Using image modelling to teach Newton's Laws with the Ollie trick

2016 Phys. Educ. 51 045008

(http://iopscience.iop.org/0031-9120/51/4/045008)

PAPERS
Phys. Educ. 51 (2016) 045008 (6pp)
iopscience.org/ped

Using image modelling to teach Newton's Laws with the Ollie trick

Marco Adriano Dias[1,2], **Paulo Simeão Carvalho**[3,4] **and Deise Miranda Vianna**[2,5]

[1] Instituto Federal do Rio de Janeiro (IFRJ), Rio de Janeiro, Brasil
[2] Instituto Oswaldo Cruz/Programa de Ensino de Biociências e Saúde (EBS/FIOCRUZ), Rio de Janeiro, Brasil
[3] Departamento de Física e Astronomia, UEC, Faculdade de Ciências da Universidade do Porto (UP), Rua do Campo Alegre, s/n, 4169-007 Porto, Portugal
[4] IFIMUP-IN, Rua do Campo Alegre, s/n, 4169-007 Porto, Portugal
[5] Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil

E-mail: marco.dias@ifrj.edu.br, psimeao@fc.up.pt and deisemv@if.ufrj.br

Abstract
Image modelling is a video-based teaching tool that is a combination of strobe images and video analysis. This tool can enable a qualitative and a quantitative approach to the teaching of physics, in a much more engaging and appealling way than the traditional expositive practice.

In a specific scenario shown in this paper, the Ollie trick, we show how image modelling can contribute to the contextualisation of Newton's Laws, foster an effective learning and spell out the relation between forces and the different moments of skateboarding.

Image modelling as a teaching tool

As digital video recording devices (DVRs) grow popular, along with a wide range of free applications for video editing and analysis, a large number of possibilities for the contextualisation of science are available for use by teachers. Nowadays such technology is easily available to schools, since most students and teachers have access to smartphones, tablets and portable computers.

The existing technology enables the recording of bodies in motion, e.g. the pursuit of isolated regular motions in nature, as well as the recording of complex movements in different sports, some of them practiced by the students themselves; this allows students to draw a qualitative and/or quantitative analysis of those motions with a computer during their science classes.

Image modelling is a teaching tool that uses video as an input of preparatory curricular material. It consists of the use of strobe images [1, 2] and/or video analysis [3]. Most of the goals aimed in the teaching of physics can be achieved through image modelling, because it enables students to engage in inquiry activities in such a way that they participate actively in the learning process, along with their fellows. Students can also choose themselves to record the videos they will study using digital technology. Thus, they develop inquisitiveness about the relationship between technology and science in the physical world [4].

Digital video recording is composed by a sequence of frames chronologically assembled, according to the image capture ratio set in the camera; thus, it is possible to digitally overlay the frames and produce a strobe image in which the time span between two consecutive positions is constant [1, 2]. This digital resource is available in some freeware applications, such as on *ImageJ* [5, 6], or in *Tracker* [7] using the *Ghost* feature.

The teaching structure of the approach for image modelling proposed in this paper compasses two stages: a first stage for a qualitative phenomenological description of the motion (watching the video and the corresponding strobe image) along with a case exposition (the motivating factor); and a second stage for a conceptual and quantitative inquiry using video analysis. Both stages should coexist for a consistent interpretation of the phenomena observed.

Skateboarding is a practice widely spread among students and features a vast number of concepts from mechanics. Among the countless moves done in this sport, this paper focuses on a trick called *Ollie,* as it is a fundamental one and the basis of most skateboarding maneuvers, englobing a wide array of concepts in physics.

For the interpretation of the phenomenon, it is fundamental to observe a strobe image since it depicts the motion as a whole. Nevertheless, the video should also be displayed simultaneously with the image. Figure 1 shows the strobe image of the *Ollie* trick, from A to F. The original video was recorded on a full-HD Canon EOS Mark III camera at a capture ratio of 60 frames per second. However, the superposition of images in figure 1 was made with increments of 10 frames, and therefore the effective frame rate is only 6 frames per second.

While doing the *Ollie* trick, the athlete performs a jump, without letting the skateboard slip away from his feet. Based on this trick, athletes overcome obstacles and perform movements that are more complex.

An activity of inquiry can be developed upon the phenomenological description of the motion. The conceptual interpretation of the several scenes in figure 1 helps to retain the students engaged with the problem.

In this paper, we show that the analysis of the *Ollie* trick based on this qualitative and quantitative approach can help the teaching of Newton's Laws.

Teaching Newton's first law (law of inertia)

In a qualitative analysis, the strobe image addresses the principle of inertia with the students from scene A before the jump to scene F when the trick ends. The video analysis shows that just before performing the *Ollie* trick (scene A in figure 1), the athlete moves forward in a straight line at a constant speed; the corresponding value can be calculated with *Tracker* software facilities, within the *Data Tool* analysis module. The graph of position x versus time in figure 2 shows a linear plot for scene A, corresponding to a speed $V_A = 2.76$ m s^{-1}. Right after performing the *Ollie* trick (scene F), the athlete lands in a straight-line motion at a speed $V_F = 2.15$ m s^{-1}.

Although it is clear that the speed decreases slightly after the jump, the most important feature to highlight is that the athlete presents a horizontal speed though no external horizontal force is applied during the whole trick; this enables the discussion of the law of inertia with students. The reasons for this decrease of speed lay the groundwork for a further discussion over the principle of energy conservation throughout the whole performance of the trick, and the influence of eventual friction forces acting upon the skateboard.

Teaching Newton's third law (law of action-reaction) and free-body diagrams

In accordance with an inquiry-based learning on a real situation, it is crucial that the students feel capable of describing the phenomena and employing properly the Image Modeling tools. Despite the complexity in the *Ollie* trick, it is commonly noticeable that the athlete crouches down as he gets close to the obstacle, with the knees bent as illustrated in scene A on the strobe picture (figure 1). Immediately after, the athlete performs two simultaneous moves: an upward movement with his body and simultaneously a downward kick on the end tail of the skateboard (scene B in figure 1). Then the skateboard flies through air.

At this point, it is important students understand that the skateboard just moves up as a result of being pushed downwards. When the athlete pushes down the tail of the skateboard, both feet exert downward forces on the skateboard (F_1 and F_2, as shown in figure 3(A)). At that moment, the forces acting on the board are the normal reaction force (N), the weight of the board (W), F_1 and F_2; F_N is the compressive force that the skateboard exerts on the ground. The net force on the board is small and is represented by F_R. When the board

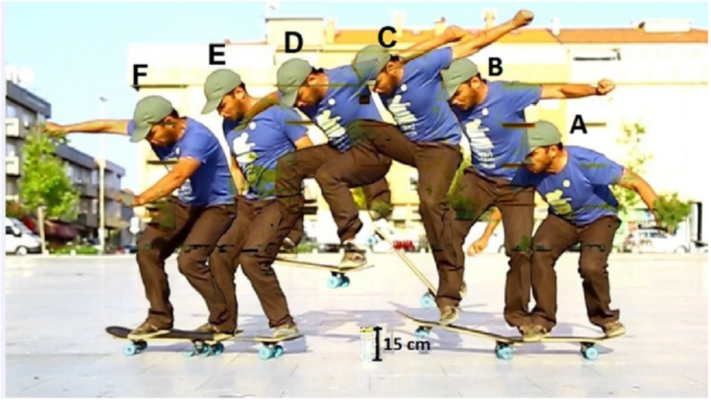

Figure 1. Strobe Image of the *Ollie* Trick, a fundamental movement in *skateboarding*.

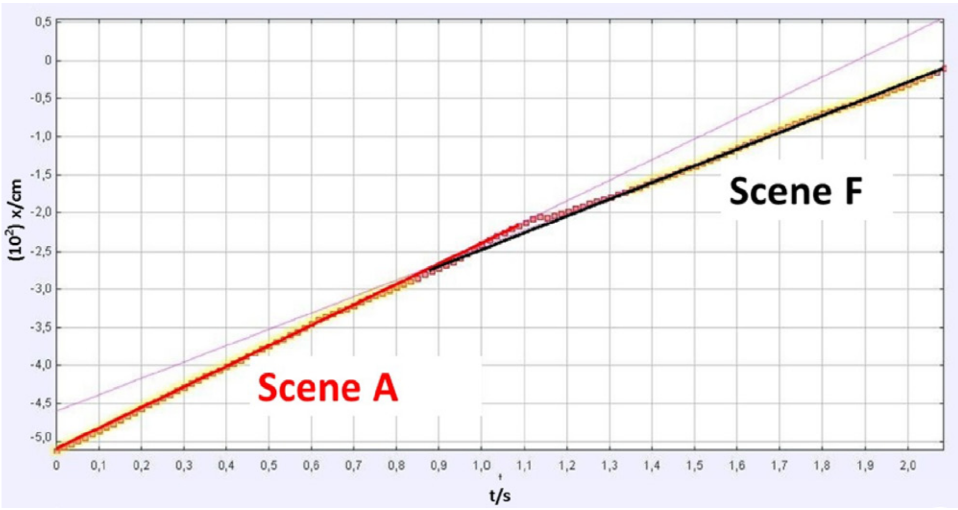

Figure 2. Plot of the horizontal position of the athlete throughout the entire movement. Scenes A and F represent the corresponding images in figure 1 over time, respectively before and after the athlete performs the *Ollie* trick.

strikes the ground, the athlete's back foot still applies a force F_1 of the board, and the board's tail transfers that force F_1 ($=F_{N1}$) to the ground (figure 3(B)). The ground (practically) doesn't get deformed, so it prevents the skateboard from penetrating it by exerting back on the board a force of equal intensity (the reaction force F'_{N1}). This (internal) pair of forces F_{N1} (exerted on the ground) and F'_{N1} (exerted on the board), as well as N and F_N, acting on different bodies with opposite directions, illustrate the law of action and reaction (Newton's third law). The net upwards force F_R on the skateboard that is responsible for its taking off, is

$$F_R = N + F'_{N1} - (W + F_1 + F_2).$$

To complete the *Ollie* trick, it is again necessary to analyse the free-body diagram in two particular instants of the move. The first one is when the athlete exerts a force F on the front tip of the skateboard, making it spin counterclockwise getting it back into the original horizontal position (figure 3(C)). The second instant is when the rotation is over and the athlete's front and back feet tap the skateboard with forces F_I and F_{II} (figure 3(D)). From this point, both athlete and skateboard start the downward movement of landing together, as the feet exert simultaneous forces on the top of the skateboard.

Figure 4 shows the position y of three points of the skate: the tail, the back and the front wheels. The most relevant result in the

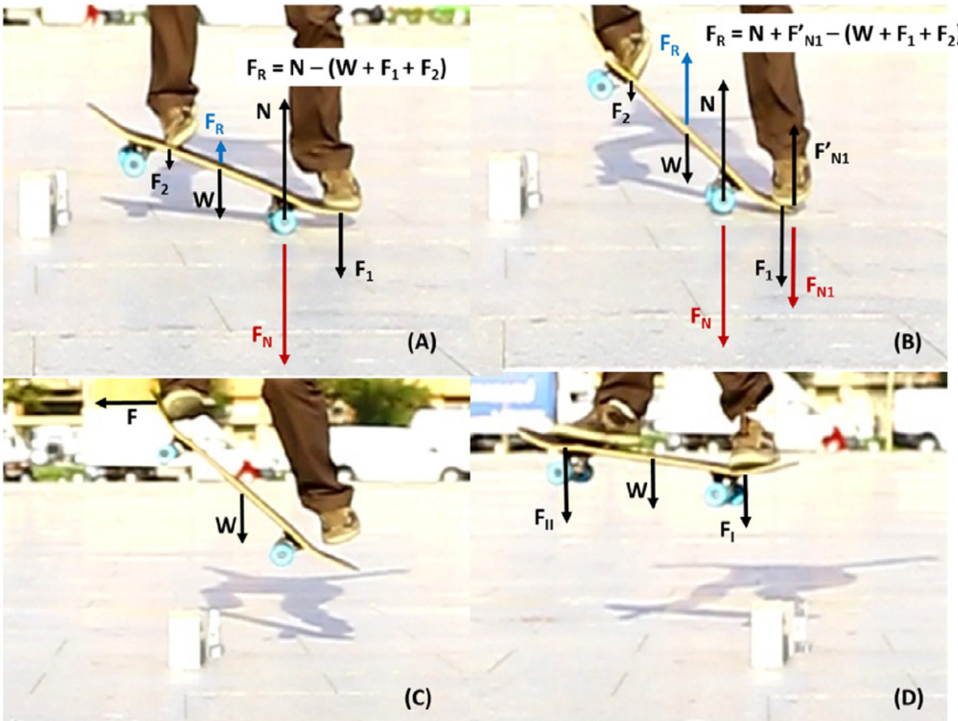

Figure 3. (A) At the beginning of the jump, the athlete's feet exert forces F_1 and F_2 on the board. The net force on the board is F_R. In this figure, W represents the weight of the skate, N is the force exerted by the ground on the back wheel and F_N is the compressing force acting on the ground. (B) The driving force comes from the interaction between the tail and the ground. When the tail touches the ground it produces an action (F_{N1})—reaction (F'_{N1}) pair of forces. The net upwards force F_R on the board results from all the forces acting on the skate. (C) The skateboard is subjected to the horizontal force F that the foot applies on the front of the skate, producing a torque that makes it turn. (D) After the transposition of the obstacle the feet apply forces F_I and F_{II} on the board, whose torques are balanced. The skate heads to the ground without rotation.

whole graph is at the last part of the motion, from the moment the skate starts to descend (figure 3(D)) until it touches the ground. Within this time interval, both tail and wheels show equally spaced parabolic curves, which are typical of a translation without rotation motion with constant acceleration in the vertical direction. This feature will be discussed in the next topic.

Teaching Newton's second law

At the moment of jumping, there are forces acting on the skateboard that produce movements of translation and rotation. Between the moment that the skateboard reaches the maximum height ($t = 0.35$ s—scene D in figure 1) and the moment it touches the ground ($t = 0.48$ s—scene E in figure 1), the skateboard is practically horizontal. During this time interval, the athletes' feet exert forces upon the skateboard (figure 3(C)) producing torques that cancel each other; consequently, no rotation of the skateboard is produced. In this time interval ($t = 0.35$ s to $t = 0.48$ s), any point on the skateboard has a trajectory that is well fitted by a parabolic curve $y(t) = -12.08t^2 + 6.89\, t - 0.42$ (m), as shown in figure 5 for the tail trajectory. The fit indicates that the acceleration is constant within this time interval and the skateboard describes a pure translation motion. Moreover, the acceleration of the skateboard, computed from the first term of the curve fit, is of about 24.2 m s^{-2}, considerably higher than the local acceleration of gravity, i.e. in this motion the athletes' feet exert important vertical forces on the skateboard, pushing it to the ground.

In this case, the athlete intuitively applies forces that get the skateboard to land horizontally,

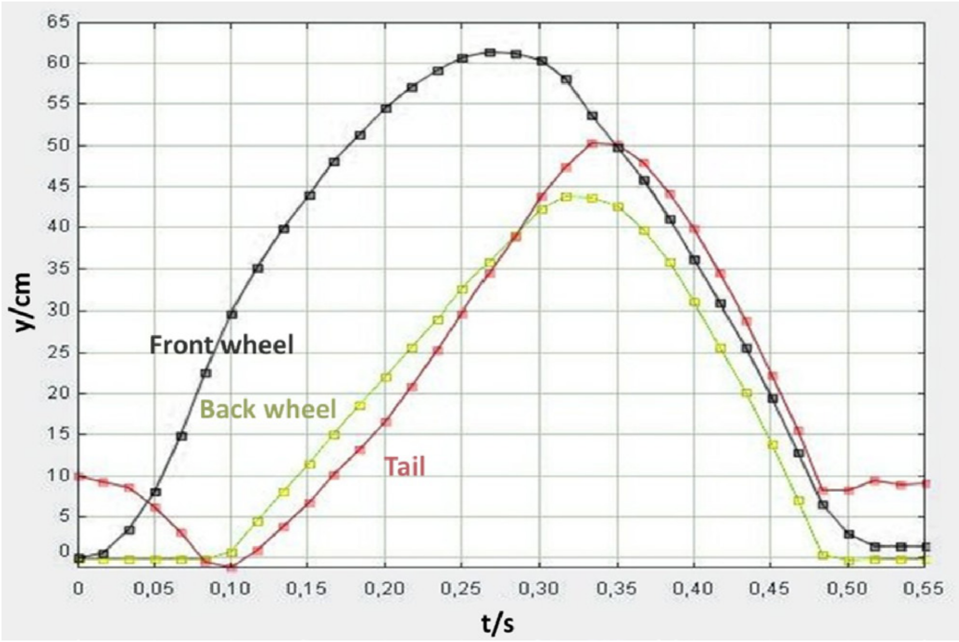

Figure 4. Superposition of plots of y-position versus time for three points of the skateboard: the tail, the rear wheel and the front wheel.

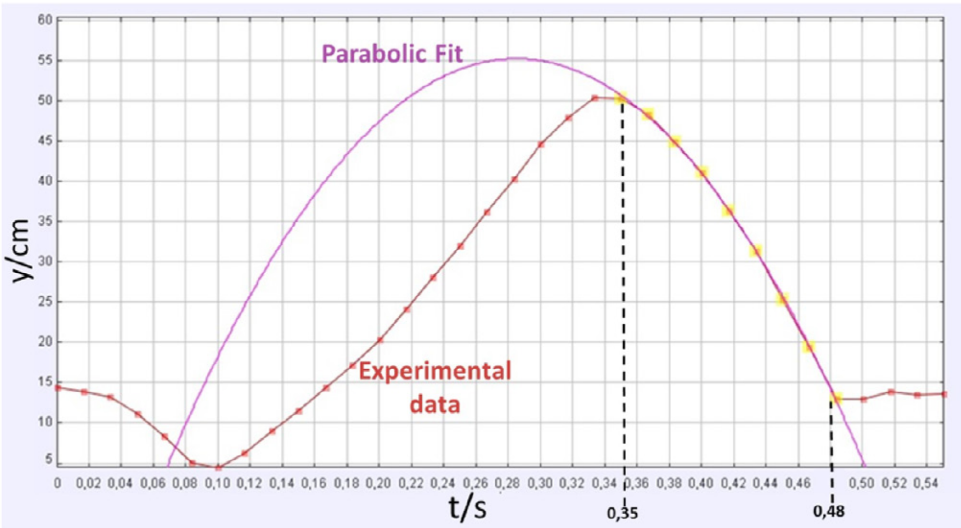

Figure 5. Experimental data for position versus time of the tail of the skateboard. Between $t = 0.35$ s and $t = 0.48$ s, a parabolic curve of equation $y(t) = -12.08t^2 + 6.89\,t - 0.42$ (m) fits data quite well, indicating a movement with a constant acceleration of about 24.2 m s^{-2}, considerably greater than the gravitational acceleration.

by pressing it directly to the ground and preventing rotation. Maybe this is the great 'secret' of a perfect performance of the *Ollie* trick. The results achieved by means of video analysis, show how subtle the body motions may be when it comes to the practice of sports.

Conclusions

It is unquestionable that students increase their engagement in the learning process when image modelling is employed while teaching mechanics. The systematic study of motions is currently possible using low-priced lab equipment.

Strobe images allow the visualisation of relevant details of motions that require interpretation of physical laws. They enable teachers to draw strategies that foster an interactive learning, based on an adequate inquiry-based approach. In a first stage of image modelling, the conceptual analysis of a real and eventually complex motion is pivotal for a second stage where video analysis is used for a quantitative study.

Image modelling is therefore a valuable teaching approach in the instruction of physics, at least at high secondary level, because it actively engages students in the description of phenomena, dealing with experimental results and in brainstorming. Students not only identify in practice the implication of physical laws, they also feel compelled to quantify mathematically the motion, in such a way that the teaching–learning process is much more appealling and engaging than the traditional expositive practice.

Acknowledgments

The authors are indebted to Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ) for the incentive to research. This work was funded by Fundação para a Ciência e a Tecnologia (FCT) Project UID/NAN/50024/2013, and by CAPES (Coordenação de Aperfeiçoamento de Pessoal de Ensino Superior) (BEX 3275/15–9).

Received 17 February 2016, in final form 2 April 2016
Accepted for publication 18 April 2016
doi:10.1088/0031-9120/51/4/045008

References

[1] Dias M A, Barros S S and Amorim H S 2009 Produção de fotografias estroboscópicas sem lâmpada estroboscópica *Caderno Brasileiro de Ensino de Física* **26** 492–513
[2] Dias M A 2011 Utilização de fotografias estroboscópicas digitais para o estudo da queda dos corpos *MSc Thesis* Rio de Janeiro, UFRJ (www.if.ufrj.br/~pef/producao_academica/dissertacoes/2011_Marco_Adriano_Dias/dissertacao_Marco_Adriano_Dias.pdf) (accessed 16 December 2015)
[3] Brown D and Cox A J 2009 Innovative uses of video analysis *Phys. Teach.* **47** 145–50
[4] Lemke J L 2006 Investigar para el futuro de la educación científica: nuevas formas de aprender, nuevas formas de vivir *Enseñanza de las ciencias* **24** 5–12
[5] http://imagej.nih.gov/ij/ (accessed 1 May 2016)
[6] Dias M A, Carvalho P S and Rodrigues M 2016 How to determine the Centre of Mass of bodies from Image Modelling *Phys. Educ.* **51** 025001
[7] http://physlets.org/tracker/ (accessed 1 May 2016)

Marco Adriano Dias is a professor at the Federal Institute of Education, Science and Technology of Rio de Janeiro (IFRJ) and a PhD student at the Bioscience and Health School of the Oswaldo Cruz Institute. His research interests are interactive educational material, image modeling, physics education and teacher training (initial and continuous).

Paulo Simeão Carvalho is an assistant professor at the Department of Physics and Astronomy, Faculty of Sciences, University of Porto since 1998. He is also researcher at IFIMUP and member of UEC (Unit for Teaching of Sciences). His research interests are multimedia curricular materials, physics education and teacher training (initial and continuous).

Deise Miranda Vianna is an Associate Professor of the UFRJ Institute of Physics, and Professor of Bioscience and Health School of the Oswaldo Cruz Institute. Her area of research is focused on investigative teaching, with emphasis on science, technology and society, within her research group PROENFIS.