Podium displayed throughout the game."
  - "Large space occupied by the podium and the player's avatar relative to the virtual game board."
  - "The tile where the player is after the dice roll is not highlighted."

Regarding the positive aspects, the professors pointed out the following:

- Participant 1:
  - "The versatility of the digital gaming platform, namely the possibility of adapting it to various themes."
  - "Easy to use."
  - "Not at all monotonous."
  - "Other aspects were mentioned in the 'global evaluation'" ("suitable for the current university students", "positive influence on the student's participation in class", and "significant improvement in relation to the physical version").
- Participant 2:
  - "Active student participation."

  - "Possibility of student evaluation."
  - "Change the classroom routine and motivate students."
  - "Train the students for their assessments."

- Participant 3:

  - "Variety of question types and tile activities."
  - "The dynamics of the dice roll."
  - "Possibility of adapting the name of the tiles and the game to different areas/courses."

Furthermore, a professor suggested creating an algorithm that distributes questions with different degrees of difficulty proportionally to each student regardless of the student's position on the game board. Meanwhile, another professor suggested having questions with different degrees of difficulty for each tile, allowing the student who landed on the tile to select the wanted level of difficulty. In this case, a student who answered a question correctly would receive a specific number of points according to the selected difficulty level. These features can be considered in future work and development of this digital gaming platform.

As for the comments regarding the Admin Back-office, all professors pointed out that it presents a simple and intuitive interface.

Chapter 6

Conclusions and Future Work

Gamification is an emerging tool that can be used in numerous areas. The introduction of this tool in the education area is an innovative idea that can make a positive impact on students. According to recent meta-analyses, gamification has an effect on cognitive, motivational, and behavioral outcomes [38].

This work was motivated by the difficulty of engaging students while teaching Histology. While using more traditional approaches, students from Histology courses have presented low motivation and engagement rates, resulting in lower learning efficacy.

The proposed solution allows professors, not only of Histology courses but, in fact, of any subject, to easily use a gamification approach to teaching. The solution consists of a digital gaming platform that combines a board game with a Web application. The digital board game presents several gamification elements that offer the students a more fun and less stressful way of improving their knowledge, while the Web application offers a more engaging way of playing, since students can use it as a game controller for the board game.

The Web application also presents an Admin Back-office with a simple and interactive interface that allows professors with admin access to easily create and edit game boards and their tiles, questions, and cards, without programming skills. This flexibility offers professors the opportunity to create personalized game boards for any subject and make them available on the digital gaming platform, where students can play.

6.1 Reflection on the evaluation results

Following similar results reported in previous experiments with gamification, the studied population of students had a significant increase in their motivation and engagement, which refers to motivational or affective outcomes. These are typically self-reported by students and include learner satisfaction, motivation, learner interests, and attitudes, as well as their perceptions of learning. Furthermore, a qualitative effect was highlighted by the student's reaction to the assignments included on the Histopólio game board. In the Senate Decision tiles, multiple activities were included, such as narrating the videos of the training station, making photos with captions

of microscopy slides, and presenting microscopy slides to their classmates. If those activities had been suggested directly by the professor, students would complain, would probably question the purpose or nature of the activity, and eventually would not commit to the suggested tasks. In contrast, when it was the game to dictate the activities, students were indeed committed and delivered their assignments on time, in order to be awarded the corresponding points in the game.

As for the effects on cognitive outcomes, no differences in final grades were noted. This lack of difference may be due to several reasons. On the one hand, gamification does not directly affect the learning outcomes. Instead, gamification is aimed at directly affecting behaviors and attitudes relevant to learning, which may lead to an improvement in the learning outcomes [20, 23]. Notably, previous studies using gamification through Kahoot in a Histology course also highlighted the positive effects on motivation and engagement, but failed to disclose an improvement in final grades [11]. On the other hand, this study had a small sample and the final exam per se is a rough measurement of cognitive improvements, which could fail to disclose subtle improvements in knowledge retention. The evaluation design would need to be refined to disclose eventual improvements in knowledge retention. Firstly, an initial test should be given to all students, in order to assess if differences between classes existed a priori. Then, a final test should be provided after the mini-evaluations and gamification classes. This strategy would allow for a direct comparison of the percentage of improvement between the control and the test groups.

The board game framework used in this study also deserves some comments. Board or tabletop games are considered excellent tools for educational purposes, since they enable learning through the exchange of experiences [46]. It is noteworthy that all students have previously played Monopoly and easily linked the presented game to that well-known board game.

Games have a specific structure that includes mechanics, components, and dynamics, which have been compared to language elements (respectively, the verbs, nouns, and grammar) [53]. The developed board game presented several of the typical game elements. As for the mechanics, it encompassed elements related to chance (provided by the dice and the Chance tiles), competition, challenge, and cooperation. These elements are extremely important for learning purposes. Increasing the cooperation between students was one of the original purposes of the presented solution and it succeeded in this regard, as recognized by the students through the questionnaires. When students were unsure of the correct answers to the quiz questions, they searched for help from their classmates. This cooperation could be further enhanced by playing the game in teams, which could be simple to perform with the presented solution. As for the components, the game included several elements, such as points, badges, leaderboards, and avatars. Finally, as for the dynamics, the Histopólio board included a simple narration technique, provided by the relation between the names of the tiles in the four rows and the four fundamental tissues of Histology.

Furthermore, it should be emphasized that the Histopólio board, particularly the Chance and Senate Decisions cards, purposefully included many humor elements. Not only does humor promote learning [28], but it also improves students' performance by reducing anxiety, as reported by students' comments, enhances participation, and increases motivation. The purpose of humor was to create an enjoyable atmosphere, contrasting the dull activity of spending 2 hours strictly

looking through a microscope.

6.2 Goals satisfaction

The two main goals of the solution were to increase the motivation and engagement of the students of the AHE I classes of the ICBAS-UP and to be flexible and easily adaptable by professors for other subjects.

Observing the results of the questionnaires given to the students of AHE I, it is possible to conclude that the first main objective was fully accomplished. In fact, students from the test group with gamification presented higher levels of motivation, engagement, and socialization with other classmates than those in the control group without gamification.

The second main goal was also satisfied, since the Web application presents an Admin Back-office where professors with admin access can create and edit their game boards, without having any programming skills. As reported by the experts, the Admin Back-office presents a straightforward and interactive interface. In fact, some questions of the Histopólio board have already been introduced by a professor without any programming skills.

6.3 Future Work

The digital gaming platform presents much potential, with many new features that have been suggested by professors and students that can be added to this platform, improving even further the flexibility, user experience, and motivation of the students. With the core of the digital gaming platform already completed with the existing features, the following features can easily be implemented in the short term:

- Edit the number of tiles of a board.
- Personalize the shape and sequence of tiles of a board.
- Edit the number of dice faces.
- Show the dice rolling simultaneously on the board game and the Web application.
- Select between showing the questions on the board game or the Web application.
- Select between rolling the dice on the board game or the Web application.
- Select between showing or not the podium on the board game.
- Select between showing or not the current player's score on the board game.
- Select between having a timer or not for answering the question.
- Show a final screen in the board game with the podium.

- Show the correct answer or a comment if a player answers a question wrong.
- Import images from the device.
- Have sets of questions of different difficulty and points for the same tile, where the student can select the difficulty.
- Have a duel mode with questions between two players, where the winner takes the points.
- Have a "Ask for help" button, when answering a question, which would enhance the role of the game as a learning tool.
- Have notifications for students and professors to remind them of pending tasks.
- Have an algorithm capable of distributing questions with different degrees of difficulty proportionally to each student regardless of the student's position on the game board.

In addition to these features, both the Web application and the board game can be more engaging by improving the overall design and adding animations.

Considering the long-term future development, the following points have been envisioned:

- Have an augmented reality mode, allowing the students to play with their personal devices, while using the physical board. In this scenario, the players' avatars positioned on the board would only appear on their personal devices when pointing the device's camera at the physical board. Moreover, the players would still roll the dice and answer questions from their personal devices.
- Redo the board game using three dimensions. This would not affect the game mechanics, only the visual aspect of the board game would be improved.
- Integrate the digital gaming platform with Moodle, allowing professors to manage their saves and students' scores from a more widely used and familiar environment. This integration would facilitate the eventual use of the platform as an evaluation tool.

Furthermore, the digital gaming platform will be used by all the classes of AHE I of the IMVM of ICBAS in the following year. The platform will also be introduced in the following year to some classes of Histology from the FMUP. This will allow for a more in-depth study, with a larger population from different contexts and faculties, and will further clarify the effect of the gamification elements on motivation and knowledge retention.

Additionally, since this platform offers the flexibility to create new game boards for different subjects, other experiments can be conducted with students from different courses and education areas, in the context of university teaching.

References

[1] Asta Adukaite, Izak van Zyl, Şebnem Er, and Lorenzo Cantoni. Teacher perceptions on the use of digital gamified learning in tourism education: The case of south african secondary schools. *Computers Education*, 111:172–190, 2017.

[2] Eike Falk Anderson, Steffen Engel, Peter Comninos, and Leigh McLoughlin. The case for research in game engine architecture. In *Proceedings of the 2008 Conference on Future Play: Research, Play, Share*, page 228–231. Association for Computing Machinery, 2008.

[3] Paulo Sérgio Silva Babo. Histological challenge a digital book that is also a game. Technical report, Faculdade de Engenharia da Universidade do Porto, January 2020.

[4] Gabriel Barata, Sandra Gama, Joaquim Jorge, and Daniel Gonçalves. Studying student differentiation in gamified education: A long-term study. *Computers in Human Behavior*, 71:550–585, 2017.

[5] Chris Bradfield. *Godot Engine Game Development Projects: Build Five Cross-platform 2D and 3D Games with Godot 3.0*. Packt Publishing Ltd, 2018.

[6] Anna Brown. Younger men play video games, but so do a diverse group of other americans, September 2017. Available at https://www.pewresearch.org/fact-tank/2017/09/11/younger-men-play-video-games-but-so-do-a-diverse-group-of-other-americans/, last accessed in June 2022.

[7] Carlos Henrique Leitão Cavalcante and Maria Luciana Almeida Pereira. Comparativo entre game engines como etapa inicial para o desenvolvimento de um jogo de educação financeira, 2018.

[8] Jorge Freire de Sousa and Helena Martins. Game on: reflexões sobre uma experiência de ludificação da unidade curricular de gestão de recursos humanos do mestrado integrado em engenharia e gestão industrial. *Educação, Sociedade Culturas*, (50):193–211, June 2017.

[9] Paul E Dickson, Jeremy E Block, Gina N Echevarria, and Kristina C Keenan. An experience-based comparison of unity and unreal for a stand-alone 3d game development course. In *Proceedings of the 2017 ACM Conference on Innovation and Technology in Computer Science Education*, pages 70–75, 2017.

[10] Jeff Drake. 20 great games that use the unreal 4 game engine, June 2021. Available at https://www.thegamer.com/great-games-use-unreal-4-game-engine/, last accessed in February 2022.

[11] Szabolcs Felszeghy, Sanna Pasonen-Seppänen, Ali Koskela, Petteri Nieminen, Kai Härkönen, Kaisa Paldanius, Sami Gabbouj, Kirsi Ketola, Mikko Hiltunen, Mikael Lundin, et al.

Using online game-based platforms to improve student performance and engagement in histology teaching. *BMC medical education*, 19(1):1–11, 2019.

[12] Ana Catarina Rodrigues Ferreira. Spot - jogo sério baseado em realidade aumentada para a prevenção do melanoma. Technical report, Faculdade de Engenharia da Universidade do Porto, July 2021.

[13] Artur Sousa Ferreira. Aplicação móvel ludificada para introdução criativa à programação. Technical report, Faculdade de Engenharia da Universidade do Porto, February 2021.

[14] Katja Fleischmann and Ellen Ariel. Gamification in science education: Gamifying learning of microscopic processes in the laboratory. *Contemporary Educational Technology*, 7, April 2016.

[15] Arunkumar Gudelli. History of angularjs, October 2019. Available at https://www.angularjswiki.com/angular/history-of-angularjs/, last accessed in February 2022.

[16] John K Haas. A history of the unity game engine. *Diss. WORCESTER POLYTECHNIC INSTITUTE*, page 32, 2014.

[17] David Helgason. Unity 1.0 is shipping, March 2005. Available at https://forum.unity.com/threads/unity-1-0-is-shipping.56/, last accessed in February 2022.

[18] Joseph Hocking. *Unity in Action: Multiplatform game development in C*. Simon and Schuster, 2022.

[19] Chia-Lin Hsu and Mu-Chen Chen. How gamification marketing activities motivate desirable consumer behaviors: Focusing on the role of brand love. *Computers in Human Behavior*, 88:121–133, 2018.

[20] Wendy Hsin-Yuan Huang and Dilip Soman. Gamification of education. *Report Series: Behavioural Economics in Action*, 29:11–12, 2013.

[21] Mehdi Jazayeri. Some trends in web application development. In *Future of Software Engineering (FOSE '07)*, pages 199–213, 2007.

[22] Mantas Jurgelaitis, Lina Čeponienė, Jonas Čeponis, and Vaidotas Drungilas. Implementing gamification in a university-level uml modeling course: A case study. *Computer Applications in Engineering Education*, 27(2):332–343, 2019.

[23] Gabriela Kiryakova, Nadezhda Angelova, and Lina Yordanova. Gamification in education. Proceedings of 9th International Balkan Education and Science Conference, 2014.

[24] Joanna Lee. *Learning unreal engine game development*. Packt Publishing Ltd, 2016.

[25] Marja Leonhardt and Stian Overå. Are there differences in video gaming and use of social media among boys and girls?—a mixed methods approach. *International Journal of Environmental Research and Public Health*, 18(11):6085, 2021.

[26] Juan Linietsky and Ariel Manzur. Showcase. Available at https://godotengine.org/showcase, last accessed in February 2022.

[27] Miguel Lira and Victor Silva. Motivação intrínseca vs. motivação extrínseca: A aplicação da escala wpi no contexto do setor público português. *Revista de Gestão, Finanças e Contabilidade*, 5:171–195, December 2015.

[28] Heidi L Lujan and Stephen E DiCarlo. Humor promotes learning!, 2016.

[29] Ana Manzano-León, Pablo Camacho-Lazarraga, Miguel A Guerrero-Puerta, Laura Guerrero-Puerta, Antonio Alias, José M Aguilar-Parra, and Rubén Trigueros. Development and validation of a questionnaire on motivation for cooperative playful learning strategies. *International Journal of Environmental Research and Public Health*, 18(3):960, 2021.

[30] Elisa D. Mekler, Florian Brühlmann, Klaus Opwis, and Alexandre N. Tuch. Do points, levels and leaderboards harm intrinsic motivation? an empirical analysis of common gamification elements. In *Proceedings of the First International Conference on Gameful Design, Research, and Applications*, Gamification '13, page 66–73, New York, NY, USA, 2013. Association for Computing Machinery.

[31] Merriam-Webster. Gamification, February 2022. Available at https://www.merriam-webster.com/dictionary/gamification, last accessed in February 2022.

[32] Olivia Miu Yung Ngan, Taylor Lik Hang Tang, Aden Ka Yin Chan, Daisy Minghui Chen, and Mei Kuen Tang. Blended learning in anatomy teaching for non-medical students: An innovative approach to the health professions education. *Health Professions Education*, 4(2):149–158, 2018.

[33] David H. Nguyen. Why is the study of histology important in your overall understanding of anatomy physiology?, May 2019. Available at https://sciencing.com/full-diagram-of-the-human-body-12741282.html, last accessed in February 2022.

[34] The Editors of Encyclopaedia Britannica. Histology. Available at https://www.britannica.com/science/histology, last accessed in February 2022.

[35] Chin Osathanunkul. A classification of business models in video game industry. *International Journal of Management Cases*, 17(1):35–44, 2015.

[36] Pierre-Yves Oudeyer and Frederic Kaplan. What is intrinsic motivation? a typology of computational approaches. *Frontiers in neurorobotics*, 1:6, 2009.

[37] Adam Rice. Websockets standard, June 2022. Available at https://websockets.spec.whatwg.org/, last accessed in June 2022.

[38] Albert D Ritzhaupt, Rui Huang, Max Sommer, Jiawen Zhu, Anita Stephen, Natercia Valle, John Hampton, and Jingwei Li. A meta-analysis on the influence of gamification in formal educational settings on affective and behavioral outcomes. *Educational Technology Research and Development*, 69(5):2493–2522, 2021.

[39] Richard M. Ryan and Edward L. Deci. Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, 25(1):54–67, 2000.

[40] Michael Sailer, Jan Ulrich Hense, Sarah Katharina Mayr, and Heinz Mandl. How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. *Computers in Human Behavior*, 69:371–380, 2017.

[41] Elar Saks. Javascript frameworks: Angular vs react vs vue. 2019.

[42] Adi Setiawan and Soeharto Soeharto. Kahoot-based learning game to improve mathematics learning motivation of elementary school students. *Al-Jabar : Jurnal Pendidikan Matematika*, 11:39–48, 06 2020.

[43] Allen Sherrod. *Ultimate 3D Game Engine Design Architecture*. Charles River Media, Inc., 2006.

[44] Jorge Simões, Rebeca Díaz Redondo, and Ana Fernández Vilas. A social gamification framework for a k-6 learning platform. *Computers in Human Behavior*, 29(2):345–353, 2013.

[45] Tarja Susi, Mikael Johannesson, and Per Backlund. Serious games - an overview. November 2015.

[46] Jonas da Silva Teixeira, Alan César Belo Angeluci, Paulo Prates Junior, and José Guilherme Prado Martin. 'let's play?'a systematic review of board games in biology. *Journal of Biological Education*, pages 1–20, 2022.

[47] Unity. Common game development terms and definitions | game design vocabulary | unity. Available at https://unity.com/how-to/beginner/game-development-terms, last accessed in February 2022.

[48] Pawan Vora. *Web application design patterns*. Morgan Kaufmann, 2009.

[49] Alf Inge Wang and Rabail Tahir. The effect of using kahoot! for learning – a literature review. *Computers Education*, 149:103818, 2020.

[50] Lara Williams. A pandemic is a dream come true for gamers, January 2022. Available at https://www.bloomberg.com/opinion/articles/2022-01-16/pandemics-boost-for-video-game-industry-is-a-dream-come-true-kyh9nekz, last accessed in February 2022.

[51] Eric Wohlgethan. *SupportingWeb Development Decisions by Comparing Three Major JavaScript Frameworks: Angular, React and Vue. js*. PhD thesis, Hochschule für Angewandte Wissenschaften Hamburg, 2018.

[52] Yang Yang, Yousra Asaad, and Yogesh Dwivedi. Examining the impact of gamification on intention of engagement and brand attitude in the marketing context. *Computers in Human Behavior*, 73:459–469, 2017.

[53] Ibrahim Yildirim. The effects of gamification-based teaching practices on student achievement and students' attitudes toward lessons. *The Internet and Higher Education*, 33:86–92, 2017.

[54] Zamzami Zainuddin, Samuel Kai Wah Chu, Muhammad Shujahat, and Corinne Jacqueline Perera. The impact of gamification on learning and instruction: A systematic review of empirical evidence. *Educational Research Review*, 30:100326, 2020.

Appendix A

Real experiment with the students

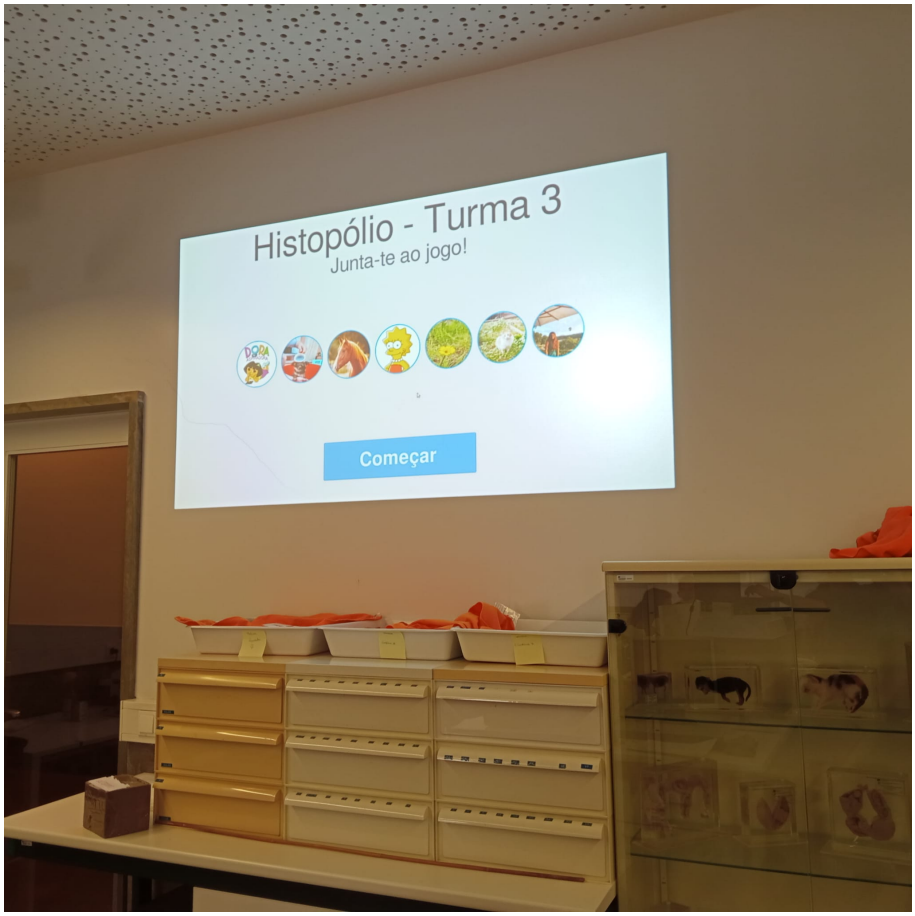


Figure A.1: Join Menu view of the board game projected in a real scenario with the students of the practical class 3

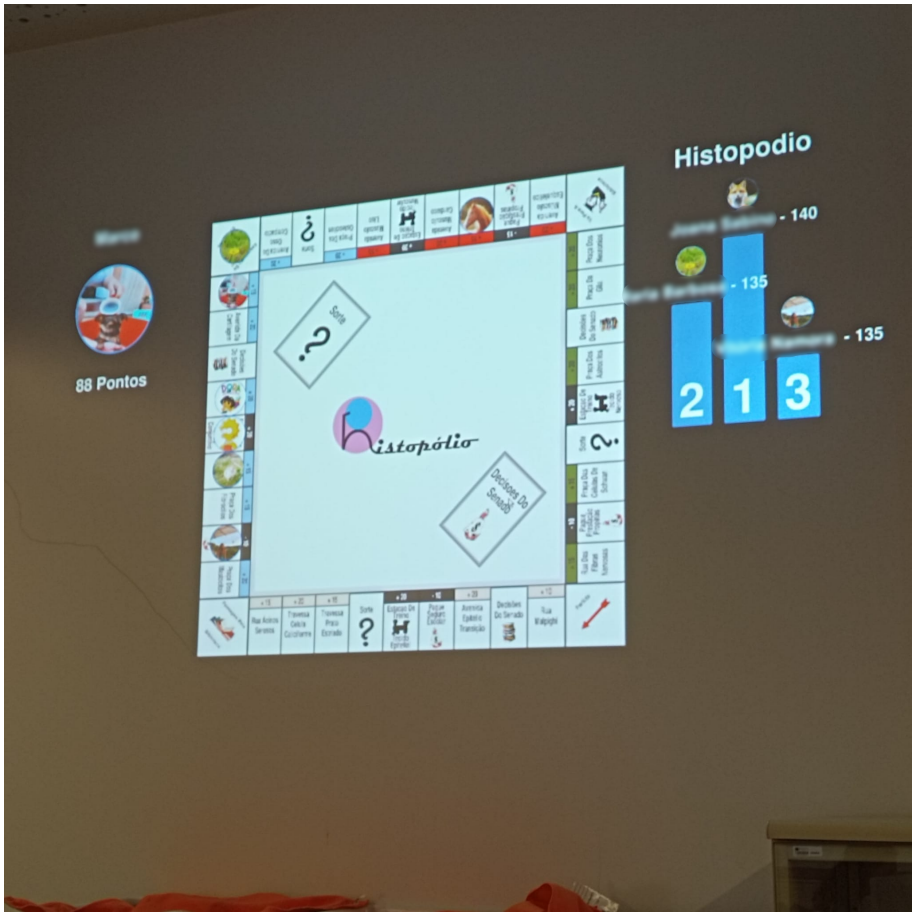


Figure A.2: Game Board view of the board game projected in a real scenario with the students of the practical class 3

Appendix B

User interface

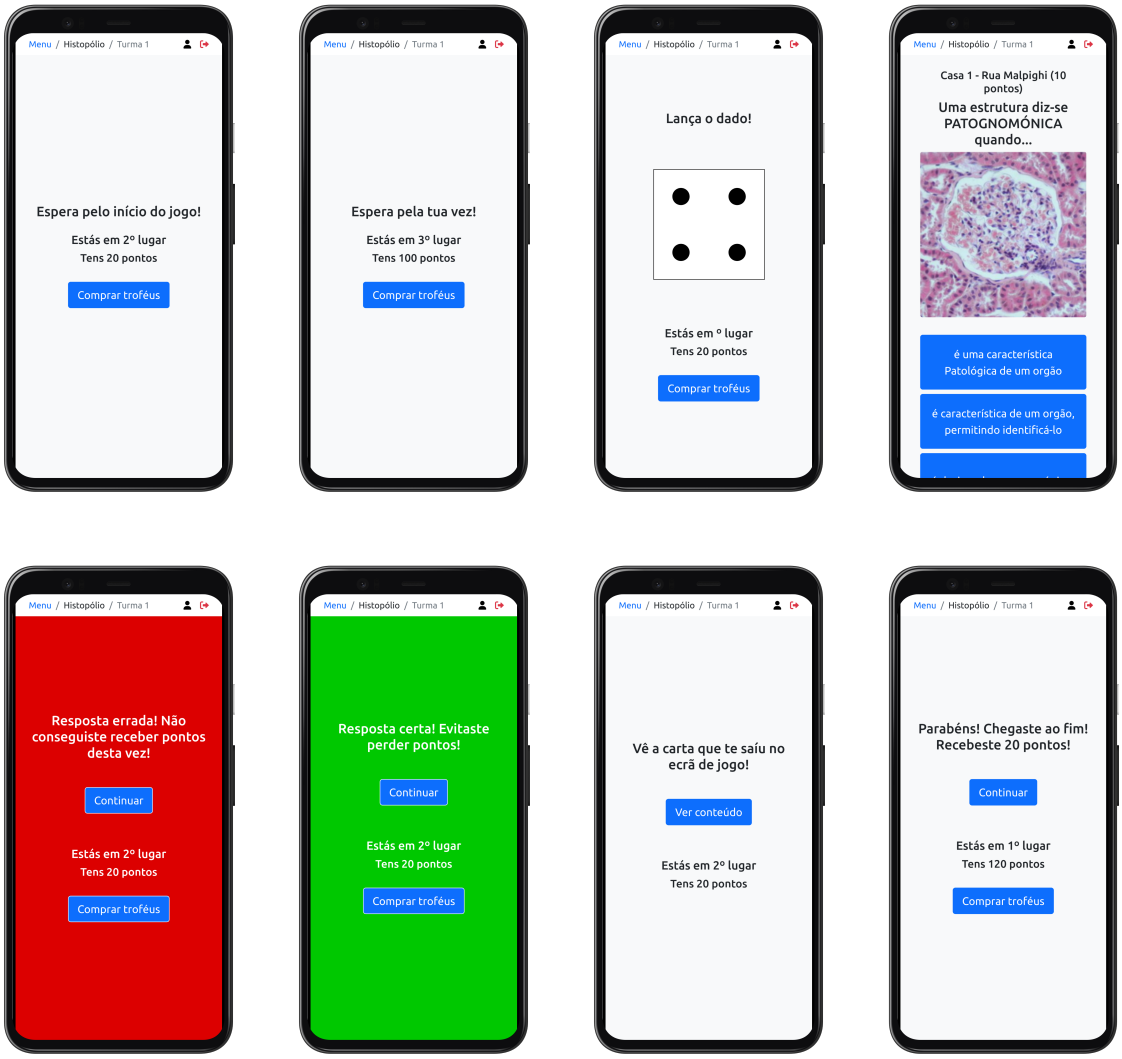


Figure B.1: The different elements of the Game Controller view

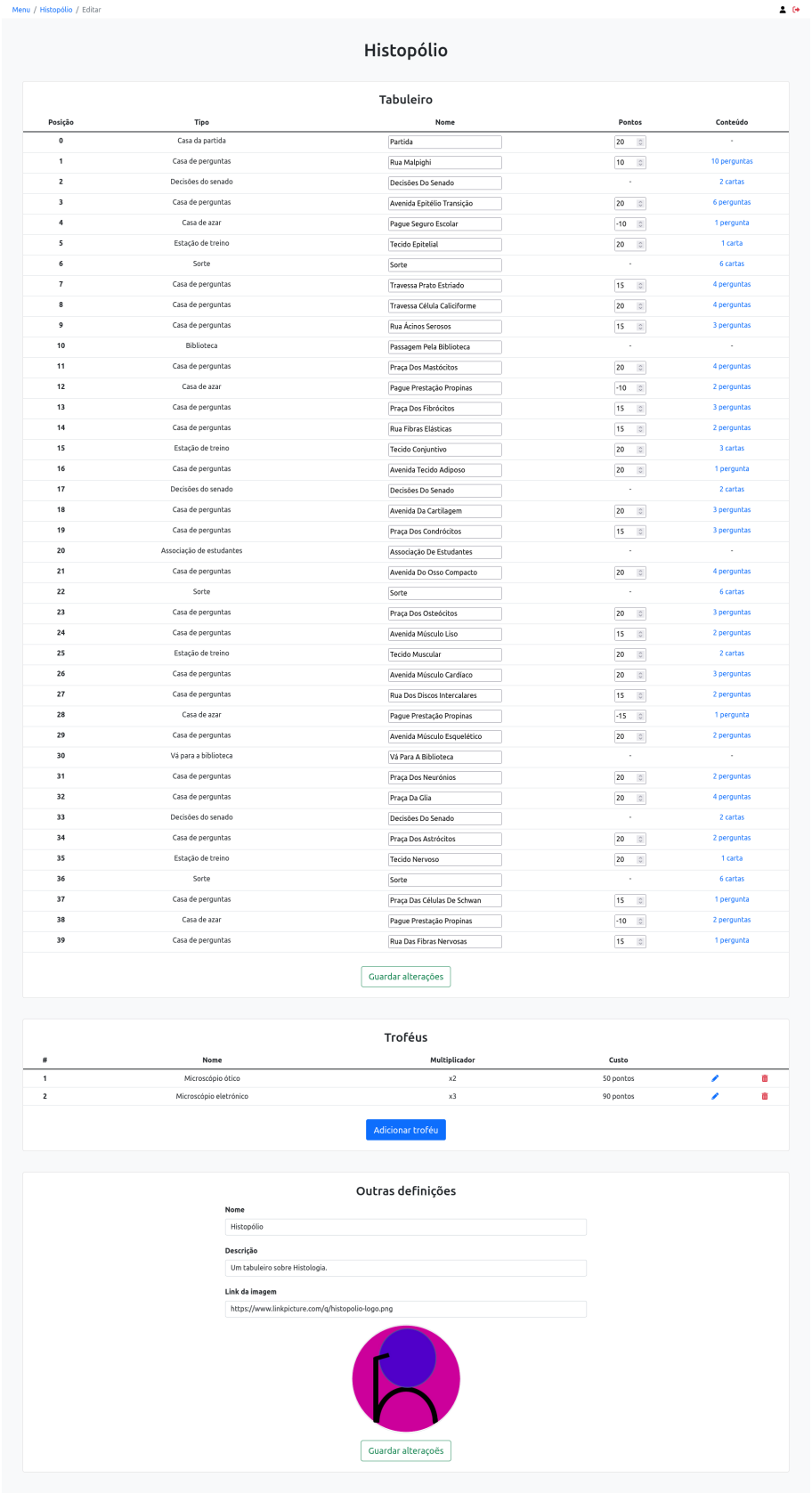


Figure B.2: Edit Board full view

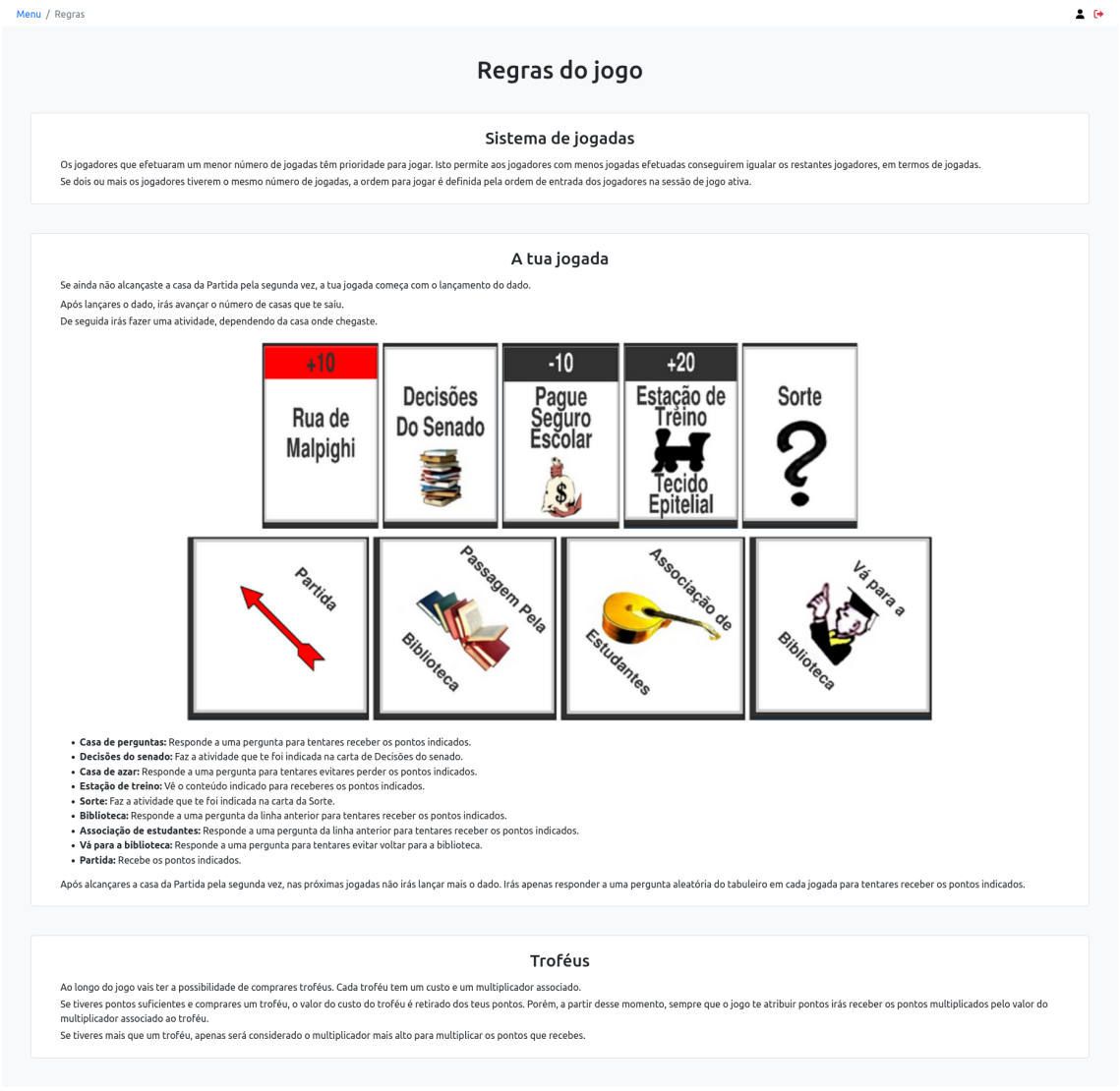


Figure B.3: Rules full view

Appendix C

Students' questionnaires

C.1 Questionnaire given to the control group

- Sex
- Age

1. In general, I have enjoyed the activities (Mini-evaluations).
2. I would repeat these types of activities (Mini-evaluations).
3. I have felt motivated with the Mini-evaluations.
4. I improved my knowledge of the subject (with the Mini-evaluations).
5. My interest in the subject has increased (with the Mini-evaluations).
6. This activity format has been appropriate to check my knowledge of the subject.
7. Mini-evaluations helped me identify my weaknesses in the subject.
8. Mini-evaluations helped me understand the content of the subject.
9. With these types of activities (Mini-evaluations) I learn a lot.
10. I feel I was able to connect with my classmates to learn.
11. I learned from my classmates during the practical classes.
12. I found the Mini-evaluations to be fun and enjoyable.
13. The Mini-evaluations have motivated me to carry out the activity.
14. While doing Mini-evaluations I was not aware of what was happening around me.
15. I felt capable of carrying out the Mini-evaluations.
16. I found the Mini-evaluations comforting and valuable to me.

- Comments/Suggestions

C.1.1 Results

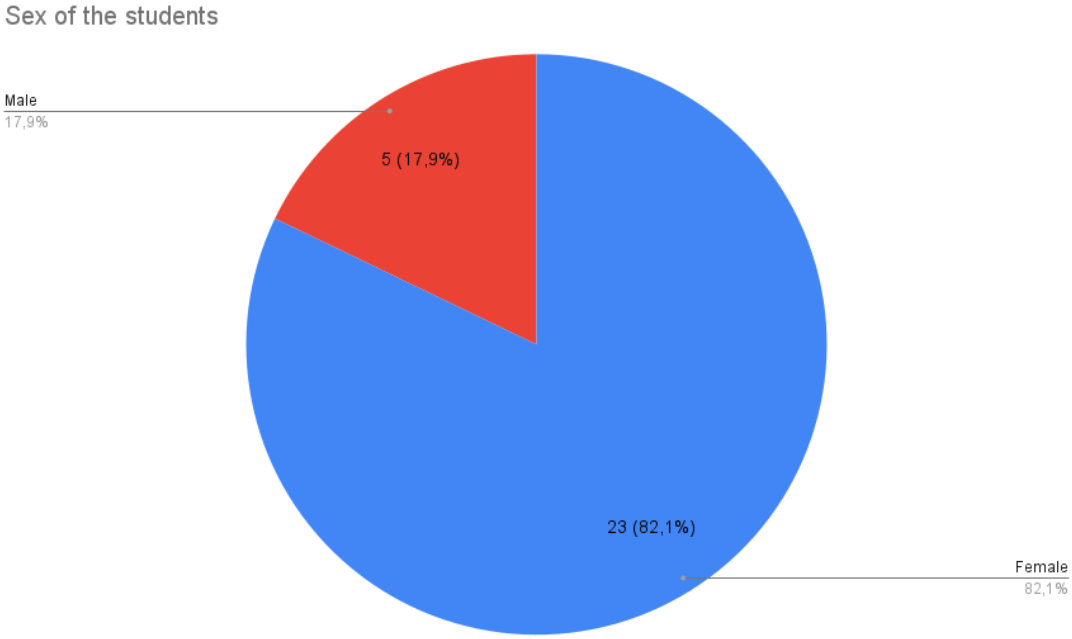


Figure C.1: Sex of the students from the control group

Table C.1: Mean of the scores given by the students of the control group to the questionnaire's statements

Statement	**Female students' mean scores**	**Male students' mean scores**	**All students' mean scores**
1	3.78	3.80	3.79
2	3.83	4.20	3.89
3	3.48	3.80	3.54
4	4.22	4.40	4.25
5	3.64	3.80	3.67
6	4.26	4.20	4.25
7	3.91	4.20	3.96
8	4.09	4.40	4.14
9	3.61	3.80	3.64
10	3.64	4.00	3.70
11	3.70	3.80	3.71
12	2.96	3.60	3.07
13	3.39	3.60	3.43
14	3.48	2.00	3.21

15	3.83	4.00	3.86
16	3.35	4.00	3.46

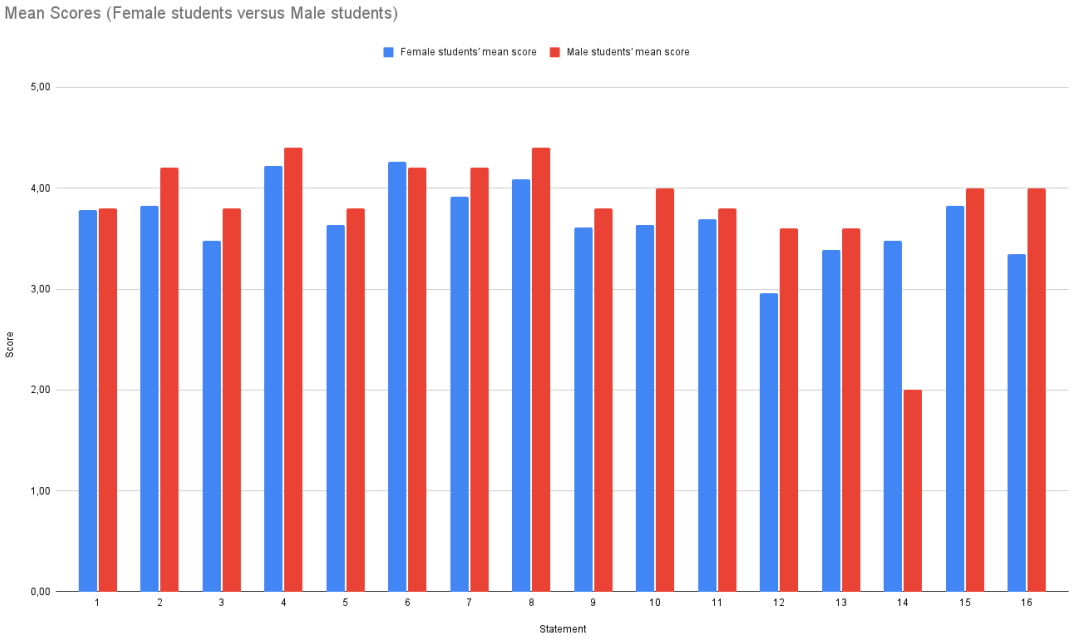


Figure C.2: Mean of the scores given by the students of the control group to the questionnaire's statements (Female students versus Male students)

C.1.2 Comments and suggestions

- "I want the Histopólio!"
- "If the evaluation were different (Histopólio), my opinion would be different."

C.2 Questionnaire given to the test group

- Sex
- Age

1. In general, I have enjoyed this playful activity.
2. I would repeat these types of activities.
3. I have felt motivated.
4. I improved my knowledge of the subject.

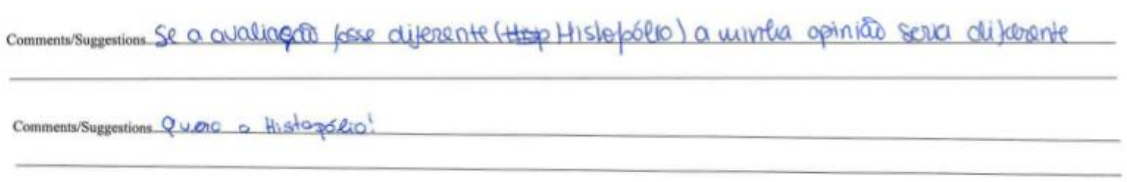


Figure C.3: Comments and suggestions given by some students of the control group

5. My interest in the subject has increased.
6. This activity format has been appropriate to check my knowledge of the subject.
7. Helped me identify my weaknesses in the subject.
8. It helped me understand the content of the subject.
9. With these types of activities I learn more than in traditional classes.
10. I feel like I was able to connect with my classmates to learn.
11. I learned from my classmates during the activity.
12. I found the game elements fun.
13. The game elements have motivated me to carry out the activity.
14. While playing I was not aware of what was happening around me.
15. I felt capable of carrying out the proposed activities.
16. I found the activities comforting and valuable to me.

- Comments/Suggestions

C.2.1 Results

Table C.2: Mean of the scores given by the students of the test group to the questionnaire's statements

Statement	**Female students' mean scores**	**Male students' mean scores**	**All students' mean scores**
1	4.75	3.83	4.54
2	4.65	4.50	4.62
3	4.40	4.17	4.35
4	4.30	3.83	4.19
5	4.25	3.33	4.04

6	4.00	4.00	4.00
7	3.90	4.17	3.96
8	4.05	3.67	3.96
9	4.20	3.33	4.00
10	4.20	4.33	4.23
11	4.40	4.00	4.31
12	4.80	4.50	4.73
13	4.45	4.00	4.35
14	2.95	2.67	2.88
15	4.05	4.17	4.08
16	4.10	3.67	4.00

C.2.2 Comments and suggestions

- "The questions should be worth more than chance, so that when you get it right, you have more advantage."
- "After the first test, everyone should advance on to the following topics (which will come out on the second test)."
- "New elements/activities in the game to make it more interactive, like exchanging points, duels between players with the same questions, etc."
- "When you get points for helping and you have the microscope, the points should double/triple. There should be a chance card that allows you to take points from a colleague if you get the question right."
- "Nice! Very useful! I liked it a lot! Good luck!"
- "It was very interesting and interactive, but as an assessment element, it is a bit unfair."
- "The only drawback is that it doesn't match/doesn't coincide with the scheduling of the theoretical classes. I found the game (especially the digital one) to be a fantastic initiative and a way to be assessed without the stress normally associated with that kind of situation."
- "Overall, I really enjoyed the game and its structure. The subject matter covered in the game should go more along with the lessons."
- "A correction when you make mistakes would be helpful to learn more. It could be a more interesting class if you look at the slides at the same time as the professor explains."

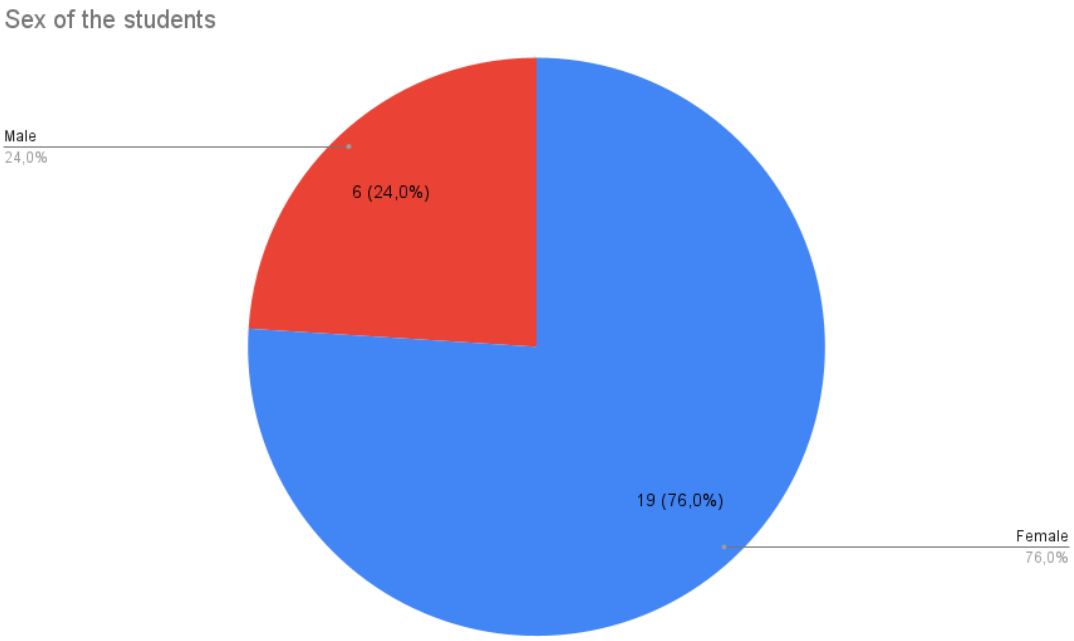


Figure C.4: Sex of the students from the test group

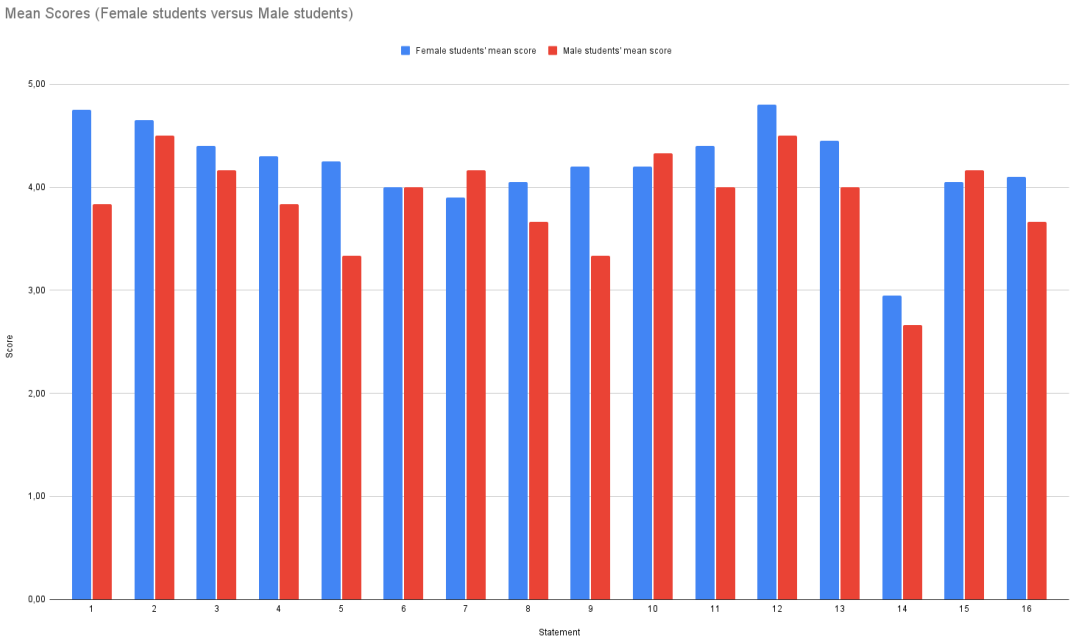


Figure C.5: Mean of the scores given by the students of the test group to the questionnaire's statements (Female students versus Male students)

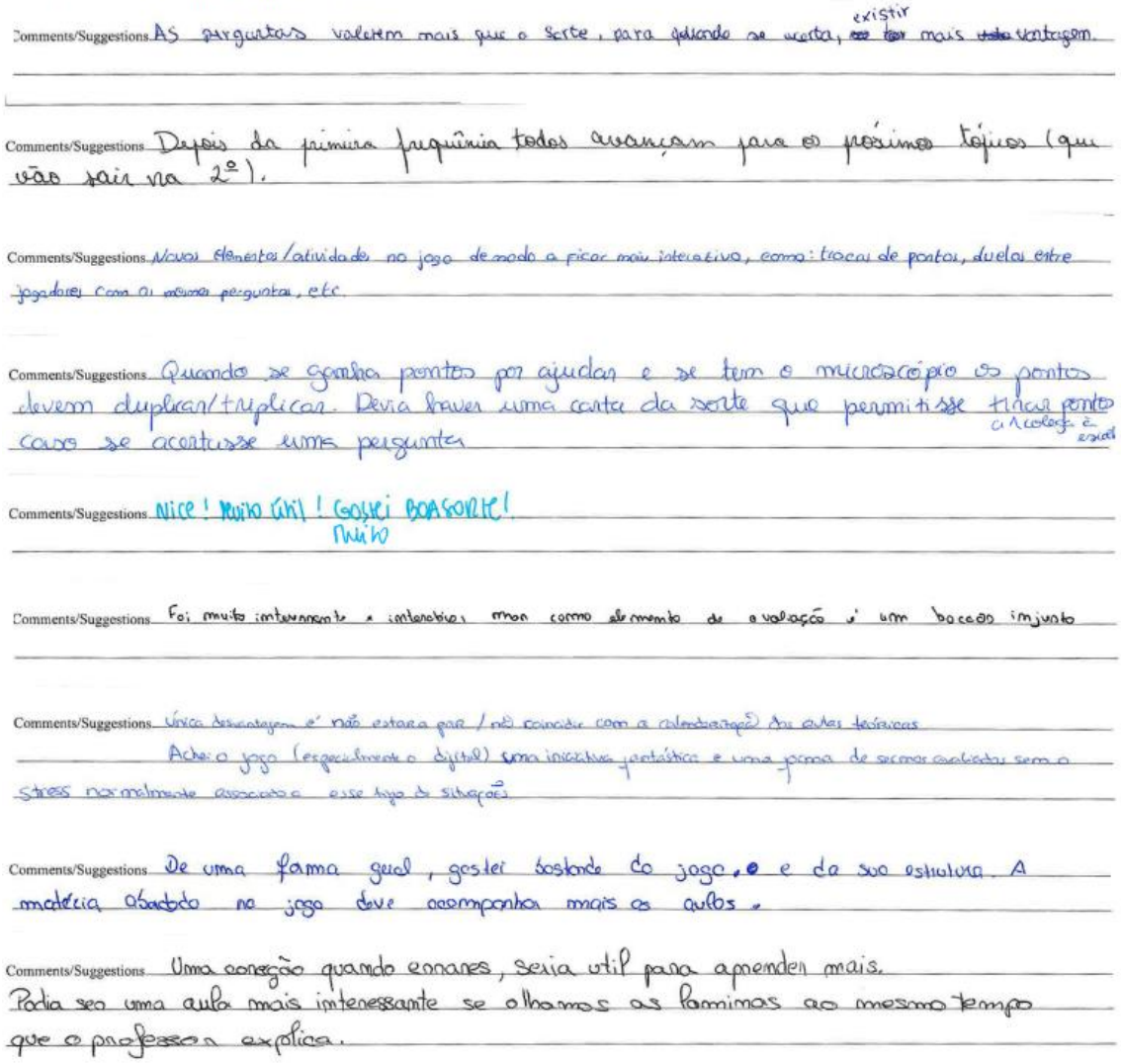


Figure C.6: Comments and suggestions given by some students of the test group

C.3 Comparison between the results of the test group and the control group

Table C.3: Mean of the scores given by the students of the control group and test group to the questionnaires' statements (*despite not registering significant differences between the total students of the two groups, significant differences were noted between the female students of the two groups)

Statement	Control group's mean scores	Test group's mean scores	Significant differences
1	3.79	4.54	Yes p = 0.0005
2	3.89	4.62	Yes p = 0.0097
3	3.54	4.35	Yes p = 0.0018

4	4.25	4.19	No
5	3.67	4.04	No (p = 0.086)*
6	4.25	4.00	No
7	3.96	3.96	No
8	4.14	3.96	No
9	3.64	4.00	No (p = 0.083)*
10	3.70	4.23	Yes p = 0.015
11	3.71	4.31	Yes p = 0.025
12	3.07	4.73	Yes p = 0.0001
13	3.43	4.35	Yes p = 0.001
14	3.21	2.88	No
15	3.86	4.08	No
16	3.46	4.00	Yes p = 0.03

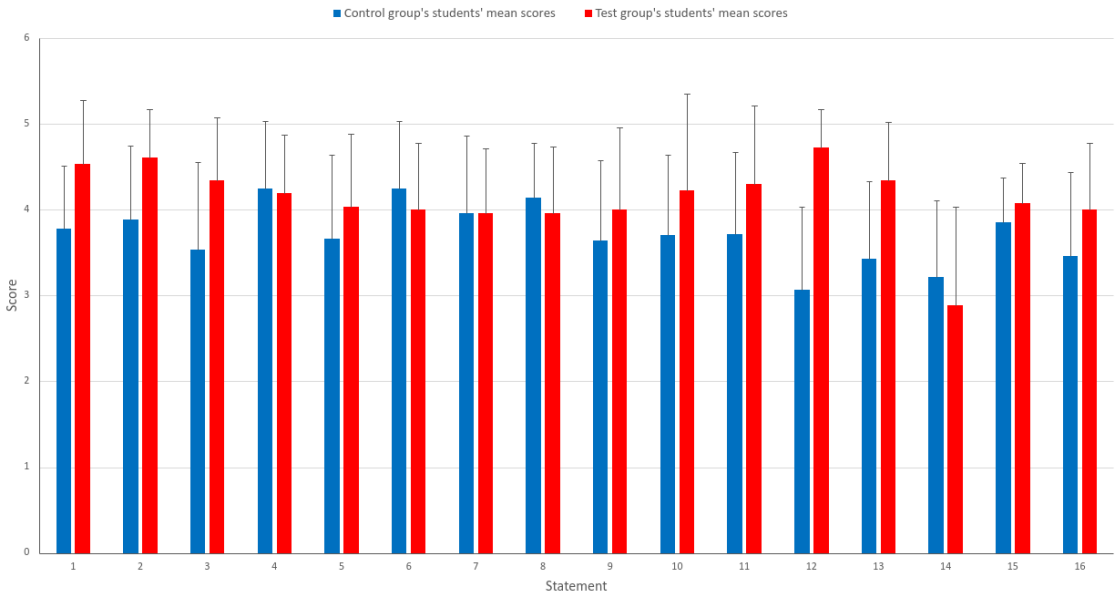


Figure C.7: Mean of the scores given by the students to the questionnaires' statements (Control group's students versus Test group's students)

Table C.4: Mean of the scores given by the female students of the control group and test group to the questionnaires' statements

Statement	Control group's female students' mean scores	Test group's female students' mean scores
1	3.78	4.75
2	3.83	4.65
3	3.48	4.40
4	4.22	4.30
5	3.64	4.25
6	4.26	4.00
7	3.91	3.90
8	4.09	4.05
9	3.61	4.20
10	3.64	4.20
11	3.70	4.40
12	2.96	4.80
13	3.39	4.45
14	3.48	2.95
15	3.83	4.05
16	3.35	4.10

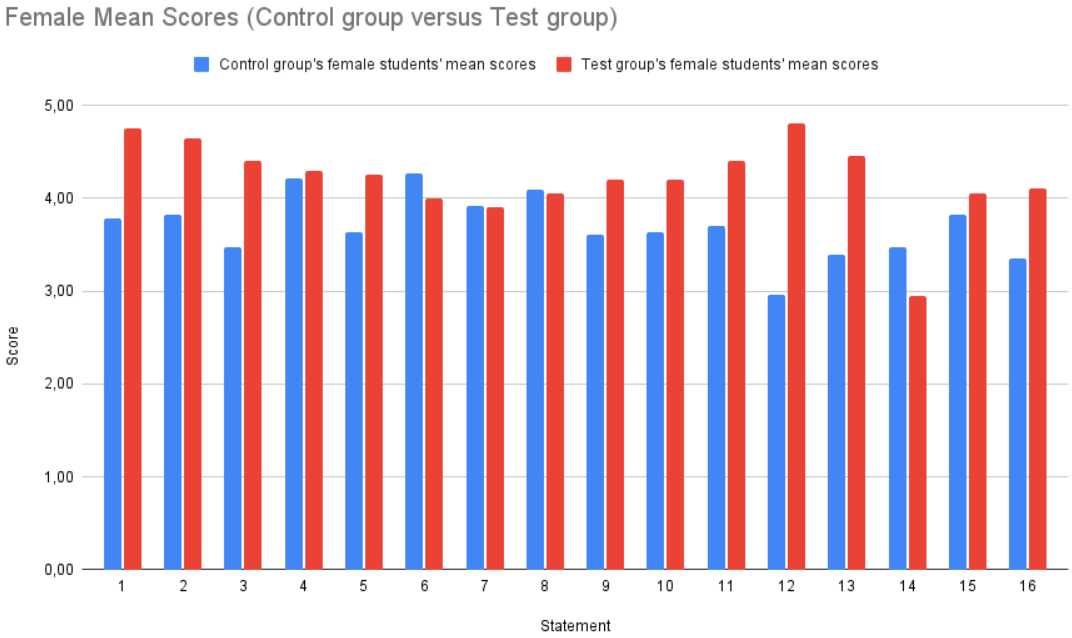


Figure C.8: Mean of the scores given by the female students to the questionnaires' statements (Control group's female students versus Test group's female students)

Table C.5: Mean of the scores given by the male students of the control group and test group to the questionnaires' statements

Statement	**Control group's male students' mean scores**	**Test group's male students' mean scores**
1	3.80	3.83
2	4.20	4.50
3	3.80	4.17
4	4.40	3.83
5	3.80	3.33
6	4.20	4.00
7	4.20	4.17
8	4.40	3.67
9	3.80	3.33
10	4.00	4.33
11	3.80	4.00
12	3.60	4.50
13	3.60	4.00
14	2.00	2.67
15	4.00	4.17
16	4.00	3.67

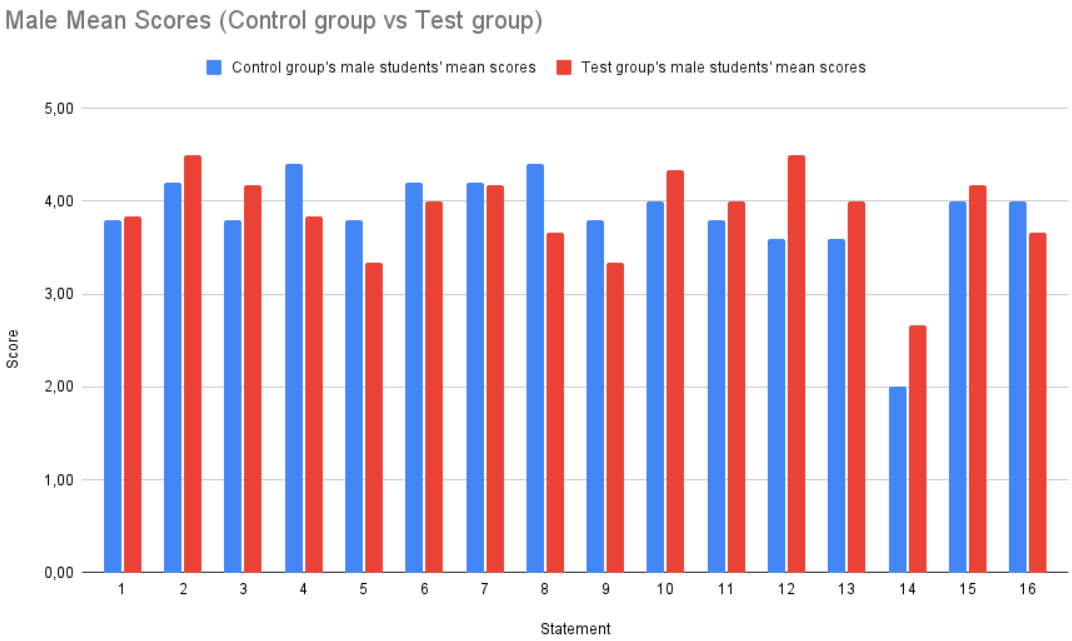


Figure C.9: Mean of the scores given by the male students to the questionnaires' statements (Control group's male students versus Test group's male students)

Appendix D

Experts' questionnaire

1. The game would increase students' motivation.
2. The game would be useful for the class activities.
3. The game could be easily integrated with the other class activities.
4. The Admin Back-office presents an interactive and straightforward interface.
5. It is easy to edit the game board and add game elements (questions, cards, and badges).

- Global evaluation
- Negative points
- Positive points
- Suggestions for Change / Comments
- Comments on the Admin Back-office

D.1 Results

Table D.1: Scores given by the experts to the questionnaire's statements

Statement	Participant 1	Participant 2	Participant 3
1	5	4	5
2	5	4	5
3	4	5	4
4	5	4	5
5	5	4	5

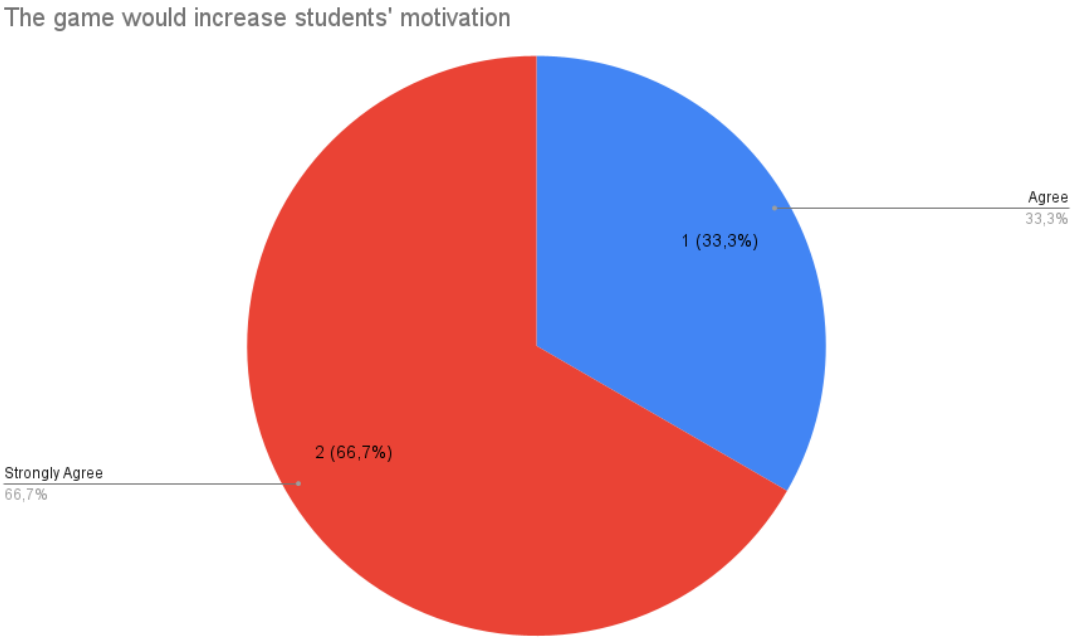


Figure D.1: Evaluations given by the experts to the first statement of the questionnaire

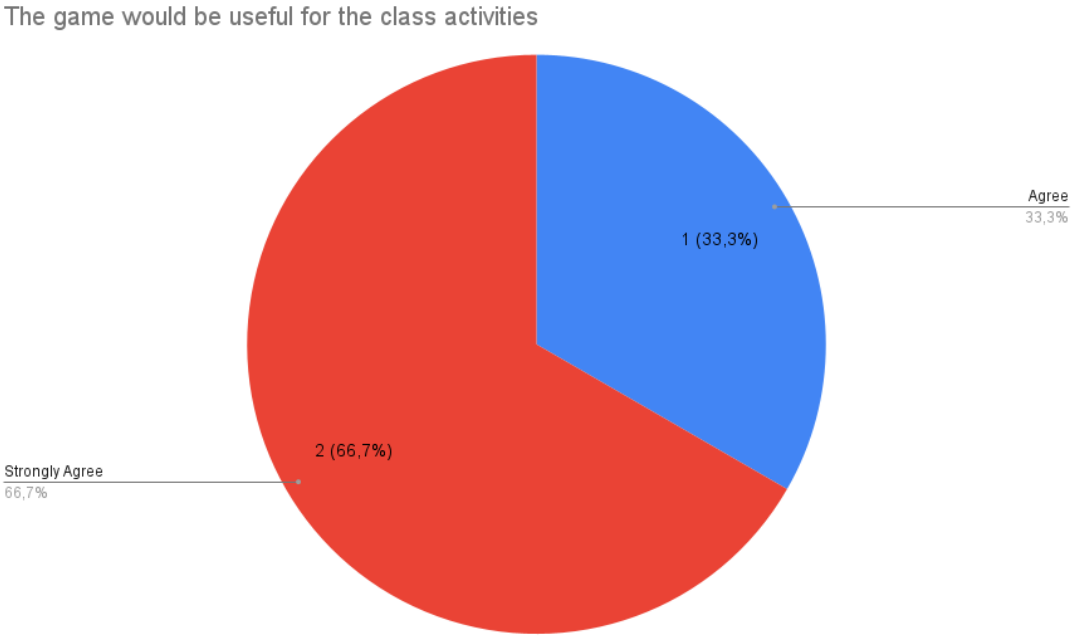


Figure D.2: Evaluations given by the experts to the second statement of the questionnaire

D.2 Global evaluation

- Participant 1:

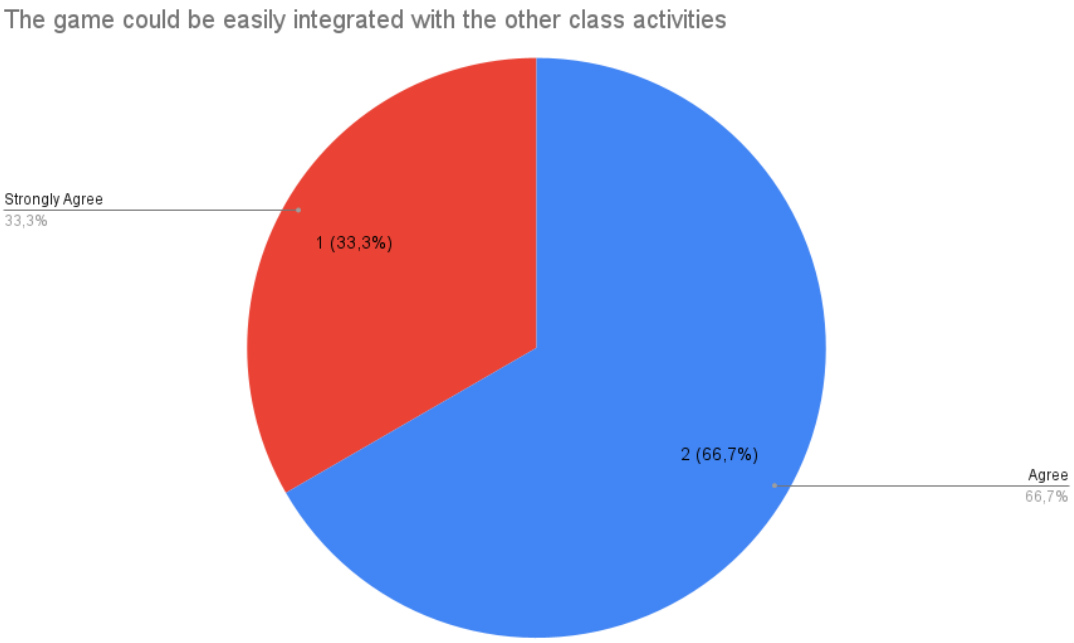


Figure D.3: Evaluations given by the experts to the third statement of the questionnaire

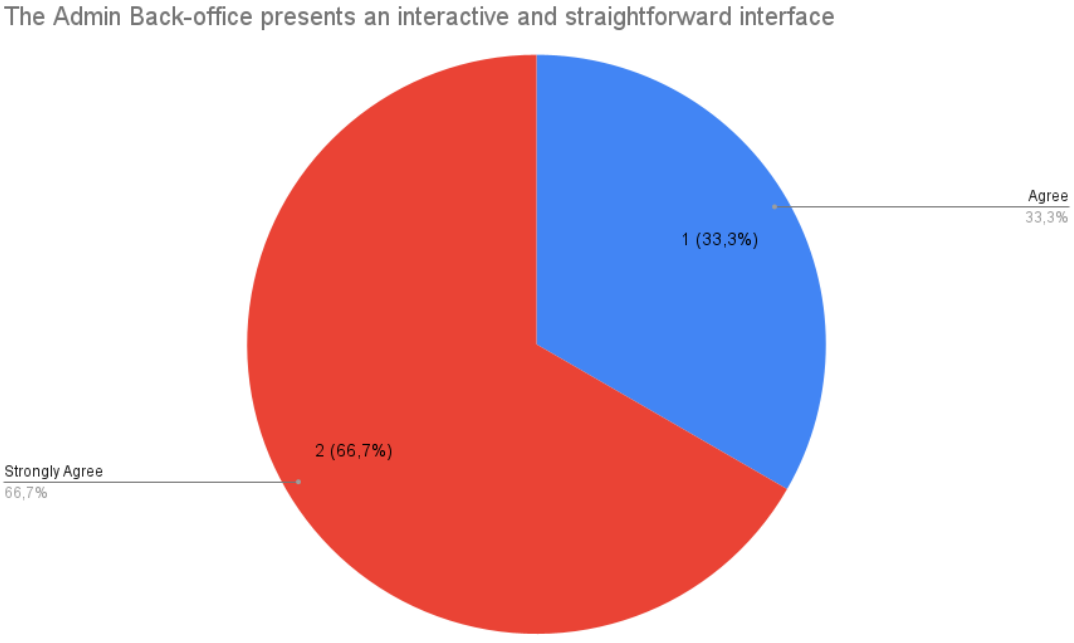


Figure D.4: Evaluations given by the experts to the fourth statement of the questionnaire

– "The game will allow us to respond to the characteristics of today's university population, namely by getting them to have a more active attitude in the classroom. It will be a chance to consolidate learning and test knowledge. The version played on

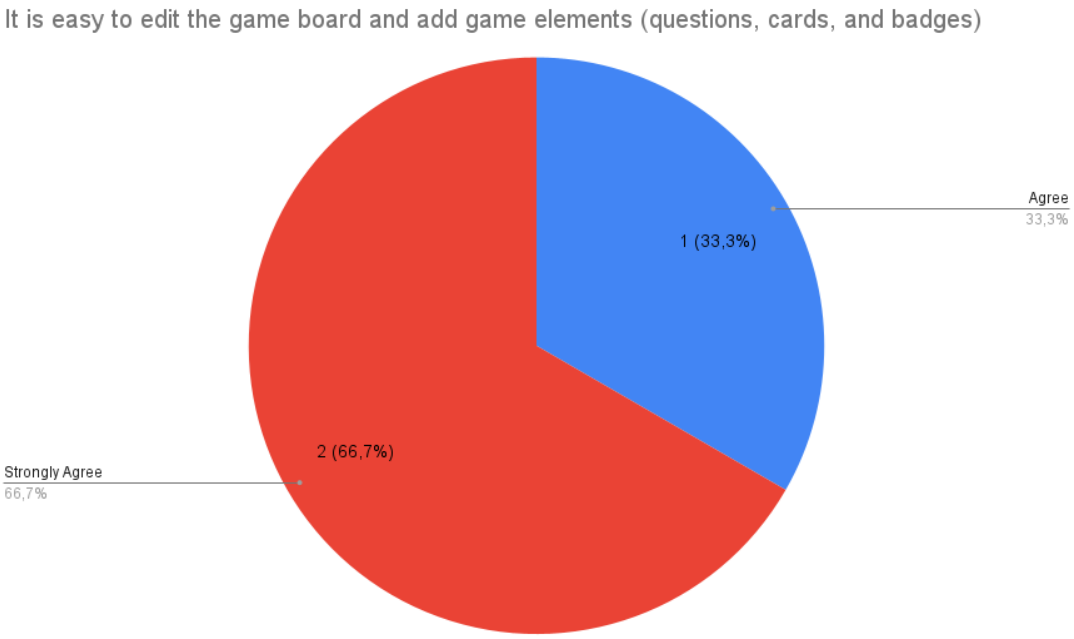


Figure D.5: Evaluations given by the experts to the fifth statement of the questionnaire

a cell phone is an added value that reinforces the adaptation to the reality of today's university population. Compared to the board version, which I already knew, I think it was a huge improvement."

- Participant 2:
  - "This game is a complementary pedagogical modality adequate to the reality of medical students. I believe that it will stimulate a more significant active participation, when compared to the traditional teaching of Histology, especially in the current generations of students. I think that the game is a very useful tool also in distance classes where it is more difficult to capture the students' attention."
- Participant 3:
  - "The game introduces a new dynamic between the students and the professor, allowing an interactive and relaxed way to integrate and continuously evaluate the lectured subject. The evaluation in this format relieves the pressure associated with the usual assessments, such as mini-tests and class questions. Being a game with the awarding of points and podium, it enhances the motivation of students to prepare and study the content already taught, in order to gain points and get a good place in the classification."

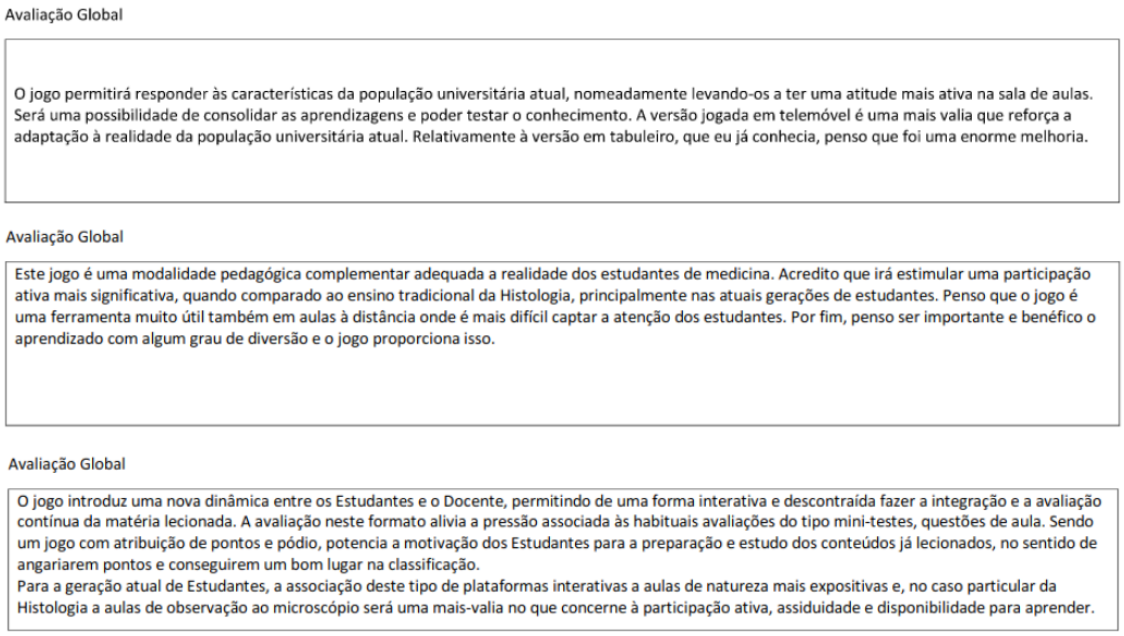


Figure D.6: Global evaluation given by the experts

  - "For the current generation of students, the association of this type of interactive platform with more expository classes and, in the particular case of Histology, with microscope observation classes will be an added value when it comes to active participation, attendance, and availability to learn."

D.3 Negative points

- Participant 1:
  - "I don't see any negative points, as long as the rooms in which it is played have good internet access. We recently had to do an intervention in the rooms precisely to guarantee equity for all students."
- Participant 2:
  - "Limitation of playing in large classes."
  - "Difficulty in having questions with the same degree of difficulty for all students due to chance associated with the throwing of the dice."
- Participant 3:
  - "Podium displayed throughout the game."
  - "Large space occupied by the podium and the player's avatar relative to the virtual game board."
  - "The tile where the player is after the dice roll is not highlighted."

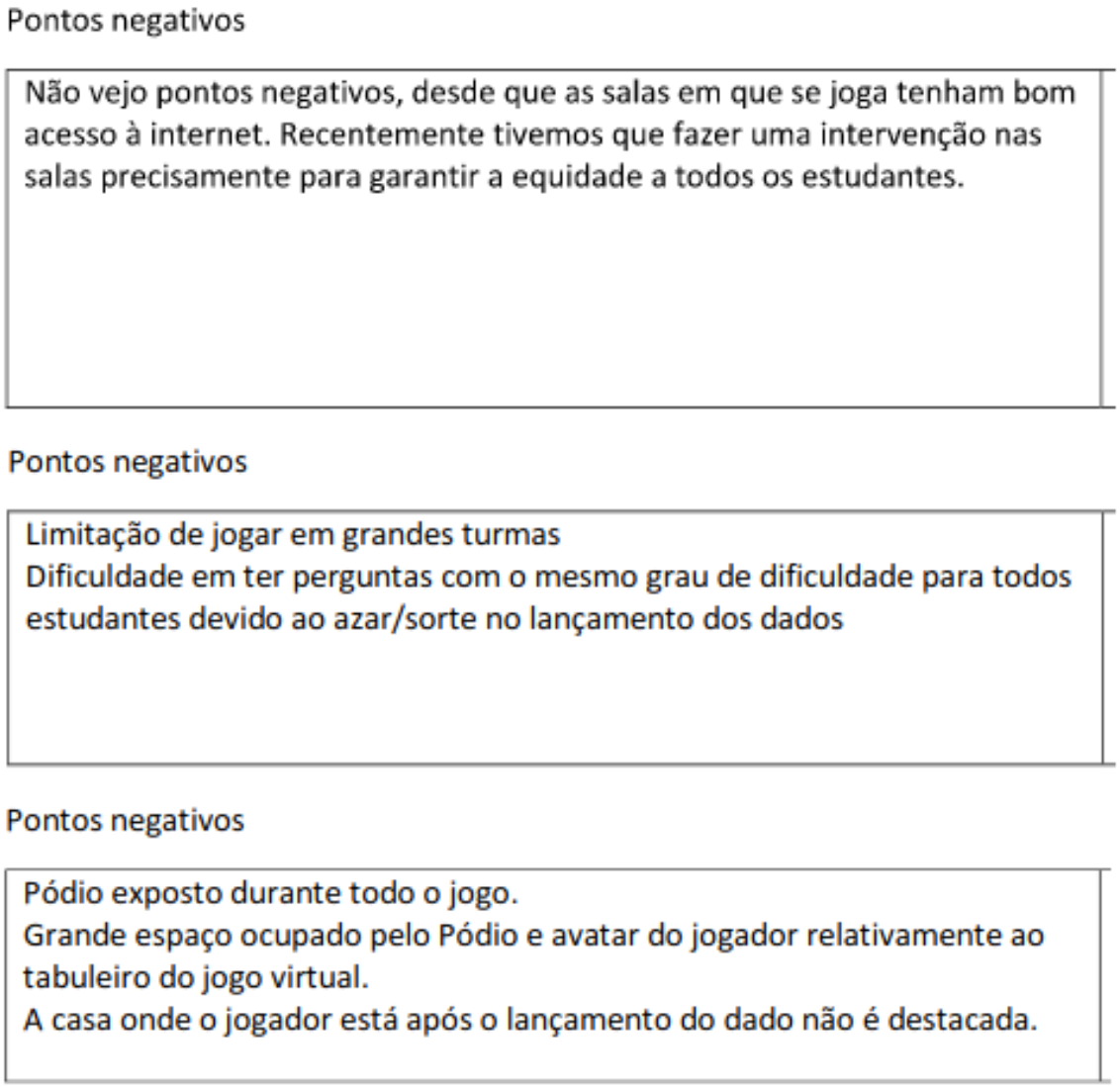


Figure D.7: Negative points given by the experts

D.4 Positive points

- Participant 1:
  - "In addition to those mentioned in the "global evaluation", I highlight the versatility of the game, namely the possibility of adapting it to various themes, as we were told."
  - "Easy to use."
  - "Not at all monotonous."
- Participant 2:
  - "Active student participation."
  - "Possibility of student evaluation."

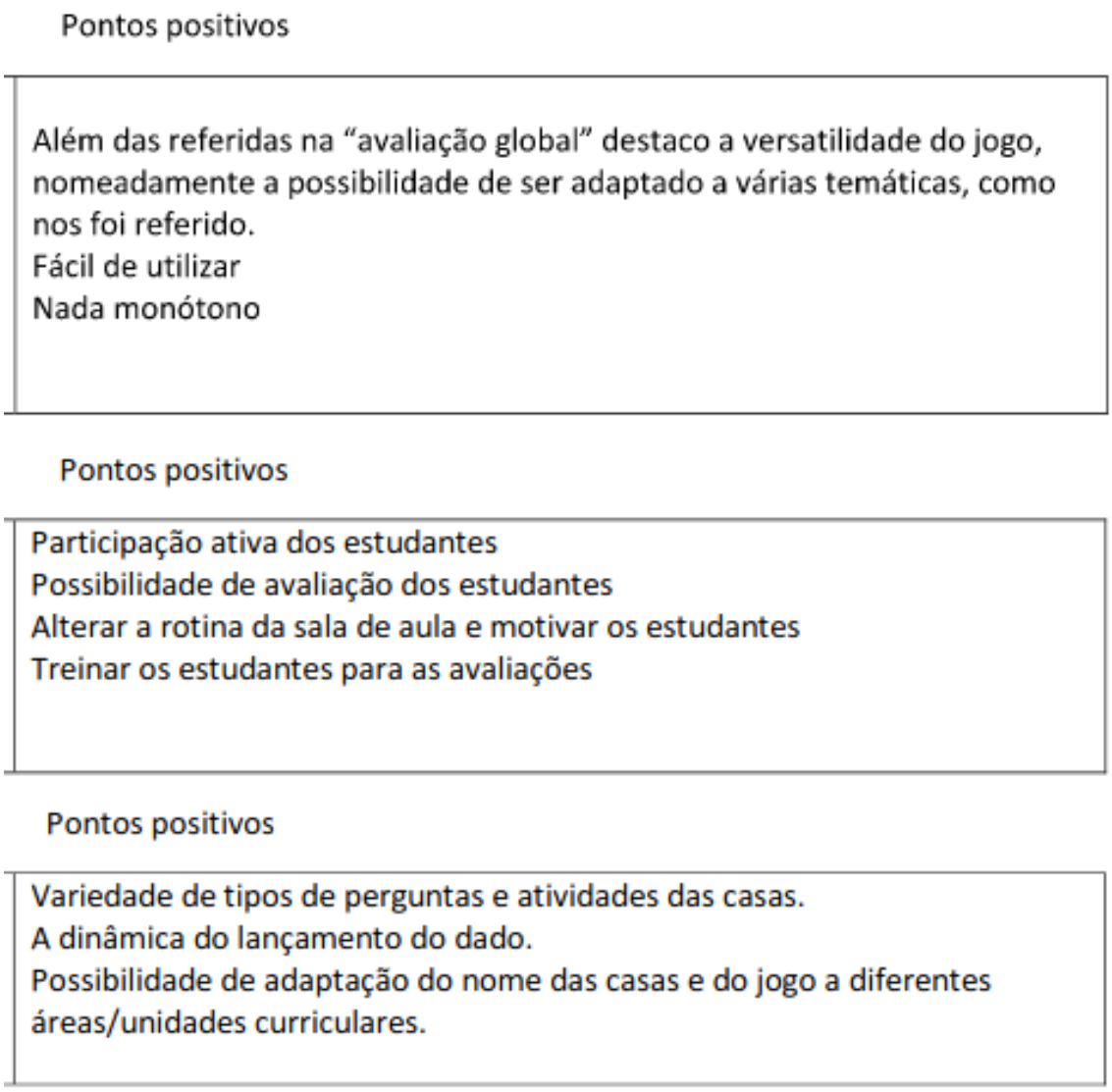


Figure D.8: Positive points given by the experts

  - "Change the classroom routine and motivate students."
  - "Train the students for the assessments."

- Participant 3:

  - "Variety of question types and tile activities."
  - "The dynamics of the dice roll."
  - "Possibility of adapting the name of the tiles and the game to different areas/courses."

D.5 Suggested changes/comments

- Participant 1:

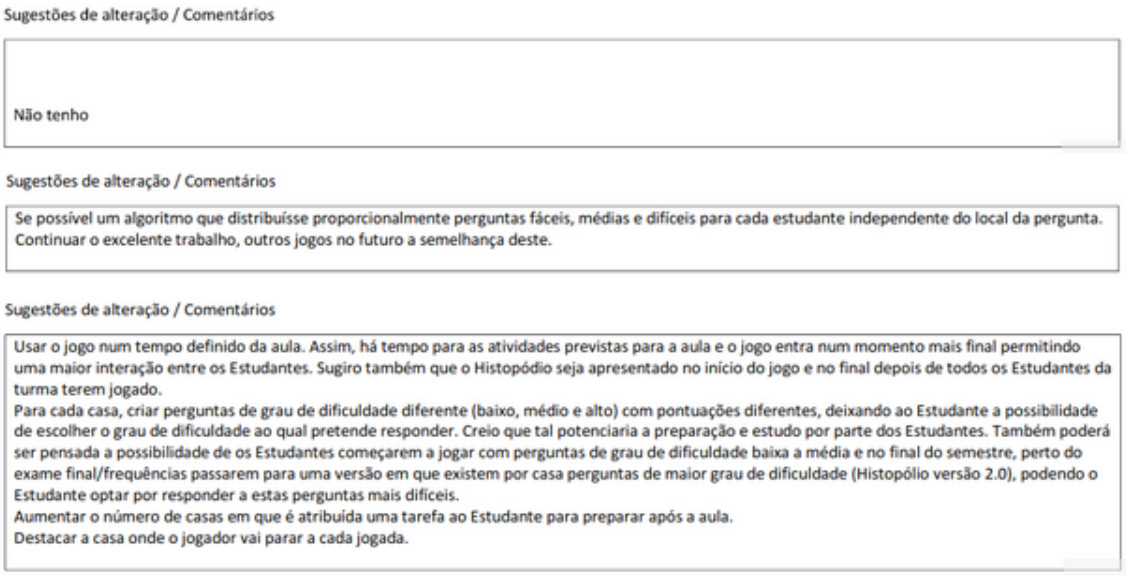


Figure D.9: Suggested changes and comments given by the experts

  - "I don't have any."

- Participant 2:
  - "If possible, an algorithm that would proportionally distribute easy, medium, and hard questions to each student regardless of the question location."
  - "Keep up the great work, other games in the future like this one."

- Participant 3:
  - "Use the game at a set time in the lesson. This way, there is time for the activities planned for the lesson and the game comes in at a more final moment allowing for more interaction among the Students. I also suggest that the "Histopódio" should be presented at the beginning of the game and at the end after all Students in the class have played."
  - "For each tile, create questions of different degrees of difficulty (low, medium, and high) with different scores, allowing the Student to choose the degree of difficulty to which they want to answer. I believe that this would improve the preparation and study on the part of the Students. We could also consider the possibility of having the Students start playing with questions of low to medium difficulty and, at the end of the semester, close to the final/frequency exam, switch to a version in which there are higher difficulty questions (Histopoly version 2.0), and the Student could choose to answer these more difficult questions."
  - "Increase the number of tiles in which the Student is assigned a task to prepare after class."
  - "Highlight the tile where the player will stop on each turn."

D.6 Comments on the Admin Back-office

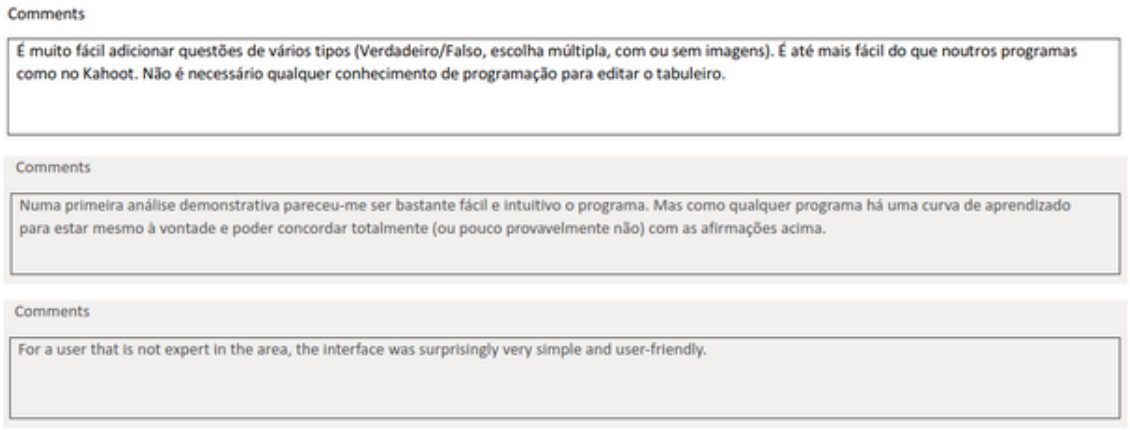


Figure D.10: Comments on the Admin Back-office given by the experts

- Participant 1:
  - "It is very easy to add questions of various types (True/False, multiple-choice, with or without pictures). It is even easier than in other programs such as Kahoot. No programming knowledge is required to edit the board."
- Participant 2:
  - "In a first demo review, it seemed to me that the program was quite easy and intuitive. But like any program, there is a learning curve to really get comfortable and be able to fully agree (or slightly probably not) with the statements above."
- Participant 3:
  - "For a user that is not an expert in the area, the interface was surprisingly very simple and user-friendly."