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Video analysis in STEM education

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1. Motivation

Task: Choose any motion of a ball for following analysis.

The game provides many examples that can bring physics to life in the classroom. Especially the kinematic and dynamic characteristics of motions are worth a physics classroom discussion [1]:

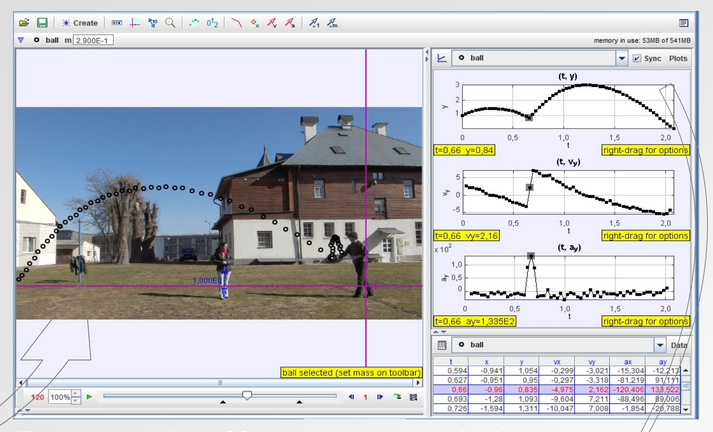
- What is the velocity of the ball?
- What is the rate of change of the velocity?
- Who of the students has given the ball the maximum velocity?
- What was the force with which they hit the ball?

The answers to these questions can provide an analysis of videos by means of the program Tracker [2] (Open Source Physics (OSP)).

For preparing the video files we used a camera Casio Exilim Ex-FH25 which allows to record videos with 30, 120, 240, 420 and 1000 frames per second (fps).

2. Analysis using Tracker

Task: Detect the relationship between physical quantities and describe a motion using time dependencies.



What do we need?

- a video in the format avi, mov, mpg, (and other formats)
- to know the number of frames per second (fps) of the video (=> Δt)
- a real displacement, for example 1 meter

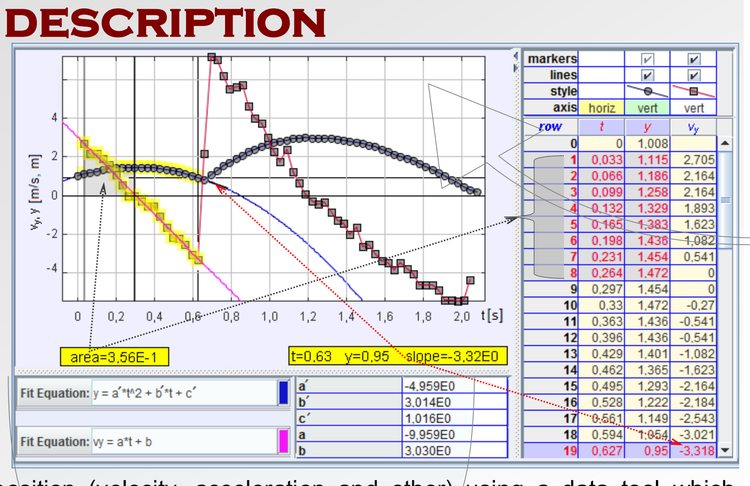
What does the program offer?

- time dependencies of 22 physical quantities (+ we can define)
- data processing by means of graphs and tables

From the number of frames per second (30 fps in our case) the time is deduced ($\Delta t = 0.033$ *s*), while the position can be measured in two dimensions *(x, y)* using a video image after calibration. The function autotracking in this program allows for accurate tracking without mouse. The motion can be divided into two parts: the horizontal component and the vertical component. These two components can be calculated independently of each other and afterwards the results can be combined to describe the total motion ($x(t)$, $y(t)$, $v_x(t)$, $v_y(t)$, $a_x(t)$, $a_y(t)$).

3. Mathematical description

Task: Investigate the mathematical phenomenon of integration and derivation.



The velocity of a volleyball ball (squares) before hitting it in the course of serving changes in the vertical direction nearly at the same rate throughout the motion (first part of motion, $t = 0 - 0.63$ *s*) => the average acceleration in the vertical direction over any time interval equals the instantaneous acceleration at any instant.

Students can fit time dependencies of position (velocity, acceleration and other) using a data tool which provides a data analysis including automatic or manual curve fitting of all or any selected subset of data. The vertical position (circles) and the velocity (squares) are plotted and fitted to see the correlation between the real data and the kinematic equations. Students have found that the trajectory of the ball (circles) is always a parabola.

before hitting (analyze): $v_y(t) = -9.96t + 3.03$, $y(t) = -\frac{1}{2}\,9.92t^2 + 3.01t + 1.02$

at the moment of serve *(t = 0.63 s)*: $|\vec{F}| = |d\vec{p}|/dt = m|d\vec{v}|/dt = 60.51$ N

area $= \int$ $\quad \Sigma v_{yi}\,\Delta t \xrightarrow[\Delta t \to 0]{} \int v_y(t)\,dt = y(t)$

slope $= d/dt$ $\quad \Delta y/\Delta t \xrightarrow[\Delta t \to 0]{} dy(t)/dt = v_y(t)$

$$\vec{v} = \frac{d\vec{r}}{dt} \qquad \vec{a} = \frac{d\vec{v}}{dt}$$

4. Physical theory

Task: Study new terms from e-books or textbooks.

"*Projectile motion*" is a type of a two-dimensional motion [3] in the *xy* plane with constant acceleration whose components are $a_y = -g$ and $a_x = 0$. It is useful to think of this motion as a superposition of two one-dimensional motions: (1) free-fall motion in the vertical direction subject to a constant downward acceleration of magnitude *g* and (2) motion in the horizontal direction at a constant velocity.

(1)
$a_y(t) = -g$
$v_y(t) = \int a_y(t)\,dt = -gt + v_y(0)$
$y(t) = \int v_y(t)\,dt = -\frac{1}{2}\,gt^2 + v_y(0)t + y(0)$

(2)
$a_x(t) = 0$
$v_x(t) = \int a_x(t)\,dt = v_x(0)$
$x(t) = \int v_x(t)\,dt = v_x(0)t + x(0)$

5. Description of motions

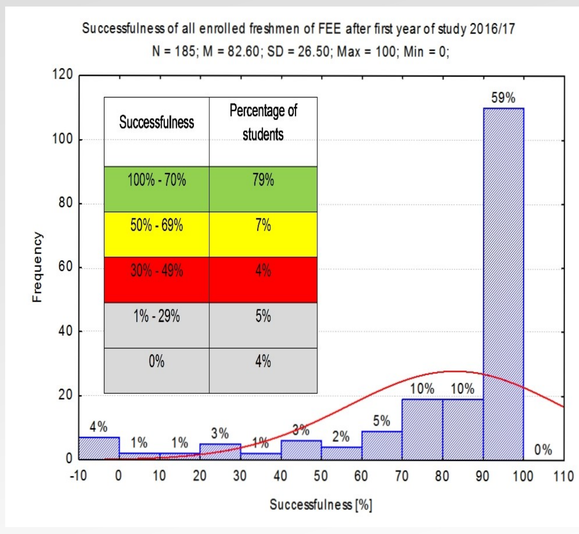
Task: Compare mathematical and physical description of motion and determine interesting physical constants and parameters.

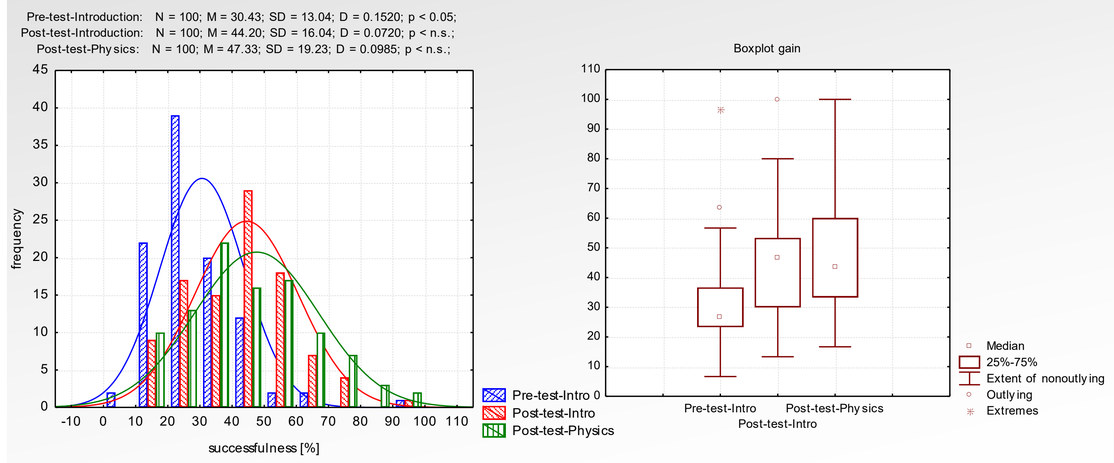
$g = 9.96\ (9.92)\ m/s^2$
$v_y(0) = 3.03\ (3.01)\ m/s$
$y(0) = 1.02\ m$

6. The results

	2013/14	2014/15	2015/16	2016/17
Faculty of Electrical Engineering	134/412 = 33 %	134/310 = 43 %	110/235 = 47 %	56/233 = **24%**
Faculty of Civil Engineering	116/246 = 47 %	62/126 = 46 %	59/109 = 54%	141/196 = 72%
Faculty of Mechanical Engineering	167/340 = 49 %	118/256 = 46 %	70/180 = 39 %	68/235 = **28%**

The drop-out rate in University of Žilina. The first number in table stands for the freshmen who drop out during their 1st year, the second number indicates the number of enrolled students.





The evaluation confirmed the statistically significant difference between mean at the beginning and the end of the 1st semester ($P < 0.001$, $t_{stat} = 9.68 > t_{critical} = 1.98$) and between mean at the beginning and the end of the 2nd semester ($P < 0.01$, $t_{stat} = 2.78 > t_{critical} = 1.98$).

Conclusion

Using the Summer Course of Physics, the Interactive Physics lectures using the video analysis and simulations (VAS) method of problem tasks and their integration into STEM (Science, Technology, Engineering and Mathematics) study programme and the implementation of intervention tools into our educational system (tutor, big brother/sister) the drop-out rate was reduced to 24% at FEE after three years from starting implementing the readySTEMgo project.

In future, we plan to continue organising the summer course of mathematics and physics, using interactive lectures and focusing on not only the cognitive skills but also the noncognitive skills of our students.

20th Conference of Czech and Slovak Physicists
7-10 September 2020, Praha

References:

[1] A. HACHNÉ, 2008. *A Cool Sport Full of Physics*, In: The Physics Teacher, Volume 46, Issue 7, 2008, 398 - 402.
[2] program Tracker: http://www.cabrillo.edu/~dbrown/tracker
[3] http://phet.colorado.edu/en/simulation/projectile-motion
[4] P. HOCKICKO, 2010. *Nontraditional Approach to Studying Science and Technology*, In: Communications, Volume 12, No. 3, 2010, 66-71.
[5] P. HOCKICKO, Ľ. KRIŠŤÁK, Ľ., NĚMEC, "Development of students' conceptual thinking by means of video analysis and interactive simulations at technical universities". *European Journal of Engineering Education* vol. 40, iss 2, pp. 145 – 166, 2014, ISSN 0304-3797.
[6] G. LANGIE, M. PINXTEN, P. HOCKICKO, P. PACHER, "Key skills of incoming stem-students", *Proceedings of the 9th International Conference PTEE 2017 Physics Teaching in Engineering Education "Challenges and Solutions for Effective Teaching"*, University of Žilina, Slovakia, pp. 14 – 22, May 18 -19, 2017.
[7] P. HOCKICKO, G. TARJÁNYIOVÁ, D. SRŠNÍKOVÁ, "The Influence of Interactive Lectures on Students' Conceptual Understanding In STEM Education", *Proceedings of 9th International Conference on Education and New Learning Technologies EDULEARN17*, 3rd-5th July 2017, Barcelona, Spain, pp. 1866 – 1873. ISBN: 978-84-697-3777-4

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