Use physics to optimize in-game projectile firing

Previous compulsory steps / Prior students' knowledge	Physics (projectile movement), Mathematics (equations, trigonometry)
Learning objectives	Discover and practice projectile motion through the lens of video games. Resolving equation of projectile range.
Subjects	Physics, Mathematics
Recommended Age	15 - 18
Material needed	Game: BallisticSimulator (Windows)
Sequence duration	60 minutes
Individual or group activity	Group activity
Skills developed (after learning goals)	Problem solving
Game price range	0
Similar games that you can use with the sequence	Angry Birds

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Tips for shorter duration	To make this sequence shorter you could use it after a theoretical class about the equations of movement, so you don't have to go through step 3. Focus on the others steps and give more time to your students to calculate the best ways to finish the game with the best score possible.
Tips to make the sequences more accessible or inclusive	The texts are a bit small in the game interface so make sure to bring the dys students close to the screen or write the texts on the board bigger for them to be seen from a distance and more easily read by dys students.

Step by step: how to implement the sequence

In this sequence you are going to play with your class a side-view shooting game similar to Angry birds. The game lets you choose a shooting angle, a projectile speed and the intensity of gravity.

This is going to be an opportunity to talk about the use of physics in games, to get an intuitive feeling of projectile trajectories and gravity. But you are also going to demonstrate the power of physics in a gamified way by optimizing the shots within the game using projectile equations.

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- **Step 1. Presenting the game and the sequence (5 minutes)**

Tell your students that you are going to play a short shooting game to explore some concepts of physics in a fun way.
As an introduction, talk about projectiles and physics in games. Games can perform physics simulations but doing so in a long game level is expensive and approximations are used.

The 2 main techniques that are used are the line-trace and projectile movement.

- Line-trace consists of tracing a vector through the level starting from the player's canon. If an actor is on the path, the damage is applied.
- Projectile movement spawns a 3D model of a bullet and makes it move along a trajectory calculated by the use of projectile kinematics. For every frame, the position of the projectile is updated using the equations.

The game you are going to play uses projectile movement. Let's start with a short gaming session.

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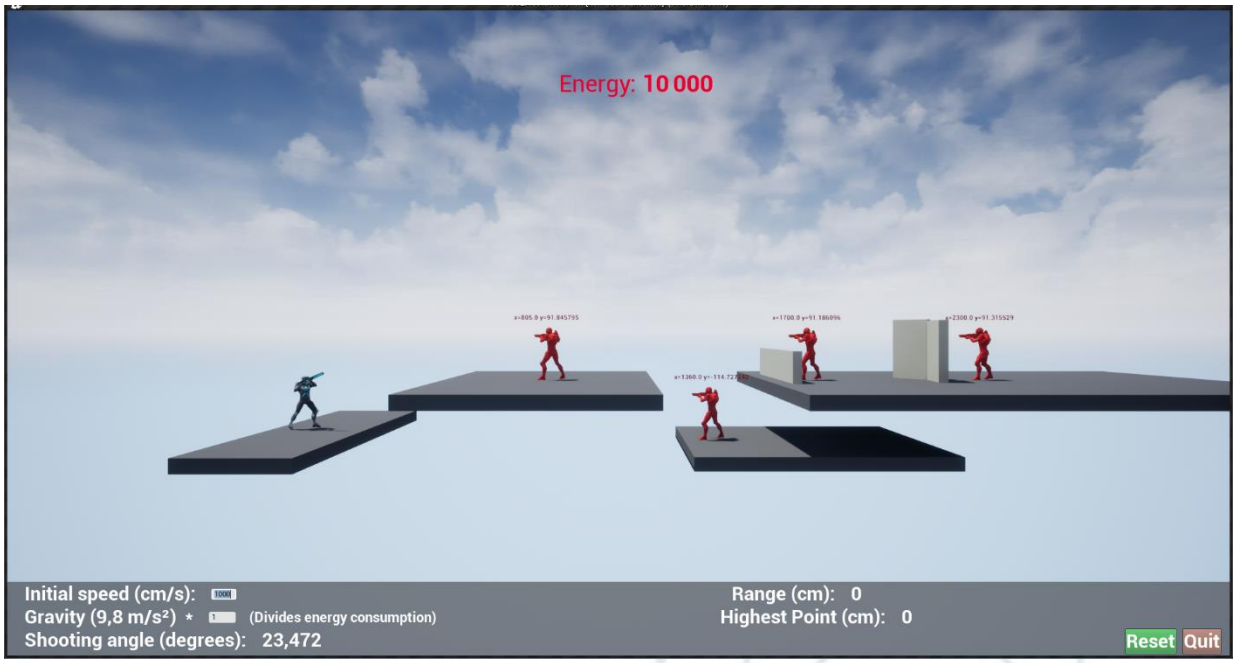
- **Step 2. Intuitive play (10 minutes)**

Launch the game. You are presented with the following interface:



Ballistics Simulator: presentation of the interface

Note the parameters at the bottom-left and the shot information at the bottom-right. The character's gun is located approximately at x=0, y=0. Enemies' coordinates correspond to their center.

By holding the right mouse button and moving up or down, you modify the aiming angle. You can input the speed of the projectile as well as the gravity.

The goal of the game is to knock out all enemies without running out of energy.
The energy consumption is calculated as follows: projectile speed divided by gravity.

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If the gravity is set to 0, speed is divided by 0.1 (x10). KO an enemy and you refill 1000 energy.

Example interactions with your class:

- What do you think happens when gravity is at 0? (input 200 speed and 0 gravity)
- What happens when gravity increases? Try several shots with fixed speed and angle but increase gravity.
- What happens when the angle increases? Show them the curvature change. Note that the maximum range is achieved at 45°.
- How do you think we can shoot this enemy? Try a shot, ask for corrective inputs from students. Try, correct, repeat.

Tell your students that you could optimize your shots using physics.

- **Step 3. Present or review trajectory equations (35 minutes)**

In this step, present to your class the notions of projectile movement. For example, use total force and Newton's second law to derive the equations of motion.

Get your class acquainted with how to find the range and the highest point of a shot.

Once you have explored these theoretical points, try to apply them to the game.

- **Step 4. In-game application of theory (10 minutes)**

Calculate with your students the angle to shoot an enemy located at a specific range:

Range equation: $d = \frac{v^2}{g} \sin 2\theta$

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If we want to shoot the third enemy (x= 1700 cm, y= -39 cm), with a 2000 cm/s speed projectile, at 1g: at which angle should we shoot?

$$\sin 2\theta = \frac{dg}{v^2}$$

$$\theta = \frac{\sin^{-1}\frac{dg}{v^2}}{2}$$

$$\theta = \frac{\sin^{-1}\frac{17 * 9.8}{20^2}}{2}$$

We get 12.3.

We aligned the y=0 axis with enemies' torsos, so you can use this value without correction for enemies' height.

For the last enemy, we see that it requires a high angle in order to go over his cover. Let's pick a 75° angle and calculate the required projectile speed:

$$v = \sqrt{\frac{dg}{\sin 2\theta}}$$

For 75° and 1g, we get 21,23 m/s (2123 cm/s).

How to kill enemies cheat sheet (there are more than one way):

Enemy number	Gravity multiplicator	Initial speed (cm/s)	Aim angle
1	1	1000	26-28
2	2	2000	13
3	1	2000	12-13
4	1	2125	75

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Get the game:

https://yuzupulse.itch.io/ballistics-simulator-g4s

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