Immune Survivors: A Serious Game for Raising Immune System Awareness

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ABSTRACT

The immune system is a crucial and relevant component of the human body, yet many people lack awareness on it. To address this, we developed a serious game called *Immune Survivors* that aims to spread awareness about the immune system while providing an engaging gameplay loop. In this paper, we discuss the design, implementation, and evaluation of *Immune Survivors*, and how we aligned it to a set of target learning objectives about the immune system. *Immune Survivors* is a "bullet heaven" game where you play the role of immune cells aiming to protect the human body from invading pathogens. Quasi-experimental results on late high school to early college students reveal significant learning gains, as measured through a pre-test and post-test, after an hour of playing the game. Furthermore, the results suggest that more substantial learning gains can be observed on concepts that were integrated into the gameplay in a more critical and ubiquitous way. These findings show the potential of serious games as a tool to supplement gaps in education while highlighting the need for deeper studies within this domain.

CCS CONCEPTS

• **Applied computing** → **Interactive learning environments**; **Computer games**; **E-learning**;

KEYWORDS

serious games, e-learning, immune system

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1 INTRODUCTION

Serious games have demonstrated great potential in education and in raising awareness. A serious game is a game that is designed with a primary goal – usually education, apart from just mere entertainment [6]. Serious games, both as an industry and as a research field, has seen continuous growth in recent years, underscoring its relevance and promise [15, 25]. They are commonly used in education and training, and has seen applications in a wide variety of domains. Some recent applications of serious games include skills development for kids with autism spectrum disorder [8, 13], climate change awareness [11, 19], bullying and cyberbullying prevention [7, 12], and disaster training and response [10, 20].

The potential of serious games in learning and raising awareness is attributed to the idea that students can learn more effectively when they are engaged. Research has shown that positive affective states such as engagement positively impacts learning, in contrast to negative affective states like boredom [5]. Games have been shown to enable emotion formation effectively, and thus are appropriate mediums to induce positive engagement on players to facilitate learning [18]. Apart from this, games have the potential to introduce to its players concepts and ideas that they would otherwise be uninterested to explore on their own. As such, serious games can be used to entice people to explore and learn about topics that are normally not given much attention in standard learning curricula but are nonetheless important to life and society.

The immune system is an example of an important and relevant, yet often overlooked topic. The immune system is an integral part of the human body tasked with protecting us from diseases, viruses, pathogens, and other entities that may bring harm. Despite the critical role that it plays in our lives, many people have a surface level understanding of the immune system or may even have misconceptions on how it functions [4, 17]. In the Philippine curriculum, various systems in the human body are introduced from 6th grade to 12th grade, but it fails to provide coverage on the immune system and immunology [22–24]. Although parts of the immune system may be covered within other topics, a search in the Department of Education learning portal does not reveal any material or module that provides a substantial coverage of the immune system [1]. This is quite surprising considering the crucial role the immune system plays in our bodies. The COVID-19 pandemic has further underscored the importance of awareness about our health, the immune system included. According to Google Trends, searches

for the immune system peaked in the Philippines during March 15 to 21 in the year 2020 [2]. This highlights the increased public interest in learning about the immune system.

Serious games can be a tool to help address the gaps in education, by introducing these concepts to students in an engaging environment. In this paper, we explore the design and development of a serious game for introducing the fundamentals of the immune system called *Immune Tactics*. The game combines the emerging "bullet heaven" genre, which has gained immense popularity in recent years [9], with fundamental immune system concepts to educate players as they play. This paper discusses the design, development, and evaluation of *Immune Survivors*, as well as the key findings and learnings from its implementation.

The paper is structured as follows. Section 2 discusses related serious games that cover the immune sytem. Section 3 discusses the game design and implementation of *Immune Survivors*. Section 4 discusses the evaluation process to test the effectiveness of the game. Section 5 discusses the results and findings. Finally, Section 6 provides conclusions directions for future work.

2 RELATED WORKS

In this section, we introduce related serious games that also aim to teach concepts about the immune system.

2.1 ImmuneQuest

ImmuneQuest is a serious game that aims to teach players immunology [3]. In the game, players take the role of a scientist who must build and control a virtual immune system to defend their human host from increasingly cunning microbes. It is a turn-based strategy game, akin to a board game, where you control units of the immune system to protect the body from enemies. Each unit has abilities and properties based on their real-world counterparts. Learning takes place through a combination of participating in the gameplay, and through tooltips and messages that occasionally pop-up to provide more information about the concepts.
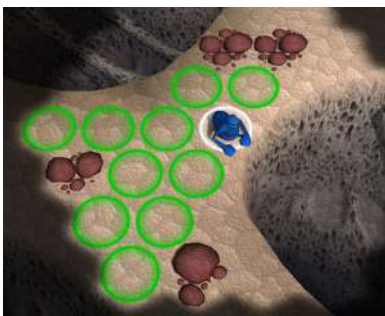

Figure 1: ImmuneQuest gameplay screenshot

The game plays out like a campaign. The story introduces different aspects of the immune system, from macrophages, neutrophils, blood vessels, and how they interact with one another. However, so far only the first two parts have been published, covering the topic of "innate immunity". Due the nature of the gameplay, replayability can be limited, as once the campaign has been completed there is little reason to play it again.

Empirical evaluation has shown that ImmuneQuest led to positive learning effects in an undergradute immunology course, as measured through pre-tests and post-tests [21]. The evaluation also revealed that the average enjoyability rating of the game was 6.6 / 10. Furthermore, many students found the game to be "frustrating". These can be attributed to the serious presentation and nature of the gameplay. Nonetheless, *ImmuneQuest* remains to be a solid evidence that serious games can indeed help educate people in serious topics like the immune system, although it is mainly targeted towards undergraduate biology majors, as it requires some preliminary knowledge.

2.2 Immune Attack / Immune Defense

Immune Attack and *Immune Defense* are strategy games about molecular immunity [16]. In both of these games, the player assumes the role of the immune system. At its core, it is a shooter strategy game, with the main control being the mouse. Both games follow a handcrafted script that follows a story, designed to introduce immunology concepts to the students. Empirical tests revealed that those who played *Immune Attack* demonstrated better performance on a test of cellular immunology, and had better self-confidence than their classmates who played a control video game [26]. However, the increase in confidence was only observed on the non-gamer group, and a positive correlation was observed between understanding of the game mechanisms and the improvement in performance, which suggest that learning is more effective when the students understand and enjoy the game.

2.3 Conflict: Immunity Game

Conflict: Immunity Game is a web game by BioMan, a web site containing various virtual labs and games about biology. The game is a simple game that introduces the functions of the different white blood cells. Pop-up message show the functions of each white blood cells, then the player is tasked to control these cells through simple actions, such as moving a macrophage towards a pathrogen, or using the space bar to shoot antibodies on a pathogen.
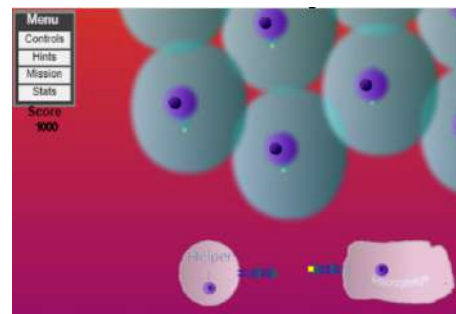

Figure 2: Conflict: Immunity gameplay screenshot

While the game is straightforward and easy to understand, there is not much complexity in its gameplay. Furthermore, to the authors' knowledge, there has not been any empirical evaluation on the effectiveness of *Conflict: Immunity Game* in terms of its learning effects or learning.

Table 1: Summary of Published Serious Games that Teach Immune System Concepts

Game	Genre	Demographic	Evaluation	Key Findings
ImmuneQuest	Turn-Based Strategy	undergraduate university students taking immunology	quasi-experiment through pre-test and post-test	positive learning effect, but average enjoyability
Immune Attack / Immune Defense	Shooter Strategy	students (varied)	experiment with a control group playing a game unrelated to immune system	positive learning effect, increased confidence, but only for gamers group
Conflict: Immunity Game	Action	students (varied)	no evaluation	
Cells of War	Card Game	anyone	perceived quality evaluation only using MEEGA+	majority reported perceived positive learning and engagement

2.4 Cells of War

Finally, a serious game called *Cells of War* was proposed in 2018. It is a card game that aims to teach players the complex functionalities of the immune system, as well various daily habits affect a person's health [14]. It is quite challenging to find detailed information about this game, as it appears to have not been published publicly. However, its gameplay was described as a turn-based card game where the player can a variety of cards related to the immune system. The goal of the game is to prevent the player's health from dropping below zero while attempting to reach level 50.

Figure 3: Some cards in the game Cells of War [14]

A pilot evaluation of *Cells of War* was conducted using the MEEGA+ model, which examines the perceived quality of a serious game through two aspects: perceived learning and player experience. Majority of the participant reported that they learning something new by playing the game, although they did not consider that the topics were important to them. Majority of the players also reported that the game was fun, but only a minority reported that they were immersed in the game. These results show potential for the game, but may need further verification to assess its real learning potential, as perceived learning does not always equate to actual learning.

2.5 Summary

There are not a lot of serious games developed about the immune system, and even less have been empirically evaluated for their effectiveness. Nonetheless, the games discussed in this section show that there is potential for serious games to be used in this domain. Furthermore, it appears that player experience plays an important role in the impact of a game in terms of learning. Table 1 summarizes the games discussed in this section. In this paper, we present a serious game for learning immune system awareness called *Immune Survivors* targeted towards high school and early undergraduate students, taking into consideration the insights from the above related games. We also present a detailed empirical evaluation on its effectiveness.

3 THE DESIGN OF IMMUNE SURVIVORS

In this section, we discuss the design and implementation of *Immune Survivors* – the serious game we developed for raising immune system awareness.

3.1 Learning Objectives

The game is aimed at three learning objectives:

- **LO1:** To leave players with a better appreciation for the role of the immune system and its significance in protecting the human body.
- **LO2:** To learn about the common elements involved in the process of the immune system in fighting off bacteria and viruses.
- **LO3:** To raise awareness of the implicit and explicit factors that could affect the immune system and its ability to protect the body from foreign entities.

3.2 Game Mechanics

The game is set in a microscopic view of the human body, artistically interpreted as a miniature city. At the start of the game, the player takes the role of a newly formed immune cell who is tasked with defending the body from a horde of invading pathogens. The gameplay follows a "bullet heaven" type of gameplay, a variant of the roguelite genre popularized by titles such as *Vampire Survivors* and *Brotato*. Figure 4 shows a screenshot of the game.

In the game, the player controls a set of immune cells that move around the map while dodging pathogens. The immune cell automatically attacks when there are nearby enemies. Each type of

Figure 4: Screenshot of *Immune Survivors*

immune cell has types of attacks that are aligned with its real-world characteristics of how it fights pathogens. Though some creative liberties were used in depicting the abilities of the immune cells, the general characteristics and properties of each cell type were preserved. Furthermore, the game explains the connection of the in-game representations of the cells with their real-world counterparts through text prompts that show various sorts of real-world information about the immune system.

Over time, other immune cells appear in the level, and can be recruited to increase the number of cells controlled by the player. The player still only controls the main cell, while the other recruited cells hover around the main cell. Once the player collects enough cells of the same type, the cell can be upgraded, and the player is presented a set of choices for the upgrade. These choices are randomly selected from a pool of possible upgrades for each cell. Most upgrades are based on characteristics of the immune cells in real life or factors that affect the immune system in some way.

When pathogens are defeated, they sometimes drop antigens which the dendritic cell can collect. The number of antigens collected is displayed in the game HUD as well. Once enough antigens are collected, helper T-Cells and B-Cells can be activated on the map. These cells are powerful units that provide huge utility in eliminating the pathogens. The helper T-Cell creates a cytokine buff zone around its radius, allowing the player to deal more damage to the pathogens that enter the zone. The B-Cell fires antibodies that shreds the defenses of pathogens that it hits. However, helper T-Cells and B-Cells only work for pathogens with the same type of antibody it was made from. The behavior of antigens, helper T-Cells and B-Cells are based on how these cells function in real life.

The goal of the game is to completely eradicate the ongoing infection by defeating all the pathogens within the level time. On the other hand, the player loses when the player's health, which is affected by the amount of infection in the body, reaches zero. The player's health is represented as a bar at the top of the HUD.

Each level is designed around a particular symptom. Symptoms are environmental hazards that first occur after 30 seconds, after which they will then occur every minute mark on the timer. Symptoms are different each level they are in. In the current version of the game used for testing, there are three levels. The first level has no symptoms. The second level focuses on fever, while the

third level focuses on cough. In the "fever" symptom, the body temperature momentarily rises, causing the player as well as all enemies to gain a damage over time debuff. The duration of the fever varies from one occurrence to another. In the "cough" symptom, a warning shows up in one of the cardinal directions. After the warning, all enemies will get pushed in the opposite direction of the warning. These symptoms are also accompanied with the relevant information regarding their real-life manifestations and how they affect the immune system response.
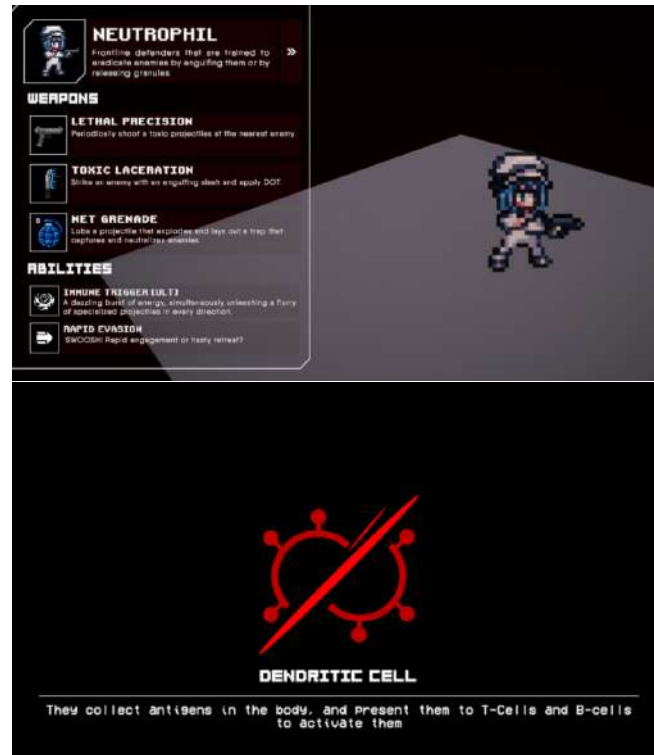

Figure 5: Text and Visual Prompts Used to Reinforce Immune System Concepts to the Player

3.3 Alignment to Learning Objectives

Immune Survivors is designed to facilitate learning through its core gameplay elements, as well as through supplementary prompts that introduce the player to the real-world concepts.

The game mechanics of *Immune Survivors* were designed in such a way that they aligned learning objectives described above. The game was developed using an iterative process of prototyping and playtesting, and the design process was done in consultation with a health expert who provided invaluable feedback and guidance. The following subsections describe how the game addresses each learning objective.

3.3.1 Appreciation of the Role of the Immune System (LO1). This is reinforced in the game by having the player control the elements of the immune system themself, giving them a feel of the role of the immune system, the threats that it faces, and how it protects the human body.

3.3.2 Knowing the Elements of the Immune System Response (LO2). This is taught to the player through the different units in the game, which were intentionally designed to have characteristics close to their real-world counterparts. For example, macrophages are specialized white blood cells that play an important role in maintaining homeostasis and protecting the body from diseases, which can engulf and destroy a wide range of pathogens like bacteria. In the game, this cell was designed as a tanky unit that specialized in engulfing swarms of bacteria.

3.3.3 Awareness on Factors that Affect the Human Body (LO3). Different levels in the game as designed around different "symptoms", which involve specific factors that affect the human body. The current version of the game, which was used for testing, contained three levels. The first level had no additional factors. The second level is a level where the human host is experiencing a fever, and the third level is a level where the human host is experiencing a cough.

In addition to these, learning is also facilitated through informative text and visual prompts that explain the relationship of the in-game components with their real-life counterparts. These are intended to help reinforce to the player the connection between the game mechanics to how the immune system actually functions. Figure 5 some examples of these text and visual prompts.

4 EVALUATION

This section discusses the evaluation process we used to measure the effectivenes of the serious game. The evaluation process can be divided into three phases: the pre-test, play session, and post-test.

To do this, we conducted a playtesting session on students. We asked the participants to answer a pre-test and post-test questionnaire to measure the effects of playing the game. This section discusses the evaluation process, the results, and a discussion on its implications.

4.1 Participants

Following the target demographic of *Immune Survivors*, we recruited senior high school students as well as first year college students from De La Salle University Integrated School and De La Salle University Science and Technology Complex for the evaluation process. A total of 21 students participated in the evaluation process. Among them, 13 (61.9%) are first year college students and 8 (38.1%) are senior high school students.

The subjects voluntarily expressed their interest to participate in the evaluation process, through an open recruitment call. The relevant informed consent forms were administered to the participants, and the evaluation procedures, including how their data will be stored and processed, were properly explained to the participants prior to their commitment.

4.2 Evaluation Methodology

The evaluation methodology followed a quasi-experimental setup, and was comprised of three phases: the pre-test, play session, and post-test.

4.2.1 Pre-test. The pre-test consists of a set of questions administered to each subject prior to playing the game. It consisted of two

Table 2: Selected Questions from the Pre-Test and Post-Test Under Each Learning Objective

Learning Objective	Sample Questions
LO1. To leave players with a better appreciation for the role of the immune system and its significance in protecting the human body. **(2 questions)**	What do you believe is the main function of the human immune system? Which of the following is not a key function of the immune system?
LO2. To learn about the common elements involved in the process of the immune system in fighting off bacteria and viruses. **(9 questions)**	Which of the following are part/s of the immune system? What is the primary role of the neutrophil in the immune system? Which of the immune cells is the first to respond during bacterial infection?
LO3. To raise awareness of the implicit and explicit factors that could affect the immune system and its ability to protect the body from foreign entities. **(7 questions)**	What is the primary purpose of a fever in the body? When should you consider seeking medical attention for a fever? Which of the following is the best way to help our immune cells fight infection?

parts. The first part contained background questions to get a better background on the student demographics and their exposure to immune system concepts. The second part contained 18 questions about immune system concepts, which all aligned with one of the three learning outcomes in this study. The 18 questions are worth 25 points, as some of the questions involve multiple answers. All these questions are multiple choice questions, so as the facilitate more objective scoring.

The questions were designed to align with the learning objectives defined in section 3.1 to ensure that they were measuring the intended objectives the game was designed for. Table 2 shows selected questions under each learning objective.

Each subject was given 20 minutes to answer the questions. The subjects were not allowed to look at any other materials while answering the pre-test. The scores of each subject, as well as the average and median scores were used to characterize the general level of understanding of the subjects about the immune system prior to playing the game. After the pre-test, the subjects were not informed about the results, nor which items they answered correctly or incorrectly. This information was only revealed to the subjects at the end of the whole evaluation process, to minimize bias in the post-test.

4.2.2 Play Session. After the pre-test, each subject was asked to play the game. The play session was mostly unrestricted; the subjects can explore the game to their hearts' content, as long as they stay in the game and play through (not necessarily beat) at least three levels by the end of the play session. The play session lasted for 60 minutes. During the play session, the subjects were

not given any additional guidance or prompts from the researchers, allowing the game itself to deliver the intended experience to the players.

4.2.3 Post-test. After the play session, the subjects were asked to answer the post-test. The post-test also consisted of two parts. The first contained a list of questions asking for feedback on the play session. This was to gain a better understanding of the students's self-reported experiences while playing the game. The second part contained the same 18 questions testing the subjects' knowledge and understanding of the immune system. Note that the students were not given the correct answers, nor which items they got right or wrong during the pre-test, so they still had no prior knowledge of the correct answers for the test. The 18 questions are still worth 25 points, as some of the questions contained multiple answers.

Each subject was also given 20 minutes to answer the questions. Similar to the pre-test, the subjects were not allowed to look at any other materials while the post-test was ongoing. The difference in pre-test and post-test scores were used as an empirical measure of learning gains.

5 RESULTS AND FINDINGS

This section discusses the results and findings of the evaluation process, along with an analysis and discussion of its implications.

5.1 Empirical Learning Gains

Figure 6 shows the scores of the test subjects for the pre-test and the post-test questions about the immune system concepts. The average score for the pre-test was 15.2857, while the average score of the post-test was 19.7143. The difference between the post-test and the pre-test average was +4826, with a paired t-test statistic of 7.801 and a p-value of 1.6959×10^{-7}, showing a statistically significant positive effect on the students' understanding of immune system concepts under a significance level of $\alpha = 0.01$.

The standard deviation of the pre-test scores was 2.8835 while the standard deviation of the post-test scores was 1.696, revealing a drop in variance. This highlights the fact that during the pre-test, the subjects' knowledge of the immune system was more variant, as some students already knew a lot about the immune system, but the others knew very little. By the end of the play session, the variance was reduced as most of the subjects who had low scores in the pre-test improved. In fact, subjects who got scores in the pre-test that are lower than the median score of 15 demonstrated the highest learning gains. Subjects below the 50th-percentile of the pre-test had an average improvement of 7.125 in the post-test. These results show promise that *Immune Survivors* was able to impact learning on its players.

5.2 Learning Objective Analysis

To check if the game was able to address its learning objectives, we looked at each group of questions under each learning objective and measured the learning gains for each. Table 3 shows the summary of this analysis. Across the three learning objectives, the evaluation showed a positive learning gain.

The learning objective that saw the most increase was LO2 (+3.0476), which pertained to the knowledge of the components of the immune system and how they function. This was followed by
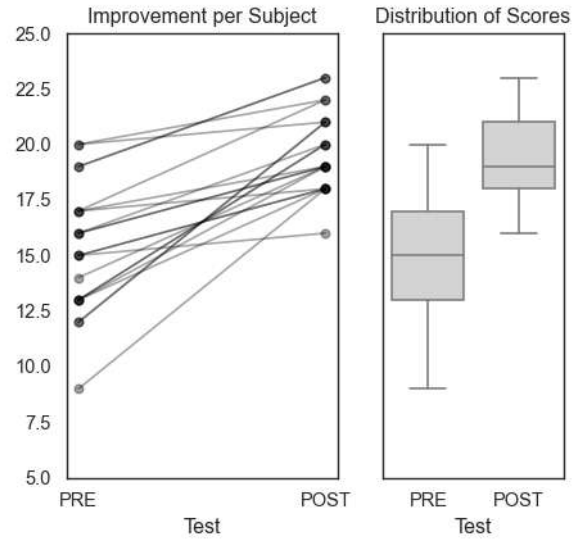

Figure 6: Improvement of scores from pre-test to post-test for each subject (left) and the distribution of scores in the pre-test and post-test (right)

LO3 (+1.2857), which pertained to the awareness of various factors that affect the immune system and their implications to it. Both these learning objectives saw a statistically significant positive difference between the post-test and pre-test scores using a paired t-test under a significance value of $\alpha = 0.01$, indicating empirical evidence of subjects' learning throughout the play session. LO1 also saw a positive learning effect (+0.0952), although it was not statistically significant ($p = 0.5471$). Two factors could have played a role to this. First, there were only two questions under this category, worth only two points. Second, more than half of the participants already scored perfectly in these two questions during the pre-test. These two factors leave not much room for improvement.

Overall, these results indicate *Immune Survivors* is able to show positive learning effects across the defined learning objectives after the hour-long playthrough session.

5.3 Item-Based Analysis

To further expand the insights from this study, we also performed item analysis on the questions with respect to the pre-test and post-test results.

Table 4 shows a list of questions with the lowest and highest number of correct answers during the pre-test. It can be seen that during the pre-test, while most subjects are generally knowledgeable about factors surrounding cough, most subjects were not aware of the components of the immune system and their roles. In addition to this, there were also a lot of incorrect answers on when one should consider seeking medical attention for a fever. These give us a general idea of which aspect students struggle with.

Comparing this with the corresponding post-test results, improvements were observed in terms of the number of wrong answers for every question. However, these improvements are not

Table 3: Observed Learning Gains for Each Learning Objective

Learning Objective	Points Possible	Pre-test Mean	Post-test Mean	Difference	*p*-value
LO1. To leave players with a better appreciation for the role of the immune system and its significance in protecting the human body. **(2 questions)**	2	1.4762	1.5714	+0.0952	0.5471
LO2. To learn about the common elements involved in the process of the immune system in fighting off bacteria and viruses. **(9 questions)**	12	6.000	9.0476	+3.0476	$\mathbf{1.4945 \times 10^{-7}}$
LO3. To raise awareness of the implicit and explicit factors that could affect the immune system and its ability to protect the body from foreign entities. **(7 questions)**	11	7.8095	9.0952	1.2857	**0.0002**

Table 4: Questions with the Highest and Lowest Number of Wrong Answers in the Pre-Test, and the Corresponding Number of Wrong Answers in the Post-Test

ID	Question	Pre-test Wrong Answers	Post-Test Wrong Answers
Highest Number of Wrong Answers in Pre-Test			
Q2	Which of the following are part/s of the immune system?	16	4
Q9	Which of the following is the primary resource that is collected when a bacteria is killed?	15	6
Q14	When should you consider seeking medical attention for a fever?	13	7
Q4	What is the primary role of the macrophage in the immune system?	12	5
Q7	What is the primary role of the B cell in the immune system?	12	9
Q3	What is the primary role of the neutrophil in the immune system?	11	6
Q5	What is the primary role of the dendritic cell in the immune system?	11	9
Lowest Number of Wrong Answers in Pre-Test			
Q15	What is the primary purpose of coughing in the body?	1	0
Q17	Which of the following is the best way to help our immune cells fight infection?	2	0
Q1	What do you believe is the main function of the human immune system?	4	0
Q16	Which of the following is a sign that a cough is becoming more serious?	6	4

equal. Q2 (Which of the following are part/s of the immune system?) showed the highest improvement, with a difference of 12. Likewise, Q14 (When should you consider seeking medical attention for a fever?), Q9 (Which of the following is the primary resource that is collected when a bacteria is killed?), Q4 (What is the primary role of the macrophage in the immune system?), and Q3 (What is the primary role of the neutrophil in the immune system?) showed decent improvement as well, with differences in the range of 6 to 9. In contrast, Q5 (What is the primary role of the dendritic cell in the immune system?), Q7 (What is the primary role of the B cell in the immune system?), and Q16 (Which of the following is a sign that a cough is becoming more serious?) did not show substantial improvements, with differences only in the range of 2 to 3. This

suggests that the game was better at teaching some concepts than others.

An interesting pattern to note is that despite all information needed to answer the questions being clearly presented in the game through information prompts, questions where larger improvements were observed tend to correspond to elements that appear more prominently in the gameplay. For example, the parts of the immune system manifest in the game as the characters that the players directly control over each level, which means that for every level, the player is constantly being reminded of the components of the immune system. The antigen is presented as the integral resource being collected by the player as the pathogens are defeated, and is also prominently displayed in the HUD. The neutrophil and the macrophage are the two first characters that appear on the character select screen, and might have contributed to the players spending more time familiarizing with those characters' abilities. On the other hand, the B-Cell is not a playable character; it instead quietly shows up when the player has collected enough antigen, without a strong or memorable prompt. The fact that it appears more subtly and sporadically in the gameplay could explain the lesser impact on learning its role in the immune system. Overall, these findings suggest that careful planning and integration of game mechanics can affect the impact of learning across different target outcomes.

5.4 Player Learning Perception, Experience, and Other Feedback

In addition to the empirical analysis conducted in the previous sections, as part of the post-test procedure, we also asked the participants to rate the game according to their perception on the following questions:

(1) Did playing the game help you understand and better appreciate the human immune system? (1 - not at all, 5 - very much)

(2) How would you rate your overall experience in the game? (1 - very bad, 5 - very good)

For the first question, the average response across the subjects was 4.4762. 12 participants(57.1429%) responded with 5, 7 participants (33.3333%) responded with a 4, while the rest (9.524%) responded with a 3. These results indicate that the subjects perceived the game to be very helpful in learning about the immune system and increasing appreciation for it.

For the second question, the average response across the subjects was 4.3333. 11 participants (52.361%) responded with 5, 8 participants (38.0952%) responded with 4, while the rest (9.524%) responded with 2. Similar to the other questions, these indicate that the subject perceived their experience with playing the game to be very positive. This is important, since as with any serious game, players must first be engaged with the gameplay before the learning objectives can be delivered.

6 CONCLUSION AND FUTURE WORK

In this paper, we presented the design and evaluation of a serious game for raising immune system awareness. The game *Immune Survivors*, is a bullet heaven game aimed at facilitating three learning objectives about the immune system. Quasi-experimental results show the students who played the game demonstrated significant learning gains on immune system concepts based on their pre-test and post-test results. Furthermore, the results show that learning gains were observed across the three learning objectives, and that the largest improvements were observed on those who had a poor initial understanding of immune system concepts.

These findings highlight the potential of serious games as a tool for education. Nonetheless, there is still much work to be done to fully understand and harness this potential. While this study presents an empirical evaluation of the game, there are limitations in its design that can still be addressed in further studies. First, although learning gains were observed, it is not clear which specific elements contributed to the learning. Multiple design choices were made to facilitate learning in the game: the multiple gameplay mechanics, the learning prompts, the reinforcement of the concepts through repeated gameplay, among others. Further studies can investigate the contribution of each component to the learning gains observed. Another future direction is to investigate the effectiveness of a serious game intervention such as this one when compared to a more traditional way of learning, such as by reading a textbook or by listening to a lecture or video. This will help us better contextualize the role of serious games in the education ecosystem and help identify in which context serious games would best be used.

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