# Teaching physics with *Angry Birds*: exploring the kinematics and dynamics of the game



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# Teaching physics with *Angry Birds*: exploring the kinematics and dynamics of the game

**M Rodrigues[1,2] and P Simeão Carvalho[2,3]**

[1] Middle and High School Rodrigues de Freitas, Porto, Portugal
[2] IFIMUP, University of Porto, Rua do Campo Alegre s/n, 4169-007 Porto, Portugal
[3] Department of Physics and Astronomy, Faculty of Sciences, University of Porto, Rua do Campo Alegre s/n, 4169-007 Porto, Portugal

E-mail: marcelojrodrigues@sapo.pt and psimeao@fc.up.pt

**Abstract**
In this paper, we present classroom strategies for teaching kinematics at middle and high school levels, using Rovio's famous game *Angry Birds* and the video analyser software Tracker. We show how to take advantage of this entertaining video game, by recording appropriate motions of birds that students can explore by manipulating data, characterizing the red bird's motion and fitting results to physical models. A dynamic approach is also addressed to link gravitational force to projectile trajectories.

## Introduction

Students' motivation is now an important goal in teaching physics, and the use of video games in classes usually increases students' attention. In fact, video games are appreciated by all kinds of students. *Angry Birds* is a very popular game from Rovio, categorised as a 'physics game' because the motion algorithms are based on the kinematics of projectiles [1]. We can use a video analyser to study the birds' motion when launched by the player from the slingshot. To do so, we only need to record video clips from the game with a screen recorder.

Kinematics analysis of the game can be an excellent teaching strategy at all levels of education, either as an introduction to a subject, or as an application of kinematics and dynamics concepts, from a problem-solving perspective.

In this paper we show how to give a basic kinematics treatment of the game with the help of video analysis and modelling software (Tracker), and outline strategies for teaching kinematics in schools.

## The game

*Angry Birds* is a game created initially for the Apple iOS in 2009 [2] and later adapted for computers and games consoles. Today, there are several thematic editions. It is a dynamic strategy game, based on the laws of physics for projectile motion, where the objective is to destroy the egg-thieving pigs, housed in their buildings, by throwing the angry birds against them with the help of a gigantic slingshot.

## The screen recorder

Fraps is benchmarking freeware developed by Beepa [3] that indicates the number of frames per second displayed on the computer screen.

This program also allows image capture and video recording of everything displayed on the screen. Here we use a version that captures video clips of up to 30 s (which is enough for our purposes).

## The video analyser—Tracker

Today, thanks to the evolution of video analysers in different areas of physics, such as biomechanics and biophysics, there is much free analyser software for didactic purposes. This is in general easy and intuitive to use, and provides excellent tools for teaching kinematics in schools.

We have used one of the best and most powerful freeware video analysers—Tracker. This open source software is authored by Brown [4, 5] and was developed for the Open Source Physics (OSP) project [6]. Tracker is also a data modelling tool because it incorporates the Data Tool module, created by the same author.

Tracker comes with a built-in manual, but whenever students are not familiar with this software we advise teachers to build simple, practical and appropriate guidelines for the activity proposed.

To make measurements with Tracker (or any other video analyser), it is necessary to know the real dimensions of at least one object in the video clip to allow conversion of the image dimensions, initially given in pixels, to real dimensions. Tracker's Calibration Tape tool sets the value of 100 units (pixels) for a predetermined length by default (figure 1). When a new value is introduced to the calibration tool the software divides that value by the number of pixels of the length, fixing the correspondence between one pixel and the standard input unit; for example, converting the video pixel lengths into metres or centimetres.

When the video does not present any object with a known dimension, an arbitrary size can be assigned to one of the objects shown in the video, or we can determine the 'real' dimensions of the game objects by making use of a simple supposition—the game takes place somewhere on Earth.

## Preparation of educational material

*Elaboration of videos*

The videos were recorded with Fraps, which was set to record at 30 frames $s^{-1}$.

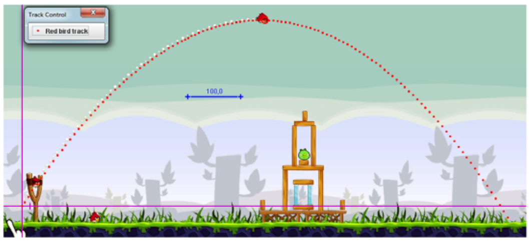


**Figure 1.** The calibration tape appears with a default value of 100, for a standard length of 100 pixels. Reproduced with permission from Rovio Entertainment Ltd.

It is desirable to launch the red bird in such a way that it can hit the ground without colliding with any obstacle, and also with the zoom set in such a way that frame translational movements and zooming of the image do not occur, keeping the reference system of coordinates unchanged. Thus, visualization of the parabolic trajectory of the red bird is more evident (it is easily achieved at the first level of the game, as illustrated in figure 1). Note that for Fraps to capture 30 frames in each second effectively, it is necessary that the computer maths processor and video card are fast enough; otherwise repeated frames will appear in the video.

## Teaching strategies

*Teaching kinematics at middle school level*

Kinematics can be introduced at middle school level by exploring *Angry Birds*.

To begin with, students may choose a convenient position for the reference axes, define a standard length and unit (e.g. the teacher may suggest that the height of the slingshot be 5 m), and track the bird's position with time to visualize the trajectory. Students should be encouraged to change the referential origin, and with this procedure observe what happens to the values displayed on the data table, in particular the position and speed values. They may also be encouraged to change the values and dimensions of the calibration tape, and draw conclusions about the importance of defining a standard unit of length.

The notion of stroboscopic images can be introduced when interpreting the bird's path, in which the spacing between successive positions has a direct relationship with time (for constant time intervals), allowing first contact with the concepts of speed and velocity.

These first video analysis procedures (creating a referential, establishing a standard unit of length and tracing the path) represent a particularly useful activity when students start studying kinematics, because we can introduce and discuss the importance of fundamental concepts such as position, trajectory, movement, rest, etc in a practical and operational ('hands on') way, making learning more effective. This kind of activity can be done: (1) at home as experimental work—the video and a guide can be provided on the internet; or (2) collaboratively by students in the classroom, if there are computers available for all of them (no more than two or three students per computer is strongly advised).

For a more advanced level, after tracing the path teachers can introduce graphs of position versus time, speed versus time and acceleration versus time by analysing and interpreting Tracker's graphs. Indeed, these can be seen simultaneously as the trajectory of the bird's motion is drawn in Tracker's main window (up to three can be viewed at the same time), promoting debate concerning well-known student misconceptions about their interpretation [7–9], namely the contradiction between the position graph and the trajectory of the body [10].

There is also space for more 'traditional' (although very useful) strategies, such as asking students to build graphs of speed and acceleration from data tables, either on paper or with a computer application (e.g. Excel). It is quite important to explain how to calculate the speed and acceleration (see figure 2), based on the bird's positions; this will help students to better understand these concepts from a mathematical and a conceptual point of view. They will have to apply algorithms to calculate the average speed and acceleration, and establish the limits for which it is physically acceptable to consider these average values as the instantaneous speed and acceleration of objects.

Teachers can also introduce the concept of composition of motions, exploring the two basic types of motion discussed in the classroom (uniform rectilinear motion (urm) and uniformly varied rectilinear motion (uvrm)), and the corresponding graphical representation.

Table • Red bird

| t | x | y | $v_x$ | $v_y$ | $a_y$ |
|---|---|---|---|---|---|
| 0 | 0,031 | -0,114 | | | |
| 0,167 | 36,364 | 53,469 | 226,625 | 320 | |
| 0,333 | 75,572 | 106,553 | 229,75 | 298 | -135 |
| 0,5 | 112,947 | 152,803 | 232,5 | 270,375 | -167,1... |
| 0,667 | 153,072 | 196,678 | 236,952 | 245,694 | -174,5... |
| 0,833 | 191,931 | 234,701 | 234,65 | 210,675 | -214,3... |
| 1 | 231,289 | 266,903 | 230,593 | 174,454 | -190,3... |
| 1,167 | 268,796 | 292,852 | 228,559 | 145,779 | -192,8... |
| 1,333 | 307,476 | 315,495 | 219,845 | 113,243 | -180,3... |
| 1,5 | 342,077 | 330,6 | 220,833 | 81,875 | -176,0... |
| 1,667 | 381,086 | 342,787 | 234,042 | 57,511 | -162,7... |
| 1,833 | 420,091 | 349,77 | 234,011 | 26,59 | -190,8... |
| 2 | 459,09 | 351,651 | 234,027 | -5,81 | -191,5... |
| 2,167 | 498,1 | 347,833 | 233,721 | -37,832 | -187,1... |
| 2,333 | 536,997 | 339,04 | 233,242 | -67,867 | -186,6... |
| 2,5 | 575,848 | 325,211 | 232,883 | -99,834 | -184,5... |
| 2,667 | 614,625 | 305,762 | 231,926 | -130,1... | -188,14 |
| 2,833 | 653,156 | 281,833 | 233,396 | -161,4... | -186,8... |
| 3 | 692,424 | 251,952 | 234,327 | -193,5... | -187,1... |
| 3,167 | 731,265 | 217,316 | 233,349 | -223,1... | -189,54 |
| 3,333 | 770,207 | 177,574 | 233,536 | -256,4... | -190,8... |
| 3,5 | 809,111 | 131,819 | 234,06 | -287,8... | -188,1... |
| 3,667 | 848,227 | 81,631 | 232,993 | -318,0... | |
| 3,833 | 886,775 | 25,813 | | | |

**Figure 2.** A data table, displayed at time intervals of five frames, obtained from the bird's positions. The speed ($v$) at the instant 0.167 s, is obtained, for both axes, by subtracting the corresponding axis positions at the instants immediately after ($t = 0.333$ s) and before ($t = 0.000$ s),and dividing the result by the time interval between these two instants. The result is approximately the instantaneous speed of the bird. This calculation process is known as the Euler method [11].

### *Teaching kinematics and dynamics at high school and university levels*

At high school and university levels it is important to maintain the procedures referred to for middle school level, because it is always useful not to assume prior knowledge. However, at this higher level kinematic analysis can be more complex and implies a clear approach to the concept of two-dimensional movement, usually associated with the projectile's motion. This approach can be first introduced through an exploration activity or by posing a problem, for example 'what kind of motion does the bird have when launched by the slingshot?'.

At this point teachers may decide to introduce, or recall, the laws of motion for

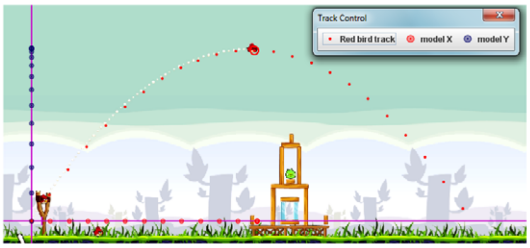


**Figure 3.** The strobe effect for the positions, marked on the *x* and *y* axes, allows qualitative conclusions to be drawn about the motion along each axis. The positions are displayed at intervals of five frames. Reproduced with permission from Rovio Entertainment Ltd.

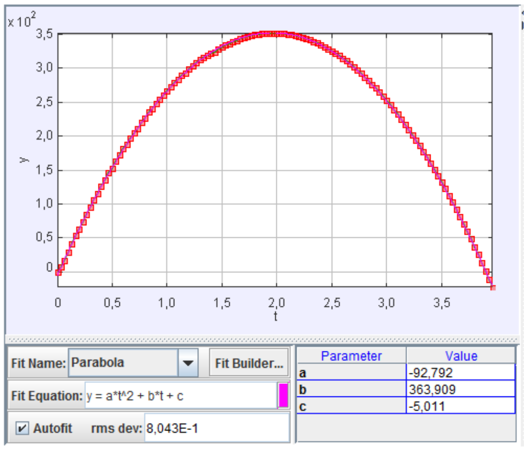


**Figure 4.** Modelling on the graph *y*(*t*). The value of the second-order term (*a*), multiplied by two, gives the vertical acceleration of −185.584 pixels per second squared (pixel $s^{-2}$).

position and speed, for the two types of motion (urm and uvrm along the *x* and *y* axes, respectively), associating mathematical expressions with the physical equations of kinematics, and giving an interpretation for the physical quantities involved.

The interpretation of the parabolic motion requires a graphical analysis of the position and speed with time, along the *x* and *y* axes. To help students analyse the two components of the motion, we suggest they should admit the motion of two independent particles, each 'particle' following the laws of motion for the bird in the corresponding axis. With Tracker it is possible to create virtual models of particles with the Model Builder module, plotting on the *x* and *y* axes the positions that obey the corresponding bird's laws of motion, as if they were shadows of the bird projected on the axes (figure 3).

The dynamic approach to the movement of the bird comes from asserting that the parabolic shape of the trajectory must be related to the existence of an external force acting on the bird (according to Newton's first law). The parabolic motion gives two important dynamic indications: (1) there is a downward vertical acceleration, suggesting the existence of a force similar to the gravitational and (2) the air resistance is negligible. The use of the Data Tool module allows identification of the acceleration of the bird.

One problem that can be given to students, in particular at university level, concerns the dimensions in the *Angry Birds* world. As already mentioned, there are no references in the game that allow us to know the 'real' dimensions of objects and birds. The only parameter that can be measured is time.

To overcome this problem, we may consider that the virtual world of *Angry Birds* is somewhere on Earth (after all it is a game created by humans). Therefore, a challenging problem can be put to the students: 'determine the dimensions of the red bird, knowing that the launch occurs on Earth'.

In the following, we suggest two methods to compute the dimensions of objects in *Angry Birds*, considering the standard gravitational acceleration on Earth as 9.8 m $s^{-2}$.

### *Method 1: fitting to the position graph data*

Using the default calibration tape (figure 1), students can use the graph *y*(*t*) by fitting parameters to a quadratic equation (figure 4). At this point they should know the physical meaning of all the parameters they need to fit, but they must recognize that the acceleration value, set by the coefficient of the quadratic term of the fitting equation, is given in pixels per second squared.

Now students must realize that if the game takes place somewhere on Earth, the gravitational acceleration will be 9.8 m $s^{-2}$. So, there is a directly proportional relationship between the value of the acceleration from the fit and the gravity on Earth that allows them to convert the standard unit (pixel) into SI units (metres)

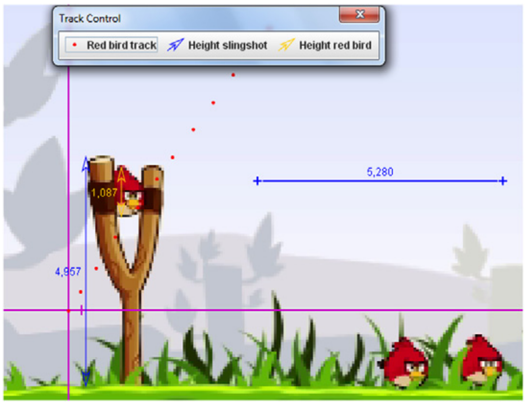


**Figure 5.** With the calibration tape in metres, the dimensions of the slingshot and of the red bird can be measured using the tape tool. Their values are approximately 5.0 m and 1.1 m, respectively. Reproduced with permission from Rovio Entertainment Ltd.

(see also [12]):

$$\frac{185.584 \text{ standard units}}{1 \text{ s}^2} = \frac{9.8 \text{ m}}{1 \text{ s}^2}$$
$$\Leftrightarrow \text{standard unit} = \frac{9.8}{185.584} = 0.0528 \text{ m}.$$

Therefore, each pixel in the video corresponds to about 5.3 cm. The estimated error for measuring positions is about 2 pixels, so the uncertainty will be about 10.6 cm.

Once the conversion factor from pixels to metres has been determined we only have to replace the number marked on the calibration tape by multiplying the number of pixels (100) by the conversion factor (in our case: $0.0528 \times 100 = 5.28$ m). Students can now use the calibration tape tool from Tracker to measure the dimensions of any object in the game (figure 5) in metres.

This method is a simple and quick way to solve the problem, but requires students to understand the functioning of Tracker's calibration process. It is based on mathematical considerations concerning the motion along the $y$ axis, but does not involve any deep kinematics knowledge.

### *Method 2: analysis of speed graphs and determination of physical parameters*

With this method students can work analytically with the equations of motion in a substantially more elaborate way.

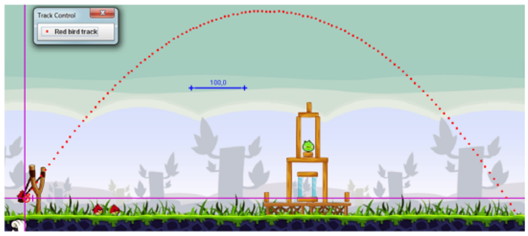


**Figure 6.** The origin of the referential is set to coincide with the initial position of the bird. Reproduced with permission from Rovio Entertainment Ltd.

Students are supposed to keep in mind that the gravitational acceleration in the game is the same as on Earth (just like in method 1). In the vertical direction, the bird has a uniformly varying rectilinear motion due to gravitational acceleration. Therefore, the vertical motion of the bird is described by expressions:

$$y = y_0 + v_{0y}t - (1/2)gt^2 \quad (1)$$
$$v_y = v_{0y} - gt. \quad (2)$$

Therefore, they only need to find $y_0$ and $v_{0y}$ to obtain the equations for the motion in their entirety.

Teachers should encourage their students to look for symmetries and invariants in the study of physical phenomena, and realize that it is convenient to choose the origin of the referential so that the initial position is $y_0 = 0$, at $t = 0$ (figure 6).

Students know that the bird must stop its vertical ascent at a given instant ($t_{hmax}$), reaching a maximum height from which it begins to fall. At that instant, the vertical speed $v_y = 0$. Note that *time* is an invariant in this analysis, because it does not depend on the calibration of the video image. By symmetry, $t_{hmax}$ is half of the flying time (considering the $x$ axis parallel to the ground).

They can find $t_{hmax}$ by looking for the instant when the vertical position is maximum, either from the $y(t)$ graph curve, or (more easily) from the data table, or even using data tool facilities (which provide the maximum value of $y$ by selecting statistics in the menu bar).

However, teachers should point out that with this procedure a considerable error may be introduced, since it is not guaranteed that the frame corresponding to the instant when the bird reached its maximum height was captured

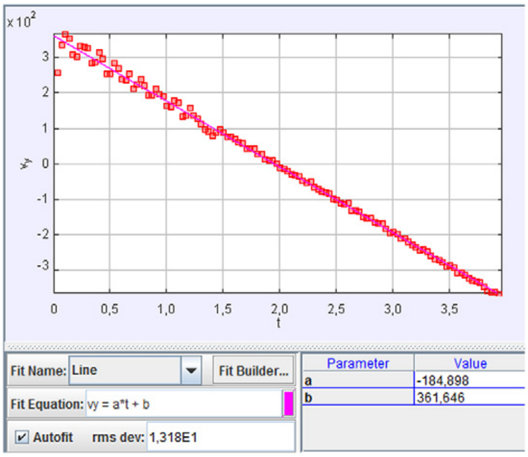


**Figure 7.** The graph $v_y(t)$. The instant $t_{hmax}$ can be determined at $v_y = 0$, using the fitting equation.

during the recording. Obviously, the error will be smaller for higher recording acquisition rates (frames $s^{-1}$). For example, if the game is recorded at a rate of three frames per second, the time error is about 0.33 s, while if recording at 25 frames per second, the time error estimate decreases to 0.04 s. In this work we recorded at a rate of 30 frames per second (time error of about 0.033 s).

Measuring $t_{hmax} = (1.967 \pm 0.033)$ s from the data table, students can determine $v_{0y}$ by solving, according to equation (2), the relation $0 = v_{0y} - gt_{hmax}$. Admitting $g = 9.8$ m $s^{-2}$, it gives $v_{0y} = (19.28 \pm 0.32)$ m $s^{-1}$. This procedure is very simple and the uncertainty is about 1.7%.

Another, perhaps more sophisticated, way to obtain $v_{0y}$ is by using the graph $v_y(t)$ (figure 7).

From the fitting parameters in figure 7, we compute as an average value $t_{hmax} = 361.646/184.898 = 1.956$ s. The estimated uncertainty is about 1.3% (this can be calculated with Excel from the standard deviations of the linear fit).

Using equation (2) and $g = 9.8$ m $s^{-2}$, at $t_{hmax} = 1.956$ s we obtain $v_{0y} = (19.17 \pm 0.25)$ m $s^{-1}$. These results are very similar to those reported above within the experimental error.

Therefore, the expressions that quantify the bird's position and speed during the vertical motion are:

$$y = 19.17t - 4.9t^2 \text{ (m)} \quad (3)$$

$$v_y = 19.17 - 9.8t^2 \text{ (m s}^{-1}\text{)}. \quad (4)$$

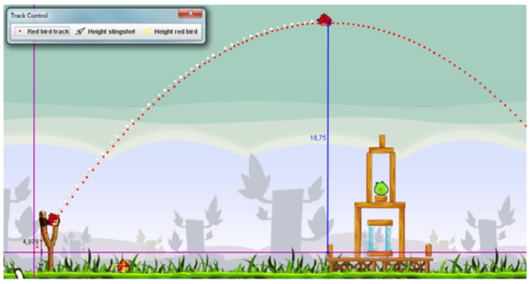

**Figure 8.** The calibration tape is placed vertically, between the $x$ axis and the marked position corresponding to the chosen instant. Reproduced with permission from Rovio Entertainment Ltd.

## Dimensions

To calibrate the dimensions of objects in the game, students must choose the highest possible lengths for the calibration tape, because the larger the tape calibration, the lower the error introduced. Taking the frame when $t = 1.967$ s and using equation (3), they can calculate the respective marked position of the bird: $y = 18.75$ m. This value must now be inserted into the calibration tape (figure 8). Finally, students can use the tape tool to measure the dimensions of the objects in the game.

Teachers can also ask students to complete the study of the bird's motion, finding the equation of the horizontal movement, by determining the horizontal initial speed with a similar procedure. This is an easy task since the necessary parameters (maximum range and flight time) are obtained from the graph $v_x(t)$.

## Conclusions

*Angry Birds* is a good example of how video games can be used in physics classes for teaching and learning physics. In this paper we have reported how to explore kinematics and dynamics, within the subject of projectile motion, using the red angry bird; other physical concepts and laws (such as linear momentum or the conservation laws) can be taught with other birds from the game [13–15].

The game itself has also now been developed to higher stages, with gravity effects around planets [16] and new features based on the successful Star Wars films being introduced [17]. This gives more opportunities for exploring physics in new contexts, teaching in richer environments and, undoubtedly, motivating students to use multimedia tools for learning physics.

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**Marcelo José Rodrigues** is a middle and high school teacher and a researcher at IFMUP. His research interests are interactive educational materials, physics education and teaching training.

**Paulo Simeão Carvalho** is an assistant professor at the Porto University Physics and Astronomy Department. He is also a researcher at IFIMUP. His research interests are liquid crystals, multimedia curricular materials, physics education and teaching training (initial and continuous).