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MechGames: Teaching and Learning Dynamics through Computer Simulations and Games

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Abstract

Engineering Mechanics is the foundation of many upper-level engineering courses. Dynamics, in particular, is a challenging subject for many students, partly due to the difficulty of visualizing some of the important concepts. With the explosion of digital technologies in recent years, computer simulation and animation have drawn great interest as a tool to teach and learn Dynamics. The concepts and problem-solving processes are presented in a dynamic environment that allows interactivity. Students can observe and interact with computer representations of physical phenomena, and develop deeper understanding of critical concepts. This paper introduces the so-called MechGames (Mechanics Games) project, which aims to blend simulations and games together to teach important concepts, and engage students with problem-solving activities that require critical thinking skills in a game-like environment, making learning more exciting and enjoyable for students. The vision is to create a series of modules on the key concepts of the Dynamics course. The modules will be self-contained with three modes: teaching/learning, assessment, and gaming. As an initial attempt, a pilot module has been developed on the subject of projectile motion. This module was deployed in this Fall semester, and a survey was conducted to obtain student feedback. Overall, the student thought highly about the module. The module helped them learn the concepts by actually "seeing" the concepts. The game-like setting helped create a more exciting learning environment, challenge their minds in a meaningful way, and directly connect their efforts with accomplishments.

1. Introduction

Science, technology, engineering and mathematics (STEM) education has become a top priority due to growing concerns regarding a shortage in the U.S. STEM workforce. Many initiatives have been taken to encourage and engage in teaching innovation to better prepare a diverse and globally competitively STEM workforce. There are numerous innovative educational tools and methods developed and studied to build and sustain interests in the STEM fields. With the explosion of digital technologies in recent years, computer simulations and animations have drawn great interest. Computer simulations present concepts in a dynamic environment and allow interactivity. It helps users observe and interact with computer representations of physical phenomena, and develop deeper understanding of critical concepts. Computer games are essentially based on computer simulations, but usually they are informal with explicit goals and rules, and are designed for entertainment. Successful games offer a series of challenges, guideing their players through intense and complex problem-solving processes.

The idea of using video/simulation games for learning started as early as the 1980s [1]. Malone reviewed a number of previous theories of intrinsic motivation and learning, and presented several empirical studies of highly motivating computer games [2]. Other notable studies on how to use video games to engage students include [3-5]. For engineering education, Coller and Shernoff [6] deployed a videocomputer game in their numerical methods course and presented a preliminary study to measure student engagement. Deshapan and Huang surveyed the state of art of the application of simulation games and highlighted a few advantages [7]. Despeisse reviewed a number of application examples of games and simulations in industrial engineering education, discussed the benefits and drawbacks of games as education tools, and provided suggestions to game developers to align the game aspects with learning outcomes [8].

This paper reports an initial attempt of incorporating computer simulations and games in a college *Engineering Mechanics: Dynamics* course. Engineering Mechanics is the foundation of many upper-level engineering courses, and Dynamics, in particular, is challenging for many students because of the complexity and diversity of concepts, combined with the fact that usually an integration of proper representation, mathematical skills, and conceptual analysis is required for students to learn and solve problems [9,10]. On the other hand, for many years (even until now), instructors have to resort to static diagrams to discuss dynamic movements, and 2D drawings to represent 3D motions. Numerous tools and methods have been developed and studied by instructors and researchers to improve the student learning environment and performance in engineering mechanics. Computer simulations and animations, in particular, have received significant interest as viable methods for better visualization and representation, enhanced interactivity, and increased excitement in the problem-solving process. Taajvidi and Fang [11] conducted a thorough review of the use of computer simulations and animations in engineering mechanics courses. For Dynamics, notable examples include [12-15].

The initial attempt was focused on projectile motion, around which a pilot module was built. The long-term goal is to create a series of modules that blend simulations and games to teach important concepts, engage students with problem-solving activities, and develop critical thinking skills in a game-like environment, making learning more exciting and enjoyable for students. Along the way, education data from students will be collected and analyzed to study the teaching and learning effectiveness of these modules for further improvement. Each module will be a complete, and stand-alone package that operates in three modes, i.e. Learning, Assessment, and Game modes. The Learning Mode teaches fundamental concepts through simulations and visualization, the Assessment Mode quizzes on the understanding of these concepts with conceptual questions, and the Game Mode gives problems for students to apply concepts and their critical thinking and problem-solving skills. All the activities are carefully thought through and planned to cover, teach, and assess critical concepts in a systematic matter.

2. MechGames: Projectile Motion module

This section discusses the pilot module in detail and its implementation in the fall semester of 2019. There are two "modes" included in the module: a learning and teaching mode that helps students learn and visualize the motion, and aides instructors to present and discuss the concepts in a more direct and effective way. There is still content and features to be added into the pilot module for improvement, but it serves as a foundation for future development. Mostly, the pilot module is built around a core simulation animating the projectile motion. The core simulation and environment are written in JavaScript with bootstrap and jquery, and the physics engine is box2D, which is a free open source C++ engine for simulating rigid bodies in 2D. For the projectile motion demo discussed in the next section, the source code associated with motion was checked and corrected. Box2D is platform-independent, and it has been used for games on Nintendo DS and Wii, and Android and iOS mobile phones. Notable games include Angry Birds, Tiny Wings, Rolando, and Transformice. Box2D can also be ported to many different languages such as Flash, Java, Javascript, Python, and C#.

Concepts and governing equations

Figure 1 shows a typical 2D free-flight motion of a projectile [16]. If the projectile is subjected to constant acceleration (a very common configuration), the motion can be analyzed by separating the motion into the horizontal x-motion and vertical y-motion. The velocity components and position coordinates can be obtained as

$$v_x = v_{x0} + a_x t = v_0 \cos\theta_0 + a_x t \, , \tag{1}$$

$$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2 = x_0 + \left(v_0 \cos\theta_0\right) t + \frac{1}{2} a_x t^2 \, , \tag{2}$$

in the x-direction, and

$$v_y = v_{y0} + a_y t = v_0 \sin\theta_0 + a_y t \, , \tag{3}$$

$$y = y_0 + v_{y0} t + \frac{1}{2} a_y t^2 = y_0 + \left(v_0 \sin\theta_0\right) t + \frac{1}{2} a_y t^2 \, , \tag{4}$$

in the y-direction, respectively, where a_x and a_y are the acceleration components in the x and y directions, respectively, v_0 the initial launch speed, and θ_0 is the initial launch angle from the horizontal. These motion equations are obtained from the general straight-line motion equations for constant acceleration:

$$v = v_0 + a_0 t \, , \tag{5}$$

$$s = s_0 + v_0 t + \frac{1}{2} a_0 t^2 \, . \tag{6}$$

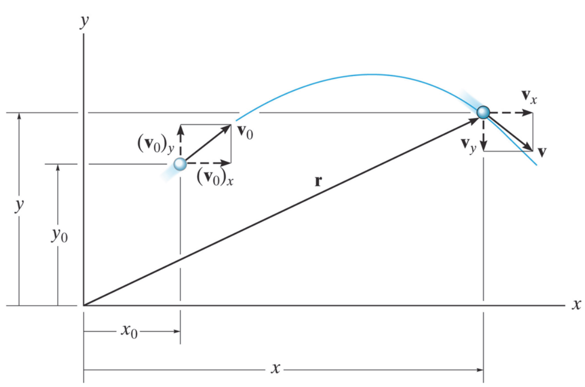

Figure 1. Kinematic diagram of a projectile

Learning and teaching mode

In the learning mode as shown in Figure 2, students interact with the animation to observe important characteristics of projectile motion, and make a stronger connection between theory and actual physics through a direct visualization of the motion. The simulation is built around the scenario that a cat (named "SuperCat") jumps up to catch a bird. The students can adjust the x and y-direction accelerations, and initial launch speed and angle. Then SuperCat's jumping motion is animated forming a trajectory with the velocity and position components displayed in real-time. In addition, this mode can also be used by instructors to present and discuss the motion characteristic in a more direct and effective way.

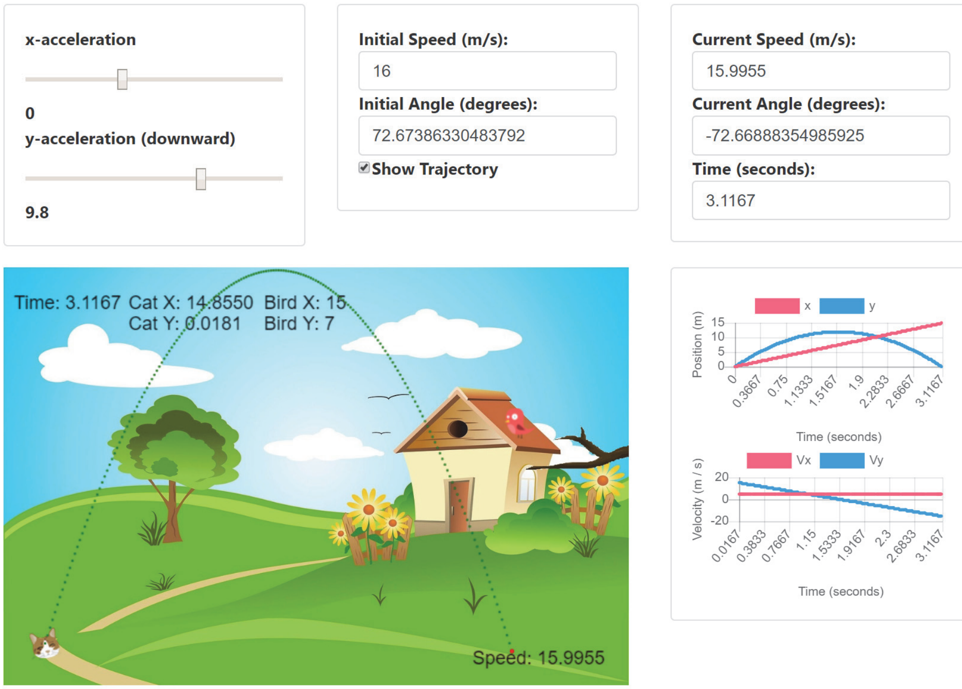

Figure 2. Learning and Teaching Mode

Example activities include:

(i) <u>Standard projectile problem</u>

Simulation settings: $a_x = 0$, $a_y = -9.8$ m/s^2, $v_0 = 14$ m/s, $\theta_0 = 70°$; cat is at (0, 0)

Before the simulation:

- Write out the mathematical expressions of velocity component v_x and v_y as a function of time, i.e, $v_x(t)$, $vy(t)$, and sketch the velocity diagram;
- Write out the mathematical expressions of the projectile's position x and y as a function of time, i.e, $x(t)$, $y(t)$, and sketch the position diagram.

Run the simulation (launch the cat)

- Observe the velocity component v_x and v_y curves. Are they what you expected before the simulation?
- Observe the position x and y curves. Are they what you expected before the simulation?
- Move the mouse over the simulation area to change the initial angle and see how the trajectory changes with it

(ii) <u>Projectile problem + wind</u>

Simulation settings: $a_x = 4$ m/s^2, $a_y = -9.8$ m/s^2, $v_0 = 14$ m/s, $\theta_0 = 70°$; cat is at (0, 0)

Repeat the activities in (i) and note the differences in the results

Assessment or game mode

The Game Mode is more exciting as the students are challenged to apply concepts and problem-solving skills to find answers, and then use the simulation to confirm. As the current module is still in its development stage, this mode is more of an assessment mode rather than a true game mode similar to PC games with scores, music, etc. In the past fall semester, there were four difficulty levels such as Basic, Advanced, Expert, and Master, and the associated tasks are listed below:

- *Level 1 Basic*: The cat jumps up off a large rock at a given launch speed and angle. Determine how high and how far the cat jumps, and the time it takes for the cat to land on the ground.
- *Level 2 Advanced*: A cat jumps up to catch a bird in a "fixed" position. Given the initial launch angle, determine the initial launch speed for the cat to catch the bird.
- *Level 3 Expert*: Similar to Level 2, but in addition to gravity, now a horizontal acceleration component is added to mimic the effect of wind blowing horizontally. Given the initial launch angle, determine the initial launch speed for the cat to catch the bird.
- *Level 4 Master*: A cat jumps up to catch a bird in a "fixed" position. Given the initial launch speed, determine the initial launch angle for the cat to catch the bird.

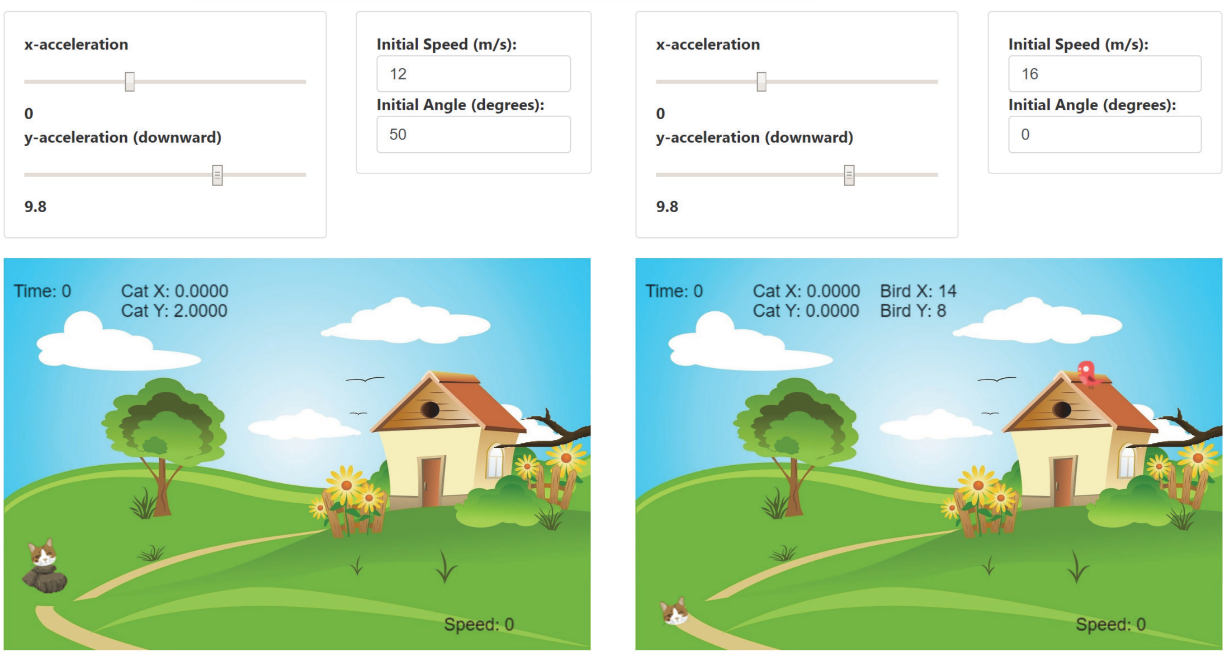

Figure 3. Game Mode settings. *Left*, Level 1; *right*, Levels 2-3.

In addition, these simulations were also used to complement a traditional by-hand homework assignment with problems similar to those Level 1-4 tasks, and the students were encouraged to use the simulations to confirm their homework answers.

3. Student survey results and conclusions

To obtain student feedback for future improvement, a survey was conducted, and the results are summarized in Table 1. It can be seen that overall the feedback was very positive. The students thought the simulation was engaging and helpful and wanted to see similar modules on other important topics as well. In addition, open comments and suggestions were also invited. Mostly, the students would like to see more "gaming" features to be added such as music and sound, scores and lives, and maybe allowance to purchase hints. In addition, many students expressed the interest of simple quiz questions on critical concepts as a transition to those more complete tasks or problems in the game mode.

In all, the authors feel that it was a very successful initial attempt, and we are encouraged by the positive student feedback. In the upcoming months and years, our work will be focused on: (i) additional contents and enhancements of the projectile motion module; (ii) education research to evaluate the effectiveness of the module and study its effect on learning and engagement; (iii) development of modules for other Dynamics topics.

Table 1. Student survey results (out of 25 students)

Survey question	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
1. The simulation was interesting and engaging	8	15	2	0	0
2. I would like to see more of these simulations in the Dynamics course	8	14	2	1	0
3. I would like to see more of these simulations in other courses	7	14	3	1	0
4. The simulation was tailored to specific areas where I needed to practice and improve	6	11	6	2	0
5. The simulations improved my problem-solving skills	4	9	11	1	0
	Very good	**Good**	**OK**	**Poor**	**Very poor**
6. How valuable do you think these simulations are in understanding the concepts…	9	11	5	0	0
7. My level of knowledge on the topic ***before*** starting these simulations was…	2	10	12	0	1
8. My level of knowledge on the topic ***after*** the completion of these simulations is…	9	14	2	0	0
9. What do you think about the idea of integrating homework problems and simulations?	9	11	3	2	0

Lastly, while the present effort is focused on the development of modules, a very critical part of this project in long term is to develop instruments to really assess the effectiveness of this tool through rigorous education research studies. For example, a comparison study between a control group and a treatment group. It is important to engage students and make learning more fun. However, the ultimate objective is "learning." Therefore, a comparison study would reveal if the simulations really have helped the students grasp the material and grow their problem-solving skills. In addition, the aspect of diversity should be considered. For example, would male and female students respond to this tool differently? Would race, financial status, age, and national origin play an important role? Any difference between those who had game experience and those who have never gamed? Addressing these important questions calls for a careful planning and collaboration with educational research experts.

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