Renovatio Quest: Engaging Students in Mathematics and Physics through Video Games

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Abstract

Renovatio Quest is an online collection of serious video games designed to make problem-solving in mathematics and physics more engaging and enjoyable for high school students. The video games are freely accessible at www.renovatioquest.it and can be played on both computers and mobile devices. The project utilizes Game-Based Learning (GBL), incorporating a strong narrative component in which players assume the role of a character in a futuristic adventure. The main objectives of Renovatio Quest are to offer an alternative and complementary method for practicing mathematics and physics both in class and at home and to facilitate consistent practice, which is essential for success in these subjects, particularly for students facing difficulties. The results are impressive. Students who were typically inconsistent in their studies have shown increased dedication and regularity, with many completing assignments well ahead of deadlines. Students with learning difficulties have also benefited from the immediacy and familiarity of the video game format. The games are assigned as homework or in-class activities for review, introduction, or consolidation purposes. Students can choose to play individually or in small groups, with each completed game yielding a score that contributes to their overall grade. At the end of the school year, top-performing students receive real-life rewards, such as science fiction books and games. To date, the project has engaged thousands of students across Italy, benefiting from media coverage and training courses. Overall, Renovatio Quest demonstrates the potential of GBL to enhance student outcomes in mathematics and physics education.

Keywords: *Serious games, Game-Based Learning, Mathematics, Physics, High School*

1. Introduction

In the world of education, traditionally taught subjects such as mathematics and physics often encounter significant obstacles when it comes to retaining student engagement [1]. The nature of these disciplines, coupled with the requirement of methodical practice and logical thinking, sometimes leads to a decrease in student motivation and interest [2]. This lack of engagement can subsequently impact student performance, limiting their understanding and appreciation of these pivotal subjects. However, the dawn of the digital age and the surge in innovative technological tools have brought forth promising solutions to address these engagement challenges. The advent of serious video games that employ Game-Based Learning (GBL) principles stands out among these solutions [7]. Through GBL, educators have found a powerful tool that combines the excitement of gaming with educational content, creating an interactive, dynamic, and engaging learning environment [3]. The premise of GBL lies in the integration of educational content within games, creating an immersive learning environment that seamlessly combines play and education. GBL is based on constructivist learning theories, positing that learners construct knowledge and meaning from their experiences. GBL offers a plethora of benefits that transform the educational landscape, with research consistently demonstrating its positive effects on motivation, engagement, and the learning process itself [4]. Video games, in particular, provide such interactive and immersive experiences, leading to deep, meaningful learning. Moreover, video games allow for adaptive learning experiences. They offer a safe space where students can experiment, make mistakes, and learn at their own pace. This adaptive and personalized learning environment not only helps students to understand concepts better but also promotes critical thinking and problem-solving skills, key competencies for mathematics and physics.

This paper presents Renovatio Quest, a free online platform with several serious video games designed with a unique blend of mathematical and physical problems woven into immersive gameplay. The games don't merely add an element of fun to learning; they also infuse a strong sense of purpose and progression into the process, thus fostering a more involved learning experience. Moreover, the

incorporation of a strong narrative component within the gameplay plunges the players into a futuristic adventure where each mathematical and physical challenge solved advances the plot.

2. Methodology

2.1 Technical Details and Game Design

Renovatio Quest is a comprehensive suite of serious video games, encompassing a wide variety of game genres including puzzle games, Role Playing Games (RPG), and a video gamebook. The diversity in game genres ensures a broad range of problem-solving scenarios, keeping students consistently engaged and challenged. Developed by Enea Montoli using RPG Maker MV, JavaScript, and Twine, these games represent the merger of technological innovation, narrative immersion, and pedagogical theory. RPG Maker MV (RPGMV) served as the foundational game development engine for most of the games. RPGMV is renowned for its user-friendly features and flexibility, while JavaScript was massively used for the customization of game mechanics. Also, Twine, a tool designed for creating interactive stories, was used for the creation of a video gamebook.

All the games are designed to be aligned with the curriculum of Italian high schools: from first-year students grappling with basic concepts to final-year students dealing with more complex theories and problems, the games offer differentiated challenges that cater to diverse learning levels. The games are available online and free of charge, requiring no installation, and can be played on various platforms, including computers and mobile devices (renovatioquest.it). This ease of access broadens the reach of the games, allowing students from different backgrounds and circumstances to engage in the learning process.

Renovatio Quest hosts a diverse array of games, most of them sharing a common protagonist, Nescio Nomen, a young English student living in a 28th-century world ravaged by global warming. All the games are in Italian, while one (Nescio Origin) is also in English.

The three main games available are:
- *Nightmares of Nescio:* This game consists of numerous standalone levels, each dedicated to a mathematical or physics topic. In "Nightmares of Nescio," players live in the dreamworld of Nescio (*populated by nightmares of Math and Physics*) and, by selecting their desired topic and level of difficulty, the gaming experience is tailored to suit their individual learning pace and proficiency level. Currently, 24 levels on different mathematics and physics topics are available.
- *RPG Saga:* The RPG saga unfolds over five episodes, corresponding to the five years of high school education, with three episodes currently available (*first, second, and fourth year*). These games are rich in narrative detail, tracing Nescio's journey from his hometown to a mysterious foundation.
- *Digital Gamebook:* The digital gamebook offers side stories involving minor characters from the same universe. Despite the change in focus, the gamebook maintains the overarching narrative of the Renovatio Quest world.

2.2 Integration into the educational context

All the Renovatio Quest games can be used in different ways and contexts, usually for topic review, introduction, or consolidation purposes. In the classroom, the games can be utilized as interactive learning activities that foster collaboration, healthy competition, and immediate feedback. Teachers can guide students through problem-solving quests, facilitating discussion, and reinforcing concepts along the way. Beyond the classroom, the games also serve as engaging homework assignments. While Renovatio Quest games are primarily designed for individual gameplay, students have the opportunity to form small groups and collaboratively navigate the games, even when controlling a single character. This method promotes cooperative learning as students discuss strategies, share insights, and collectively solve problems. Moreover, adding an element of tangible motivation, at the end of the school year, student's performance in the games contributes to an overall ranking. This score-based classification, in addition to a final mark, also culminates in a real-world awards ceremony. The top-performing students receive rewards that range from science popularization books and science fiction novels to vintage gaming consoles and other thematic gadgets. These prizes not only serve as an incentive for students to actively participate and perform well in the games throughout the year but also reinforce the link between the game-based learning environment and real-world outcomes. This tangible recognition of effort and achievement fosters a

sense of accomplishment among students, further motivating them to engage with and excel in mathematics and physics.

3. Examples from the games

In this section, concrete examples of game mechanics and the type of problems posed to players within Renovatio Quest's games are presented. These examples illustrate the innovative approach taken to integrate learning objectives into an immersive gaming environment.

3.1 Maze and Scientific Method

A game level within "*Nightmares of Nescio*" focuses on teaching students the fundamental principles of the scientific method - observation, hypothesis formulation, experimentation, and deriving a general theoretical law. In this particular level, the player's task is to navigate through a complex labyrinth filled with numerous forks, each branch providing different directions (*Fig. 1., Left*). To assist in this task, the player can access three clue videos, each depicting a robot navigating through three labyrinths obeying the same rules as the player's current maze. The rules are not explicitly stated but are instead for the player to decipher. By carefully observing these videos, the players can attempt to infer the laws governing the labyrinths' layout. By playing, they then experiment with their hypotheses, testing their validity as they try to escape the labyrinth. Successful navigation confirms their laws' accuracy, allowing the player to formulate generalized laws governing the forks in the labyrinth. Interestingly, the educational outcomes vary among students. Some students might find laws that work but are not necessarily identical to the original design. This reflects the reality of scientific research, where different models can accurately represent the same phenomenon. A clear example from physics is how wave optics and geometric optics – two different models – both successfully explain certain light phenomena.

3.2 Fighting the Odds

Another compelling example of Renovatio Quest's innovative gameplay mechanics is present in "The Foundation", the fourth episode of the RPG Saga. As the story unfolds the player must retrieve a vital item (*a first edition of "The Hobbit"*) to progress through the story. Unfortunately, it's only attainable via participation in an auction. To earn the right to participate in this auction, the player needs to gain the trust of the shady characters running it and amass enough money. The only viable way to do this is by taking part in an underground fighting ring's betting scheme (*Fig. 2., Center*). This game segment requires the player to calculate each fighter's winning probabilities. To do this, they must gather information about the fighters' habits and their fighting statistics. Using this information, the player can determine the most favorable betting odds. By making the optimal bet based on their calculations, the player can win the necessary funds and advance in the game. Here, mathematical concepts of probability and statistics are not presented as dry textbook problems but are intricately woven into an engaging narrative scenario.

3.3 Pirates and Linear Systems

An additional illustrative example of the interplay between narrative and problem-solving can be found in a level of "Nightmares of Nescio", set on the mythical Mandelbrot Island. According to the in-game lore, an old pirate has stashed away parts of a treasure in five locations on this island. However, a band of threatening pirates has now overrun the island, promising to lay waste to it unless they receive assistance in locating the five treasure pieces (*Fig. 3., Right*). The player's clues to the treasure's location are embedded within the old pirate's tales of pirates walking in straight lines until they cross paths at certain points. In essence, this level presents the player with multiple linear equations. By solving systems of these equations, the player can determine the points of intersection - the locations where the pirates' paths cross - and thus the locations of the hidden treasure parts. Linear systems, which might typically appear as mere abstract concepts in a textbook, are brought to life within an exciting treasure hunt scenario.

Fig. 1. Screenshots from the game (*Left: Maze and Scientific Method; Center: Fighting the Odds; Right: Pirates and linear systems*)

4. Results

This section presents the learning and teaching effectiveness of Renovatio Quest assessed through multiple sources of direct feedback: the experience in the classroom, the self-reported experience of the students and the testimonials from other teachers who have adopted Renovatio Quest after participating in training courses. All the feedbacks come from a large number of students and teachers since, currently, the project's website has recorded 24,709 unique visits since January 2021 and the games have been used by more than 50 teachers and almost 5000 students across Italy.

From the classroom perspective, a marked increase in student engagement has been observed. Traditionally, homework assignments are typically viewed as tedious or demanding, often leading to late submissions. However, with the introduction of Renovatio Quest, a significant shift has been noted. Homework assigned through video games has often been submitted well ahead of due dates, suggesting that students are not only engaged but also motivated to tackle problems promptly.

Interestingly, this heightened level of engagement cuts across different types of students, even those who generally do not engage in video gaming.

Another significant finding relates to students with learning difficulties (*dyslexia, ADHD, dyscalculia, dysgraphia, and dyspraxia*). For these students, traditional teaching methods can sometimes prove to be ineffective or discouraging [5]. However, feedback indicates that Renovatio Quest's video game format has brought about considerable benefits since it naturally provides an inclusive educational environment that does not necessitate dispensations or compensatory measures. The immediacy of the games, wherein feedback and progress are instant, and the familiar format of a video game, have made learning more accessible and enjoyable for these students. This is a promising result, showcasing how game-based learning can help bridge the gap in educational disparities.

In summary, the results point towards Renovatio Quest being a powerful and versatile tool in teaching mathematics and physics. The combination of strong narrative elements, game-based interactivity, and careful alignment with curriculum objectives seems to capture students' interest and improve their understanding of complex concepts, paving the way for more immersive, engaging, and effective learning experiences.

5. Discussion and Future Work

The empirical findings from the classroom application of Renovatio Quest underscore the potency of Game-Based Learning (GBL). Particularly, when GBL is supplemented with a compelling narrative component, it appears to significantly enhance learning outcomes in mathematics and physics education. These findings echo and expand upon previous research that has similarly highlighted the educational potential of GBL [6].

One of the critical achievements of Renovatio Quest lies in its careful alignment with the curriculum content. Often, educational games can be perceived as disconnected from the formal curriculum, leading to a disjointed educational experience. However, Renovatio Quest, developed specifically around the Italian high school curriculum for mathematics and physics, ensures complete integration of gameplay with educational content. This synergy facilitates the incorporation of the games into the educational process, enabling teachers to use them as effective teaching aids in the classroom and for homework assignments.

Additionally, the wide adoption of Renovatio Quest by other teachers after training courses indicates the scalability of this approach. It suggests that with the appropriate resources and support, GBL can

be successfully integrated into classrooms on a broader scale, potentially transforming the educational landscape for mathematics and physics.

However, a significant hurdle in the broader adoption of Game-Based Learning, particularly with tools like Renovatio Quest, arises from the entrenched perceptions held by many educators. Teachers, influenced by prevalent public opinion and common misconceptions, often view video games with skepticism. Video games are frequently dismissed as distractions, or worse, labeled as potentially harmful. This resistance hinders the integration of innovative teaching methodologies like GBL in classrooms. Therefore, an essential part of future work is to dispel these misconceptions and to emphasize the educational value of video games, demonstrating their effectiveness as engaging and inclusive tools for teaching and learning.

In the near future, the next development and enhancement steps of Renovatio Quest will focus on three primary aspects.

The first is about expanding its current portfolio by developing new games that cover a wider spectrum of mathematical and physics concepts. This would allow Renovatio Quest to cater to an even more comprehensive curriculum, further enhancing its value as an educational tool. This will be done also by exploration of new game modalities. Incorporating different formats like 3D gaming experiences and point-and-click adventures can further diversify the learning experience, reaching a wider range of learner preferences.

The second area of focus is the systematic collection and analysis of data to provide empirical evidence for what collected feedbacks have suggested. By gathering detailed data on student engagement, learning outcomes, and teacher feedback, it will be possible to quantitatively validate the effectiveness of this game-based learning approach. This evidence will be crucial in countering skepticism, encouraging the wider adoption of such innovative teaching methodologies, and further developing and refining Renovatio Quest.

The last aspect is related to the translation of all the games into English, opening the door for an even broader audience. This would not only increase the reach of Renovatio Quest but also contribute to the global discussion on innovative educational strategies. However, a significant challenge lies in aligning the game contents with the curricula of Anglophone countries. These often differ from the Italian curriculum around which Renovatio Quest has been developed, presenting complexities in terms of ensuring educational relevance and coherence.

In summary, while challenges exist, particularly in changing teacher perceptions towards video games, the potential of GBL in transforming educational practices is considerable. Renovatio Quest, with its compelling narrative and diverse gameplay, stands as an example of the promise that innovative, game-based teaching methodologies hold for the future of education.

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