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Design and Implementation of a Gamified Online Education Platform for Teaching and Learning Secondary-School Physics

Toshiki Katanosaka *, M. Fahim Ferdous Khan *,
Ken Sakamura *

Abstract

As digital transformation progresses in different sectors of the society, online educational platforms are becoming more and more prevalent. Since the outbreak of COVID-19, educational organizations throughout the world have been forced to provide online education. Online learning platforms have the advantage of allowing students to take courses from anywhere at any time, making them learn at their own pace and convenience. However, online education lacks supervision from teachers as compared to its offline counterpart, many young students struggle to maintain their motivation and hence become less engaged with online classes. To solve this engagement problem, many researchers have proposed the use of gamification in online education. In accordance with the research in educational gamification, this paper presents FunPhysics, a gamified web-based platform for teaching and learning secondary-level Physics. Apart from incorporating major game elements like points, badges, leaderboards, and levels, FunPhysics makes learning interactive, dynamic, and playful by visual simulation of core concepts of high-school Physics. Our two preliminary user studies indicate that interactive and gamified learning platforms can contribute positively with regard to user engagement, motivation, and perceived sense of achievement and learning ability.

Keywords: Engagement, Gamification, Interactive teaching, Online education

1 Introduction

Online education has become more prominent in recent years due to spread of digitalization. The onslaught of the COVID-19 pandemic has also propelled the growth of online education. Examples of online education platforms include e-Learning, distance learning, and MOOCs, which have the advantage of allowing students to take courses from anywhere and at any time. However, one of the major problems with online education platforms such as MOOCs is low completion rates [1], with a study reporting a completion rate of only about 10%, where difficulty to retain learners' motivation has been cited as the major factor [2].

* Toyo University, Tokyo, Japan

This issue of engagement or motivation is not only limited to MOOCs platforms; it is common to other online education platforms as well. As schools are forced to operate online under the impact of the COVID-19 pandemic, keeping students engaged has proven to be a great challenge. This is especially true for STEM education as there is significantly reduced opportunities for students to learn by experiencing something for themselves, as in-person experiments and exercises have become few and far between. Teaching and learning of science concepts – especially for Physics and Biology – have been reported to be a major challenge for both students and instructors alike [3-5]. Therefore, there is a need for devising more engaging ways of teaching science concepts to students at all levels. Science concepts cannot be learnt effectively only by text-based description, and that is why science textbooks and lecture materials are usually supplemented with illustrations or visual depiction of the concepts in some way. These supplements definitely aid better understanding, but they are static and only represent a specific state of the concept being discussed. The students have no way to learn interactively by tweaking the parameters involved, and explore by themselves how the concepts works in different situations. In order to make lessons more dynamic and interactive, web-based gamification can play an important role. Moreover, many studies have linked gamification to improved learning achievement, enhanced motivation, or increased engagement [6-9]. On this premise, in this paper, we present FunPhysics, a web-based learning platform leveraging gamification for teaching-learning of Physics geared toward secondary school students.

The rest of this paper is organized as follows. Section 2 briefly presents some examples concerning use of gamification in science education. Section 3 and 4 explains the main features, design and implementation of FunPhysics. Section 5 describes the results of the preliminary evaluation, and the limitations of this work. Finally, Section 6 concludes the paper.

2 Background and Related Work

2.1 Gamification

Kapp defines gamification as "the use of game mechanics, aesthetics, and game thinking to engage people, motivate behavior, facilitate learning, and solve problems" [10]. Gamification succeeds by changing user behavior and making them want to do more and have fun throughout the process. According to Rohan et al. elements of gamification include points, badges, progress, leaderboards, storyline and so on [11]. Among them points, badges, and leaderboards are most widely used, often dubbed as the PBL triad [11, 12].

2.2 Use of Gamification in Science Education

Use of gamification in science education has increased significantly in the last decade. Kalogiannakis et al. have done a comprehensive literature review on this topic [13]. In the following, we present three examples of secondary-level science education where gamification is used.

Tsai developed Science Detective Squad (SDS), computer-simulated and gamified environment that encourages students to investigate electricity problems in usual day-to-day life [14]. The storyline in the simulated environment mimics that of a detective story to keep the students engaged. The system was developed for teaching ninth graders in Taiwan.

In order to address the reluctance of many students in participating in flipped learning activities, Lai and Foon developed a web-based learning platform utilizing gamification where various gamification elements are mapped to the different components of 5E instructional model [15]. The system was developed for a secondary school in Hong Kong, and was reported to be effective in engaging students though self-directed learning.

Khan et al. developed a gamified web platform for teaching patterns of reactivity in an eighth grade Chemistry class in Pakistan [16]. This system uses various game elements including levels, progression, points, multimedia contents and interactivity (e.g., arranging metals in order of reactivity by drag-and-drop, shooting balloons representing metals) with a view to promoting self-based learning with minimal supervision.

3 Background and Related Work

FunPhysics is a web-based tool designed for secondary school students to learn Physics. It incorporates different game elements like points, leaderboards, levels and badges. It also enables students to learn interactively in a simulated game-like environment. The current implementation supports interactive learning of projectile motion and moment of force. There are many formulae related to projectile motion involving parameters like initial velocity, angle of launch, initial height, time of flight, range and so on. Moment of force computes the equilibrium at a balance point. Students can understand the motion when the simulation executes. Students often memorize these formulae without really understanding them. It is conjectured that if students can tweak these parameters and fire a projectile accordingly, learning projectile motion will be engaging and fun. We simulate this by asking the students to calculate the initial velocity or angle of launch so that the projectile would hit a specific target. Based on their calculation, students can fire the virtual projectile, and see it in flight on its way to the target. Since hitting the target has a game-like charm, we believe this game will help them engage more with the lesson and make students want to learn them.

3.1 System Architecture

Figure 1 shows the architectural diagram of this system. For the sake of simplicity, some parts of the system are represented in abbreviated form. In the processing flow, the red parts indicate presence of simulation, while the blue parts indicate no simulation. The following describes what each of these operations in detail.

(1) User browses a web page. (2) User accesses Django REST Framework (DRF) [17] using Ajax within React [18]. (3, 4) DRF retrieves appropriate information from SQLite [19]. (5) DRF returns the database information. (6, 7) DRF converts the retrieved problem information into data that can be run in Matter.js [20]. (8) Display the data on the user terminal.

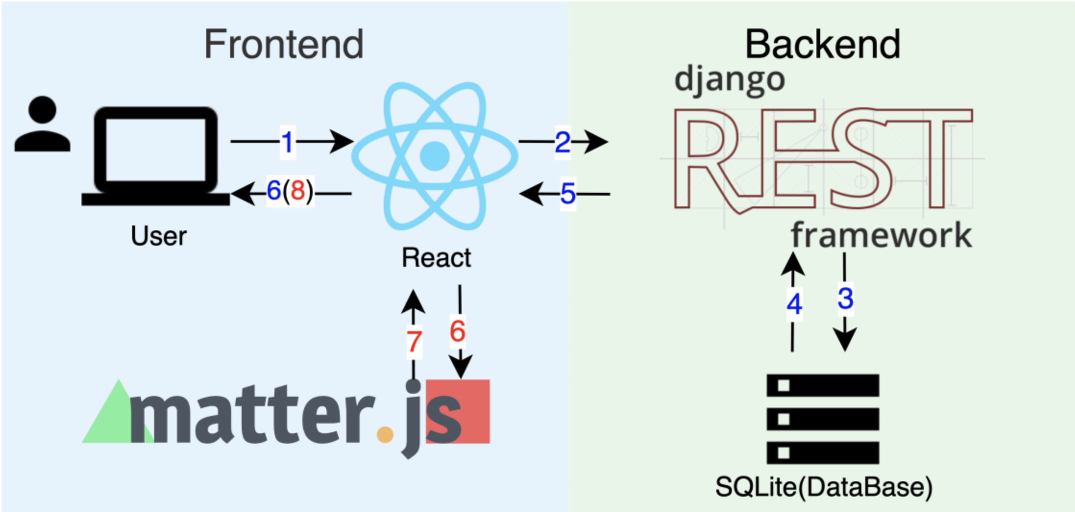

Figure 1: Architecture Diagram

3.2 Entity Relationship Diagram

Figure 2 shows the Entity Relationship (ER) diagram of this system. Data stored by each model (a table in a typical database is called a Model in Django) is described below.

- CustomUser: Stores user information such as cleared stages and achieved goal, earned badges and so on.
- Problem: Stores the detail information that makes up the question. The model stores also information with parent-child relationships (e.g., Problem-1 and Problem-1-1, etc.).
- Role: The role is divided into three categories: student, teacher and administer. –
- Badge: Stores badge images, names and so on.

The relationship between some model is explained with represents to the CustomUser model. It is assumed to be used by teachers in their classes. Teachers can create some problems to solve. Badges can be created only by authenticated users.

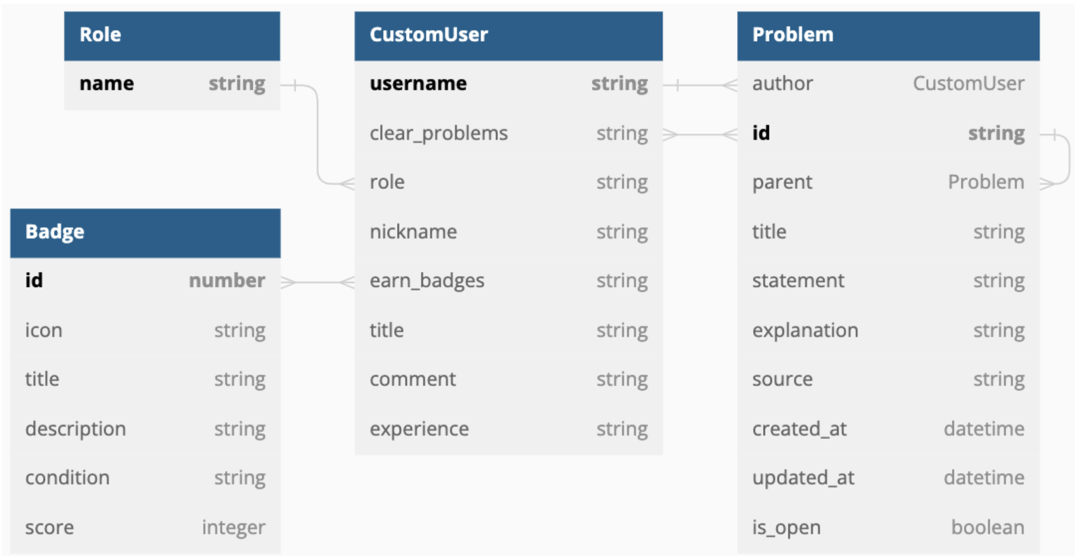

Figure 2: Entity Relation Diagram

4 Implementation

4.1 System Workflow

Figure 3 shows that flow of use after transitioning to the index page of this system. Blue background color indicates processing, red indicates repetition, and green indicates branching. The procedure is described below.

(1) Register an account. (2) Log in to FunPhysics. (3) Go to the problem list. (4) Solve the problem on paper. (5) Check if you are in the simulation mode. (5-a) If you are in simulation mode, go to (7-a). (5-b) If it is not in simulation mode, go to (6). (6) Check if you are in the quiz mode. (6-a) If you are in quiz mode, go to (7-a). (6-b) If it is not in quiz mode, go to (7-b). (7-a) Enter your answer from four choices into the system. And if you are in simulation mode, run the simulation.(7-b) Enter your answer into the system.(8) Check if the answers are correct. (8-a) If the answer is correct, go to (9). (8-b) Read the explanation. (9) Go to the other question. (10) Go back to step-3 while the problem remains unsolved. (11) Continue with the goal of earning badges and moving up on the leaderboard.

4.2 Frontend Development

For the backend, we used DRF, a Python web framework that can convert data types (JSON and XML) by using a function called a serializer. FunPhysics also uses a REST API using DRF's ModelSerializer in part, which has been developed to support general CRUD (Create, Retrieve, Update, Delete) processing.

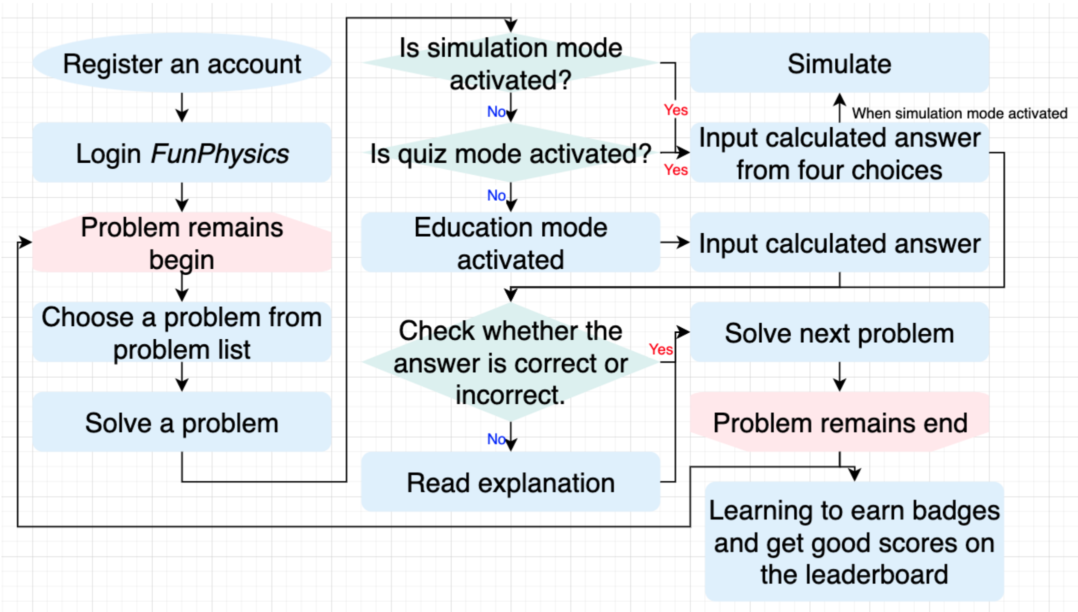

Figure 3: Flow of processing

4.3 Backend Development

For the frontend, we used React and JavaScript physics engine Matter.js. React was chosen because it is component-based, easy to reuse, and improves user experience. In addition, Matter.js is a 2D physics engine that allows one to easily build and use a physics environment. Data is acquired and processed through an API built with DRF, which is then rendered using a combination of React and Matter.js.

4.4 User Interfaces

Figure 4(a) shows a list of badges. There are 27 badges in total which users can earn for solving problems of worth certain points, clearing levels or problems. Figure 4(b) rep-resents the leaderboard, which allows students to keep track of their relative learning status.

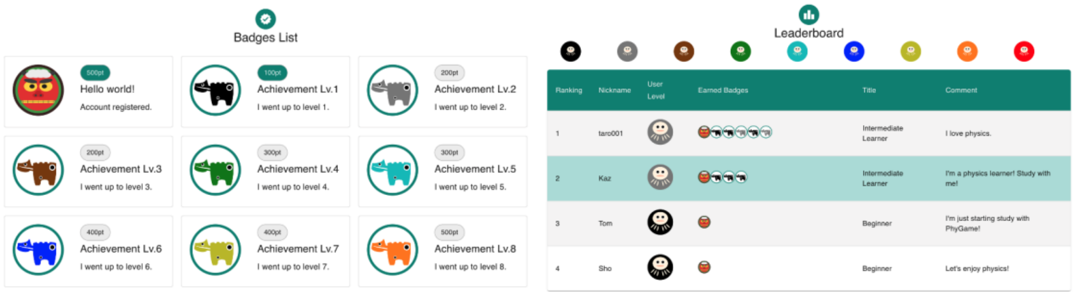

Figure 4(a): Badges and (b) leaderboard in FunPhysics

4.5 Projectile Motion

Figure 5 shows the simulation screen for projectile motion. After the calculations are done on paper, the calculated answers are input. When the start button is pressed, the object moves. Figure 6(a) shows the case where the simulation results in the correct answer (i.e., red ball hitting the crane). For correct answers, a snack bar pops up, and informs user answers are corrects. At the same time, the crane grows larger. On the other hand, if the user makes a mistake (i.e., target missed), as shown in Figure 6(b), the user is given as many chances as needed to re-enter the answer by pressing the reset button. Basically, the simulation and the quiz modes are almost same: questions are presented in MCQ format and the user has to select the correct answer from four options. Feedback is provided for correct and incorrect answers. However, there is one difference. In simulation mode, the simulation is based on user input.

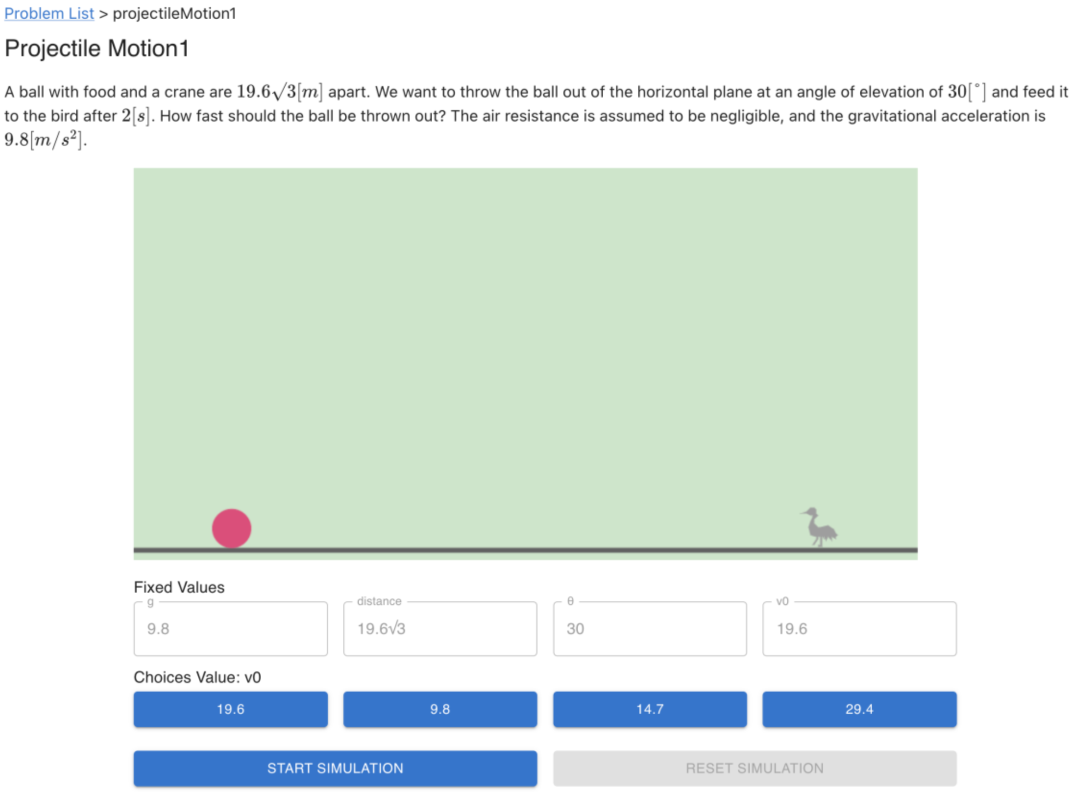

Figure 5: Simulation page for projectile motion. User inputs her calculated answer in the v0 textbox, and then press the button on the left to fire the projectile.

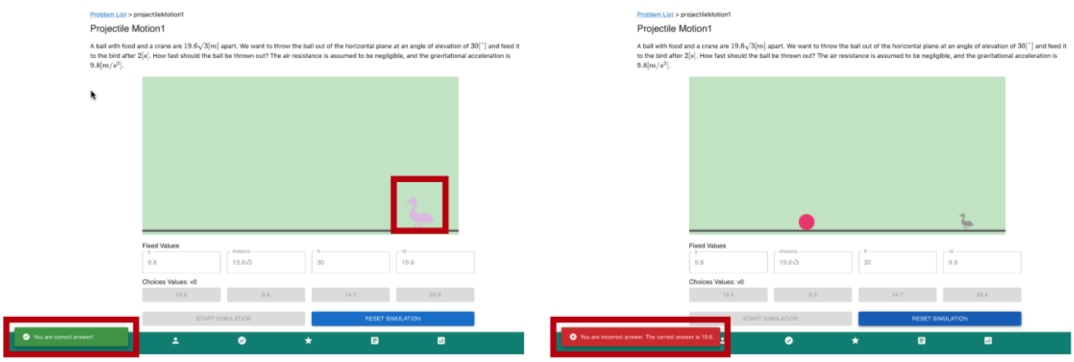

Figure 6(a): Result of projectile motion simulation: correct answer and (b) incorrect answer

4.6 Moment of Force

Figure 7 shows the simulation screen of moment of force. In this example, the user is asked to calculate the quantity of balls on the left side so that the moment of force is balanced. After completing the equations learned in class or in the textbook on paper, the user selects a button from a list of options that shows the calculated answer. Figure 8(a) shows the case where the simulation results in the correct answer choose (i.e., the horizontal bar is balanced). Alternatively, if the user makes a mistake (i.e., the horizontal bar lost balance), as shown on Figure 8(b).

By using the simulation, the user can see how the problem would behave if the balance were not maintained, rather than simply solving equations if the user only learns about the problem from textbooks or other sources.

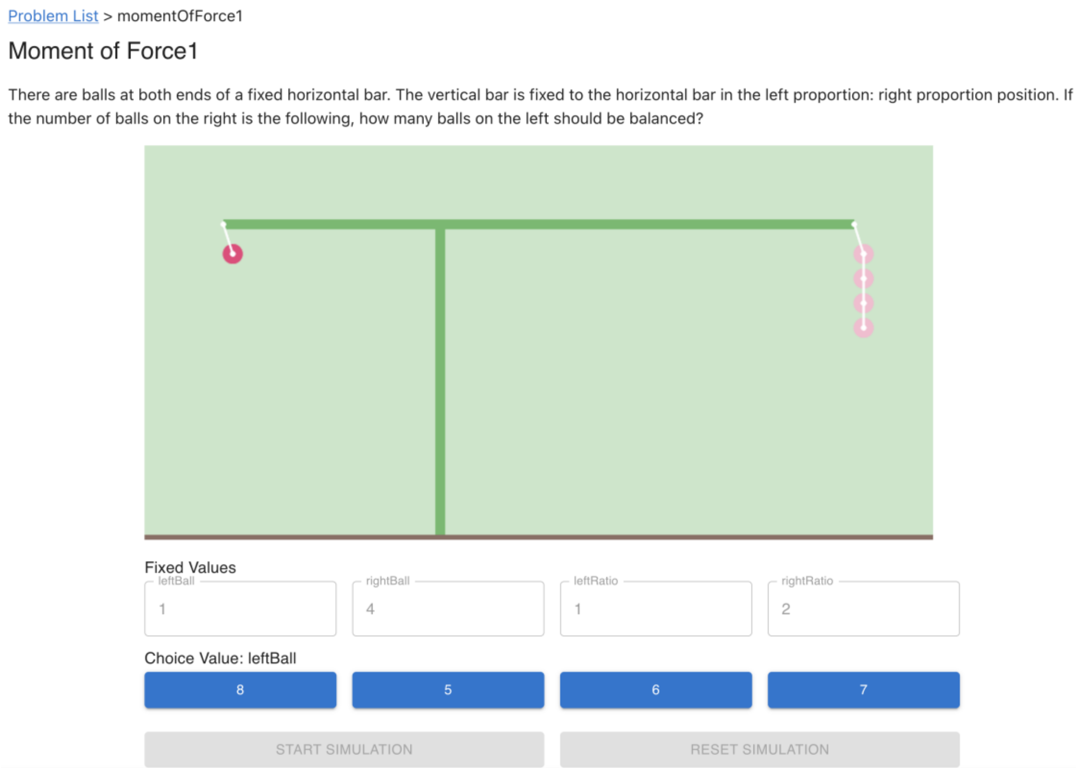

Figure 7: Simulation page for moment of force. User inputs her calculated answer in the leftBall textbox, and then press the button on the left, if you make a mistake, the horizontal bar will be unfastened and fall from the vertical bar to the left or right.

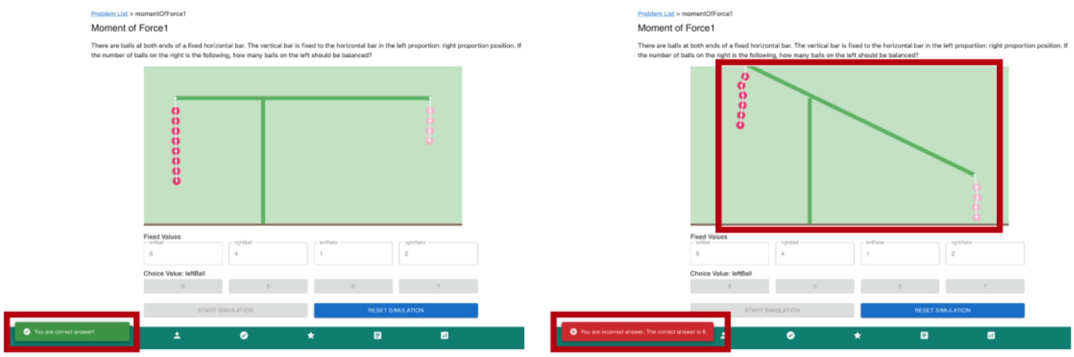

Figure 8(a): Result of moment of force simulation: correct answer and (b) incorrect answer

5 Evaluation

We conducted two preliminary user studies for evaluating the system with six participants in total. The participants were four males, one female, and one don't want to answer, and all in their 20s. An instructor explained the participants how to use the system, and the participants used the system by themselves. After that the participants were asked to take part in a questionnaire survey. Prefix each evaluation item name with an "I" or "II" respectively.

5.1 First Evaluation in April 2022

5.1.1 Items and answers

Table 1 shows the evaluation items and corresponding responses. There are 7 questions in total. A 6-point Likert scale was used for I-Q2-I-Q7, with 1 representing strong negation and 6 representing strong agreement.

Table 1: First preliminary user study in April 2022

Question No.	Question	Answer User1, User2
I-Q1	Have you ever used cram schools, or any other learning material for studying Physics in the past?	Yes, Yes
I-Q2	If you have used cram schools, study materials, etc. in the past, compared to them, how would you rate FunPhysics?	5, 5
I-Q3	If you have studied Physics at high schools, compared to them, how would you rate FunPhysics?	3, 5
I-Q4	Did you feel that you improved your ability and understanding after using FunPhysics?	4, 4
I-Q5	Did you have fun using our system?	4, 4
I-Q6	Would you like to try FunPhysics in the future for other fields of study?	4, 6
I-Q7	Overall, how was your experience?	4, 4

5.1.2 Results

The responses to I-Q2 and I-Q3 suggest that FunPhysics is more enjoyable than using general educational materials. The responses to I-Q4 indicate that FunPhysics positively contributed in improving the participants' learning ability. The participants also found FunPhysics fun (I-Q5), and expressed their willingness to use it in future (I-Q6). Finally, they reported their overall experience with FunPhysics was positive (I-Q7).

Next, the two subjects were asked to freely opine on merits and shortcomings of the system. They mentioned that they found seeing the projectile in motion specially interesting. They also suggested that the user interfaces should be made easier to operate.

5.2 Second Evaluation in September 2022

5.2.1 Items and answers

Table 2 shows the evaluation items and corresponding responses. There are 11 questions in total. A 10-point Likert scale was used for Q3-Q10, with 1 representing strong negation and 10 representing strong agreement.

Table 2: Second preliminary user study in September 2022

Question No.	Question	Answer User1, User2
II-Q1	Have you ever studied Physics at high school?	Yes, Yes, No, Yes
II-Q2	Have you ever studied Physics used cram schools, study materials, etc?	No, No, Yes, No
II-Q3	If you have studied Physics at high schools or used cram schools, study materials, etc, compared to them, how would you rate FunPhysics?	5, 8, 8, 8
II-Q4	How about what is your sense of achievement with Fun-Physics?	7, 8, 8, 8
II-Q5	How about the immersive experience of FunPhysics?	6, 5, 9, 7
II-Q6	Did you feel socially connected using FunPhysics?	4, 3, 6, 5
II-Q7	Did you have fun using our system?	7, 7, 8, 8
II-Q8	Did you feel more motivated using FunPhysics?	6, 6, 9, 7
II-Q9	Did you see an increase in engagement using FunPhysics?	7, 6, 8, 6
II-Q10	Would you like to try FunPhysics in the future for other fields of study?	9, 8, 10, 7

5.1.2 Results

The responses to II-Q1, II-Q2 and II-Q3 suggest that FunPhysics is more enjoyable than using general educational materials. II-Q4 responses indicate that the application gives users a sense of accomplishment. II-Q5 responses indicate that some users are enthusiastic. Response of II-Q6 indicate FunPhysics needs to add social connection elements. The participants also found Fun-Physics fun (II-Q7), and felt increased motivation and engagement to use FunPhysics (II-Q8, II-Q9). Finally, they expressed their willingness to use it in future (II-Q10).

Next, we asked the four subjects to freely opine on good points and needs to be improved points of the system. They mentioned that they found it is good points to visually see whether the simulation results are correct or not. They also suggested that input elements should be displayed in a more recognizable manner.

5.3 Limitation and Future Work

This is a work in progress and the number of participants in the user study was small. Although the system was well accepted by the subjects, there is room for improvement in terms of coverage and user experience. The present implementation includes the projectile motion topic and moment of force from Mechanics, but – apart from including other topics of Mechanics – we are working on including other branches of Physics, for example, Optics, Fluid Mechanics and Electromagnetism. We also intend to conduct a large scale user study in future.

6 Conclusion

In this paper, we have explained the design and implementation of FunPhysics, a web-service for learning Physics targeted toward secondary school students. FunPhysics aims at improving engagement and learning ability by making learning fun and interactive. The system utilizes many gamification elements such as points, badges, leaderboards, and levels, as well as an interactive simulation game environment. In addition, users can test their understanding of the concept of projectile motion in the target-hitting game and the concept of moments of force in the balance game. Our two preliminary user study suggested that such application of gamification can enhance user engagement and help them learn with fun. We intend to further develop FunPhysics covering other areas of secondary-level Physics.

Note: An earlier version of this paper was published at the 12th International Conference on Learning Technologies and Learning Environments (LTLE2022) [21].

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