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

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Abstract

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

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INTRODUCTION

Nowadays, students' motivation is one important goal to teach Physics, and the use of videogames in classes usually increases students' attention. In fact, videogames are appreciated by all kind of students. *Angry Birds* is a very popular *Rovio´*s game, catalogued as a "physics game" because the motion algorithms are based in 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 in all levels of education, either as an introduction to a subject, or as an application of kinematics and dynamics concepts, under a problem solving perspective.

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

THE GAME

Angry Birds is a *Rovio Entertainment*'s game that was created initially for the *Apple iOS* in 2009 [2], and later adapted for computers and game consoles. Today, there are several thematic editions. It is a dynamic strategy game, based on the laws of physics of projectiles motion, where the objective is to destroy the pigs egg thieves, housed in its buildings, throwing against them the angry birds with the help of a gigantic slingshot.

THE *SCREEN RECORDER*

Fraps is a benchmarking freeware software 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 that is displayed on the screen. In this work we have used a freeware version of *Fraps* that captures video clips up to 30 seconds (which is enough for our purpose).

THE VIDEO ANALYSER – TRACKER

Today, thanks to the evolution of the video analysers in areas of physics, such as Biomechanics or Biophysics, there is a lot of free analyser's software for didactic purposes. These softwares are in general easy and intuitive to use, and are excellent tools for teaching kinematics in schools.

In this work we have used one of the best and powerful freeware video analyser – *Tracker*. This open source software is authoring by *Douglas Brown* [4, 5] and was developed for the *Open Source Physics* project (OSP) [6]. *Tracker* is also a modelling data tool because it incorporates the *Data Tool* module, created by the same author.

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

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 the conversion of the image dimensions, initially given in pixels, to the real dimensions. *Tracker´s Calibration Tape* tool, by default, sets the value of 100 units (pixels) for a predetermined length (figure 1). When a new value is introduced on 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 meters or centimeters.
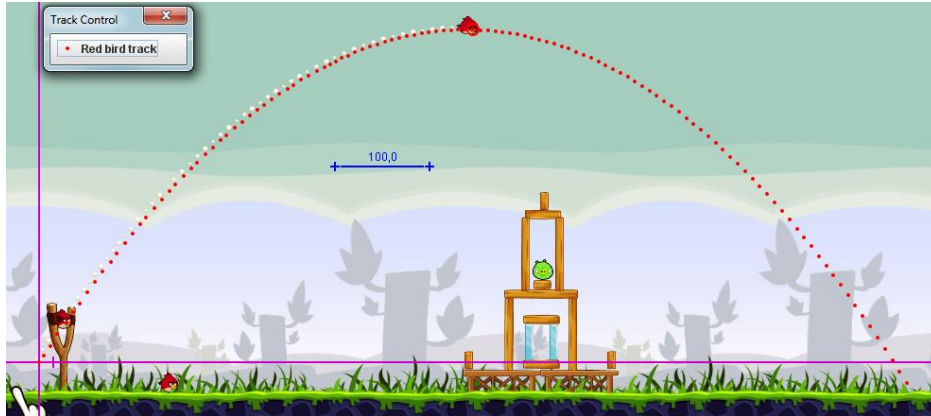

Figure 1: The *calibration tape* appears with the default value of 100, for a standard length of 100 pixels.

When the video does not present any object with a known dimention, we can assign arbitrarily the size of 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*. This was set to record at 30 frames per second.
It is desirable to launch the red bird in 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 unchanged the reference system of coordinates. 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). Notice that for *Fraps* effectively capture 30 frames in each second, it is necessary that the computer math processor and video card are fast enough; otherwise repeated frames will appear in the video.

TEACHING STRATEGIES

Teaching kinematics in middle school level

Kinematics can be introduced at the basic level of education 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 could be

5 m), and track the bird´s positions with time to visualize the trajectory. Students should be encouraged to change the origin of the referential, 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 take conclusions on the importance of defining a standard unit of length.

The notion of stroboscopic image 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 a first contact to the concepts of speed and velocity.

These first procedures of the video analysis (creating a referential, establishing a standard unit of length and tracing the path) represent an activity particularly useful for when students start studying kinematics, because we can introduce and discuss the importance of fundamental concepts like 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 an experimental work - the video and a guide to explore can be provided by internet; or (2) collaboratively by students in classroom, if there are computers available for all of them (one computer for every two or three students is strongly suggested).

For a more advanced level, after tracing the path, teachers can introduce graphs of position vs time, speed vs time and acceleration vs time, by analysing and interpreting *Tracker*´s graphs. Indeed, these graphs can be seen simultaneously as the trajectory of the bird´s motion is drawn in *Tracker*'s main window (up to three graphs can be viewed at the same time), promoting the debate concerning the well known students' misconceptions about their interpretation [7-9], namely the confrontation 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 the acceleration (see table 1), based on the bird's positions; this will help students to better understand these concepts in a mathematical and a conceptual point of view. They will have to apply algorithms to calculate the average speed and average acceleration, and establish the limits for which it is physically acceptable to consider these average values as the instantaneous speed and acceleration of objects.

▦ 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			

Table 1: Data table, displayed at time intervals of 5 frames, obtained from the bird's positions. The speed (*v*) at the instant 0.167 s, is obtained, for both axis, subtracting the corresponding axis positions at the instants immediately after (t = 0.333 s) and before (t = 0.000 s), 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].

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

Teaching kinematics and dynamics at high school and university levels

At the high school level and university, it is important to maintain the procedures referred for middle school level, because it is always useful to avoid the lack of student's prerequisites. 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 to the projectile's motion. This new approach can be first introduced through an exploration activity or by a problematic question – the problem issue (for example: "What kind of motion has the bird when launched by a slingshot?").

At this point teachers may decide to introduce, or recall, the laws of motion for position and speed, for the two types of motion (*urm* and *uvrm* along the *x* and *y* axes, respectively), associating mathematical expressions to the physical equations of kinematics, and giving an interpretation for the physical quantities involved.

The interpretation of the parabolic motion, separating the two distinct and independent types of 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 motion's law of the bird in the corresponding axis. With *Tracker*, it's possible to build virtual models of particles with the *Model Builder* module, plotting in *x* and *y* axes the positions obeying to the corresponding bird's motion laws, as if they were shadows of the bird projected on the axes (figure 2).
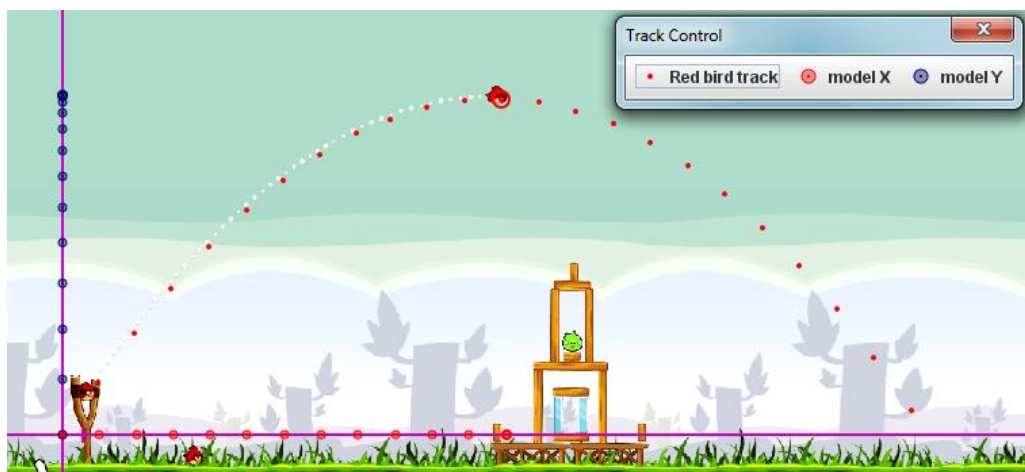
Figure 2: The strobe effect of the positions, marked on *x* and *y* axis, allow qualitative conclusions about the motion along each axis. The positions are displayed in intervals of 5 frames.

The dynamic approach to the movement of the bird, comes by 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 force, (2) the air resistance is negleted. The use of the *Data Tool* module will allow the identification of the acceleration of the bird.

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

To overcome this problem, we may consider that the virtual world of *Angry birds* is somewhere on Earth (after all it's a game created by humans!). Therefore, a challenging problem issue can be proposed to the students: "Determine the dimensions of the red bird, knowing that the launch accours on planet Earth."
In the following, we suggest two methods to compute the dimensions of objects in *Angry birds*, considering the standard gravitational acceleration on Earth (9.8 m/s^2).

Method 1: fitting to the position graph data

Using the default *calibration tape* (figure 1), students can make the modelation of the graph *y(t)*, fitting parameters to a quadratic equation (figure 3). At this point they should know the physical meaning of all parameters 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 square.
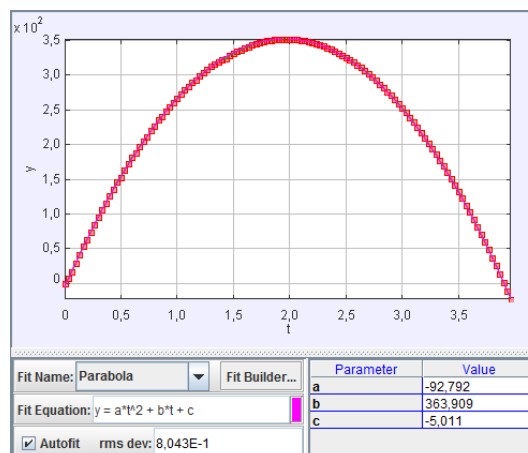

Figure 3: Modeling of the graph *y(t)*. The value of the second order term (*a*), multiplied by two, gives the vertical acceleration of - 185.584 pixels per square meter (pixel/s^2).

Now students must realize that if the game takes place somewhere on Earth, the gravitational acceleration will be 9.8 m/s². So, there is a direct proportional relationship between the value of the acceleration from the fit, and the gravity of Earth that allows them to convert the standard unit (pixel) into the International System of units (meters) - for a similar reasoning, see also [12]:

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

Therefore, each pixel in the video corresponds to about 5.3 cm. The estimate error for measuring positions is of about 2 pixels, so the uncertainty will be about 10.6 cm.
Once the conversion factor from pixels to meters is determined, to obtain distances in meters we only have to replace the number marked on the calibration tape, multiplying the number of pixels (100) by the conversion factor (in our case: 0.0528 x 100 = 5.28 m). Students can now use the *tape* tool from *Tracker*, to measure the dimension of any object in the game (figure 4).
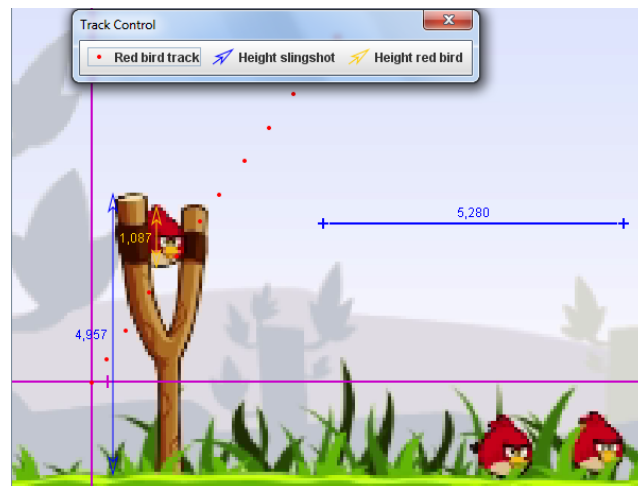

Figure 4: With the *calibration tape* in meters, the dimensions of the slingshot and of the bird can be determined using the *tape* tool. Their measured values are approximately 5.0 m and 1.1 m, respectively.

This method is a simple and quick way to solve the problem issue, but needs that students understand the functioning of *Tracker*´s calibration process. It is based on mathematical considerations concerning the motion along *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 the equations of motion in a substantially more elaborated way.
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

varied rectilinear motion due to gravitational acceleration. Therefore, the vertical motion of the bird is described by expressions:

$$y = y_0 + v_{0y}t - (1/2)\, gt^2 \tag{1}$$

$$v_y = v_{0y} - gt \tag{2}$$

therefore, they only need to find y_0 and v_{0y} to completely obtain the equations of the motion. Teachers should encourage their students to look for symmetries and invariants in the study of physical phenomena. Those should 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 5).
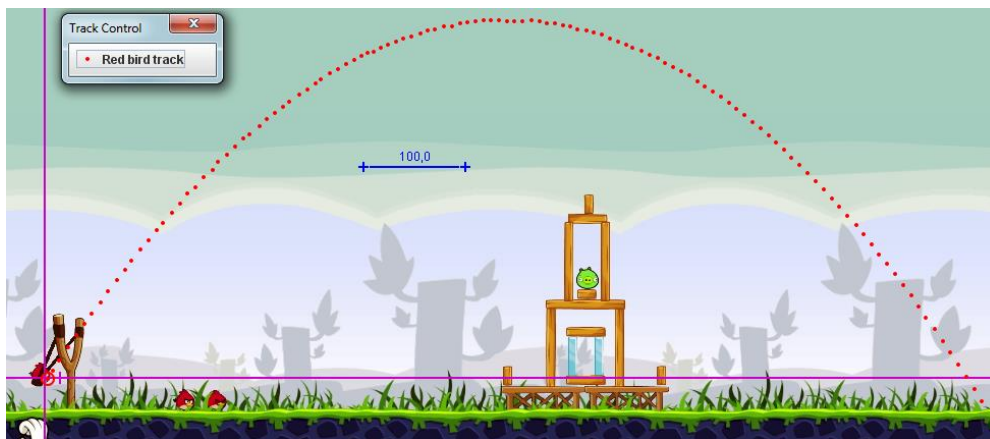

Figure 5: The origin of the referential is set to coincide with the initial position of the bird.

Students know that the bird must stop the 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 *Date Tool* facilities (which provides the maximum value of y by selecting statistics in the menu bar). However, teachers should point out that with this procedure we can introduce a considerable error, since it is not guaranteed that the frame corresponding to the instant when the bird reached its maximum height, was captured during the recording. Obviously, the error introduced will be smaller as heigher the recording acquisition rate (frames/second). For example, if the game is recorded at a rate of 3 frames per second, the time error is of about 0.33 s, while recording at 25 frames per second, the time error estimated decreases to 0.04 s. In this work we have recorded at a rate of 30 frames per second (time rrror of about 0.033s).

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. This procedure is very simple and the uncertainty is of about 1.7 %.

Another way, perhaps more soffisticated, to obtain v_{0y} is by modelation of the graph $v_y(t)$ (figure 6).
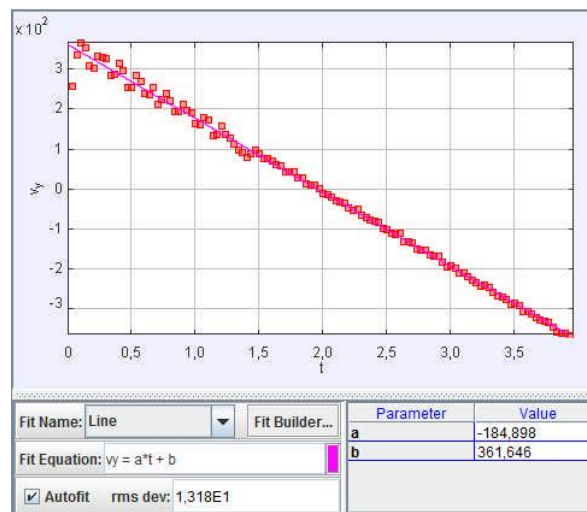

Figure 6: Modeling graph $v_y(t)$. The instant t_{hmax} can be determined at $v_y = 0$, using the fit equation.

From the fit parameters in figure 6, we compute as an average value, $t_{hmax} = 361.646$ / $184.898 = 1.956$ s. The estimated incertainty is of about 1.3 % (this can be calculated in *Excel*, from the standard deviations of the linear fit).
Using equation (2) and g = 9.8m/s^2 , at $t_{hmax} = 1.956$ s we obtain $v_{0y} = (19.17 \pm 0.25)$ m/s. 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:

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

$$v_y = 19.17 - 9.8t \text{ (m/s)} \tag{4}$$

In order 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 is 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 in the *calibration tape* (figure 7).
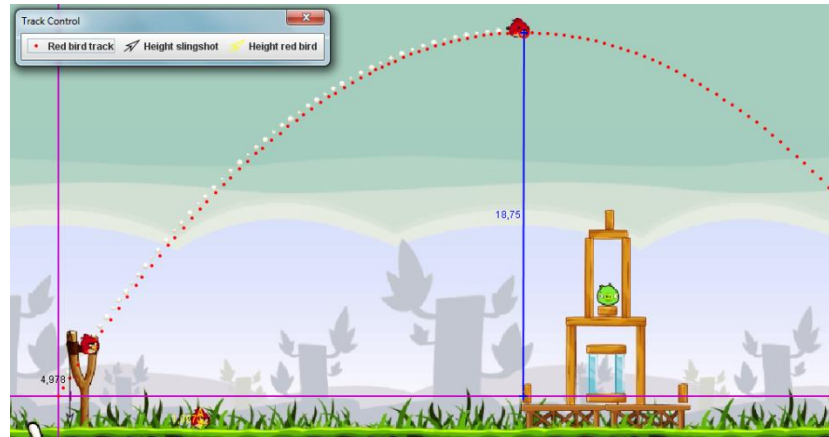
Figure 7: The *calibration tape* is placed vertically, between the *x* axis and the marked position corresponding to the chosen instant.

Finally, students can use the *Tape* tool to measure the dimensions of the objects in the game, as previously reported (figure 7).

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 modelation of graph $v_x(t)$.

CONCLUSIONS

Angry Birds is, indeed, a good exemple of how vídeo games can be used in physics classes for teaching and learning Physics. In this work we have reported how to explore kinematics and dynamics, whithin the subject of projectile motion, with the red angry bird; other physical concepts and laws (such as the linear momentum or the conservation law) can be taught with other birds of the game [13-15].

The game itself has also developed recently to higher stages, introducing gravity effects around planets [16] (http://space.angrybirds.com/launch/, retrieved in 02/04/2012) and new features based on the successful Star Wars films (http://angrybirds.tumblr.com/, retrieved in 12/11/2012). This gives more opportunities for exploring Physics in new contexts, teaching in richer environments and undoubetedly, to motivate students to use multimedia tools for learning Physics.

Acknowledgements

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