On the use of Video Based analysis and coding for solving problems in mechanics

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Abstract- *Creating constructivist inquiry based active classrooms the teacher has to resort to new methods of teaching. To make mechanics concepts more meaningful and visible we propose the use of an open source software Tracker, which can be easily downloaded. Teaching of fundamental concepts of mechanics can be easily done by visualizing and analyzing the motion of the objects in the Tracker software environment. In this article we deal with some mechanics problems (free fall, determination of acceleration of mass in string using Atwood machine, coefficient of restitution and simple harmonic motion) and how they can be visualized and solved using the tracker software. This software can be very useful right from high school students to college students for analyzing different types of motions. This method is also known as video based analysis (VBA) method. This method can widely be used across different problems of mechanics and can be helpful in effective teaching learning process. Coding is a necessary skill that all students need regardless of their field. It helps them visualize the problem and hence understand it more deeply in some cases. In this paper we also present the results of using coding and video analysis for selected mechanics problems on a group of students. These approaches help the students in visualizing the mechanics problems and also developing the mathematical modeling skills.*

1. Introduction

Several experiments are conducted by students in mechanics in the laboratory but the traditional method of performing these experiments puts a restriction on the critical analysis of the results. In the era of implementation of NEP 2020, which talks about gaining the skills of computational thinking and coding, it is essential to plan activities involving both computational thinking and coding.

Introduction of computational thinking can be very much useful across different grades and some research studies have already proven this (Lekan and Abiodun, 2020; Okal et al. 2020). Coding and computational thinking activities are helpful in building the 21st century thinking skills like problem solving, critical thinking, collaboration, and innovative thinking. Using computers for problem solving, data analysis and interpretation can help students build computational thinking. Understanding the applications of physics in the real world is far more complex and interesting as compared to the theoretical knowledge. Fortunately, computers make it possible to perform extremely lengthy calculations in a negligible amount of time. Coding using Python language gives us a solution to simulate complex equations of physicals systems on graphs and generate navigable real-time 3D animations. Tracker a video analysis and modeling tool enables its users to extract motion information from movies. These videos can be easily made in the classroom or at home. Using tracker helps in developing the data and graphical interpretation ability of the students. Tracker features are available in the online manual and can be easily downloaded. Use of coding and tracker software was tested on a group of 50 students of Demonstration Multipurpose School, Bhopal belonging of the higher secondary level. A pre test and post test was conducted to see whether the intervention made any significant difference between the experimental group and control group.

For solving problems in mechanics we propose the use of coding which helps to visualize the ideal theoretical curves and the Tracker video analysis which involves the use of high speed cameras to perform various mechanics experiments. Tracker video analysis is an innovative approach in this direction to make mechanics problems more interesting. A camera is used to record the motion of the object and the video so obtained is loaded and opened in the tracker environment. Manual and automated object tracking with position, velocity and acceleration overlays is possible with this software. Inbuilt model builder creates kinematic and dynamic models of point mass particles and two-body systems. Model overlays are automatically synchronized and scaled to the video for direct visual comparison with the real world. In this article we present, four experiments are performed to validate the proposed method. The first experiment is to verify the value of acceleration due to gravity (g) of freely falling body on earth. Free Fall is the most common motion that we encounter in our daily lives. Second experiment is to determine the acceleration of the mass in the string of Atwood machine. Atwood's machine is a common classroom demonstration used to illustrate principles of classical mechanics. After determining the acceleration we also find the coefficient of static friction. Third experiment is dedicated to determine the coefficient of restitution of tennis ball**.** The determination of the coefficient of restitution is of major interest in the design of balls and surfaces. The fourth experiment presented in this paper is determining the period of a simple pendulum swinging through small angles is a common lesson at the undergraduate level. The set up for performing these experiments is simple and constructed from low cost materials.

2. Objectives

The specific objectives of the study are :

1) To validate the effectiveness of video based analysis software Tracker for understanding various concepts in mechanics.
2) To validate the effectiveness of coding for understanding various concepts in mechanics.

3. Methods and Procedure

The research was conducted at Demonstration Multipurpose School (DMS), Bhopal. The respondents of the study were the two sections of the Class 12th students wherein the research was carried out. In total of 50 students were selected for the study, out of which the control group comprised of 24 students and experimental group comprised of 26 students. The students of experimental group were exposed to the tracker software and coding in Python language. Students performed the following experiments:

Determining the value of acceleration due to gravity (g) of freely falling body on earth using Tracker and coding

Determination of acceleration due to gravity g using tracker and coding

A body is said to be in free fall when no other forces except gravity is acting on it. How we can we determine the acceleration due to gravity of a body under free fall? There are experiments in which acceleration is determined by calculating the distance, an object has travelled from a starting point and the time elapsed since the motion began. Using tracker one needs to only record the motion of free fall and open it in the tracker environment. We use a ball as the object under free fall. The experimental set up is shown in Figure 2. A digital camera is used for recording the motion of the ball and calibration scale of 1m is used. First of all the video is captured at 25fps then the digital video file is opened in the tracker environment. In a typical video analysis, the motion of the ball is captured and saved. Then we open the digital video file through the tracker software, calibrate the scale, and define appropriate coordinate axes.

In mathematical physics, equations of motion are equations that describe the behaviour of a physical system in terms of its motion as a function.

From the first equation of motion we have

$$v = u + gt \qquad (\text{here, } u = 0) \qquad (1)$$

The graph between velocity and time obtained from tracker is shown in Figure 3. Clearly, graph satisfies the first equation of motion $v = u + gt$. From the graph the value of constant A (which is our g) comes out to be 994.7. So we obtain acceleration due to gravity of freely falling body (ball) on earth as 994.7 cm/sec^2.

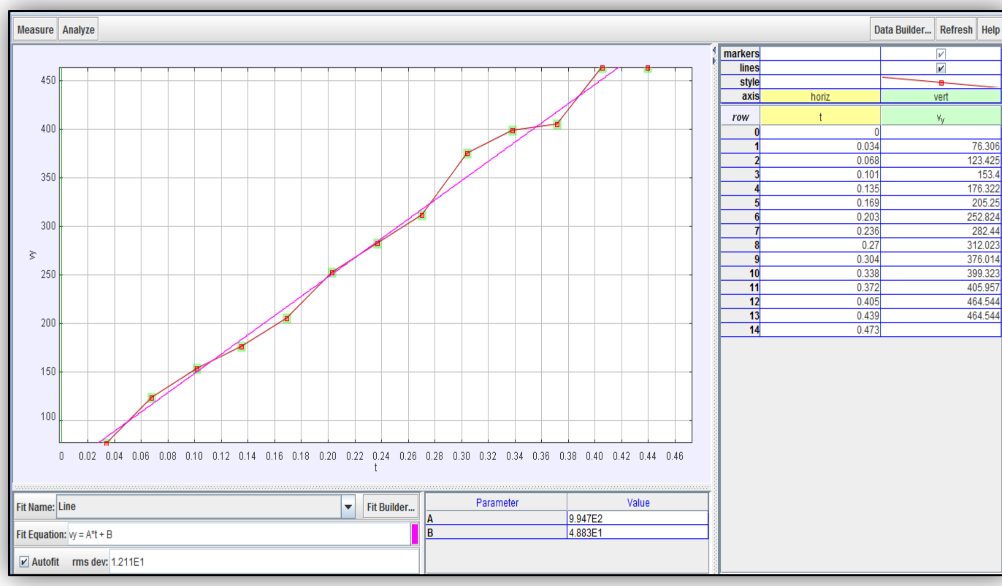

Figure 1: Visual display of the analyse menu in Tracker which shows graph and table data of mass A where the velocity v_y versus t is displayed. Fit line equation of v_y=A*t+B with parameter A=9.947E2 is used as determined by Tracker

The same experiment can be simulated using coding in python language. The results are shown in Figures in 2 and 3. The graphs show how the velocity and acceleration of a freely falling body would vary ideally.

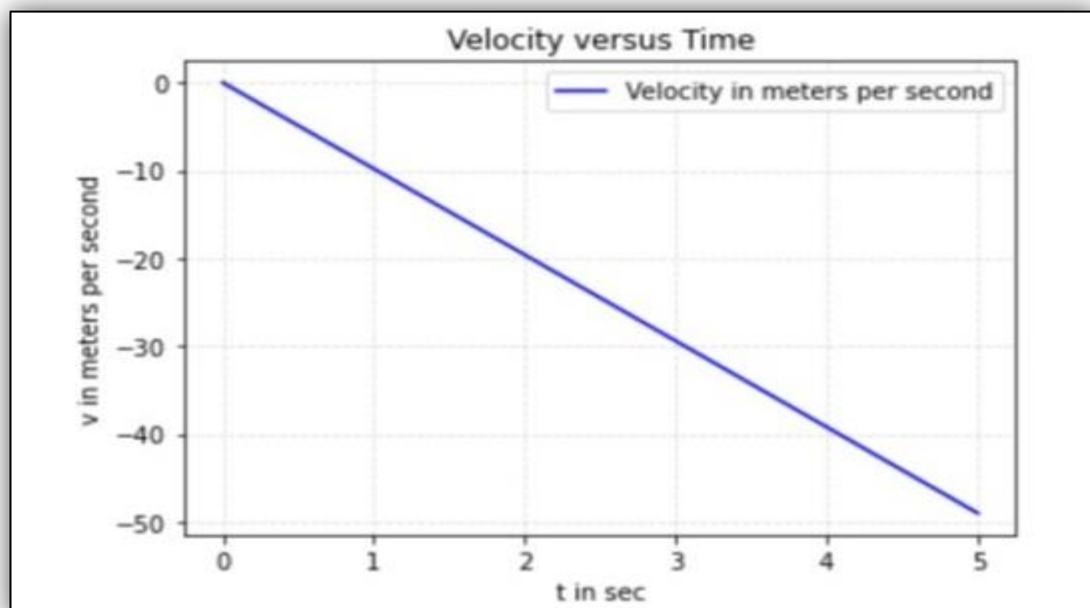

Figure 2: Velocity versus time graph obtained from coding simulation

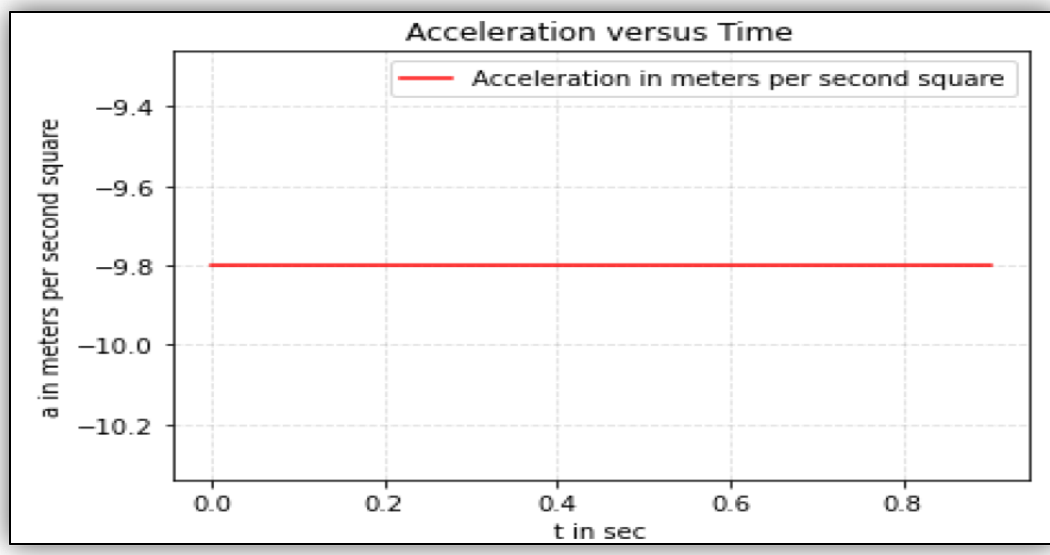

Figure 3: Acceleration versus time graph obtained from coding simulation

Determining the acceleration of the mass in the string of Atwood machine using Tracker

Atwood's machine is a device where two masses, m_1 and m_2, are connected by a string passing over a pulley. There are at least three pedagogical reasons that time is devoted in graduate physics classes to analyzing Atwood's machine. First, as an example of constructing free-body diagrams and deducing the relevant equations from them, it is an instructive application of both the translational (F = ma) and rotational ($\tau = I\alpha$) forms of Newton's second law. Second, it furnishes mathematical practice in the simultaneous solution of linear equations. Finally, Atwood's machine is often used in the laboratory as an experimental means of calculating g to a measurable value. Many possible experiments can be implemented using this machine. In our experiment we use the tracker software to calculate the acceleration of the masses and then calculate g.

The acceleration of the masses can be determined. **Atwood's machine is commonly used in the laboratories and classroom to demonstrate the basic principles of uniformly accelerated motion.**

The acceleration of two bodies can be calculated using the following formula:

$$a=\frac{(m_2-m_1)}{(m_1+m_2)}g \qquad (2)$$

The acceleration due to gravity can be calculated from the equation

$$g=\frac{a(m_2+m_1)}{(m_2-m_1)} \qquad (3)$$

where m_1 and m_2 are the two masses hanging on the ends of a string passing over a pulley.

To determine the acceleration using the tracker software we need thread, stand, pulley, two masses, scale, weighing machine. We choose mass m_1= 200.846gm and mass m_2= 180.228 gm. As the string attached to the two masses slides over the pulley we record the motion of the two masses using digital camera. The video is then opened in tracker environment and we obtain two graphs shown in figures 4 and 5. The obtained graphs are parabola and on the basis of the fit equation from the first graph we obtain:

$$A = 27.83$$

Therefore from figure 5 we obtain, $a_1 = 2A = 55.6$ cm/sec^2
And from figure 6 we obtain $a_2 = 2A = 47.0$ cm/sec^2
Averaging the two values we get acceleration of the masses as ~51cm/sec^2

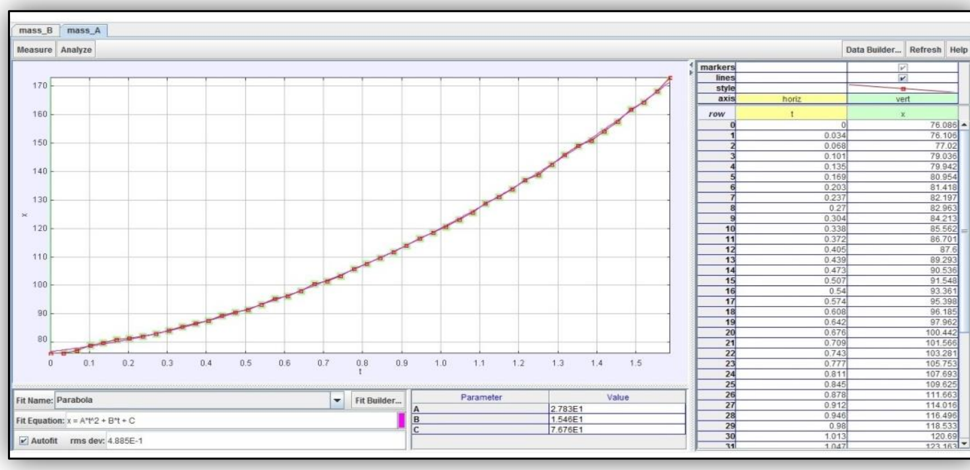

Figure 4: Visual display of the analyse menu in Tracker which shows graph and table data of mass A where the x position versus t is displayed. Fit equation of x= At^2+Bt+C with parameter A=2.783E1 is used as determined by Tracker

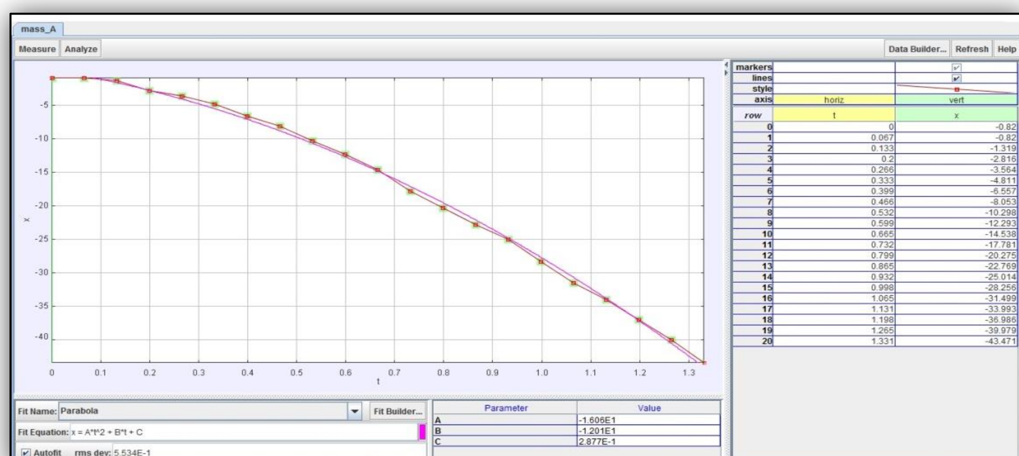

Figure 5: Visual display of the analyse menu in Tracker which shows graph and table data of mass B where the x position versus t is displayed. Fit equation of x= At^2+Bt+C with parameter A=2.355E1 is used as determined by Tracker.

Determining the period of a simple pendulum swinging through small angles

In this experiment we study the simplest form of periodic motion which is the simple harmonic motion using tracker. Pendulums are in common usage. Some have crucial uses, such as in clocks; some are for fun, such as a child's swing; and some are just there, such as the sinker on a fishing line. For small displacements, a pendulum is a simple harmonic oscillator. For this consider a small mass also called bob that hangs from the end of a thread, wire or string. We also assume that the wire has a small mass compared to that of bob. Fixing the wire at the upper end makes it a simple pendulum. Pulling up the bob to an initial angular displacement say Ө keeping it small. As the bob swings back and forth, Ө changes continuously. We can easily see that this motion is periodic. Determining the time period is a common experiment conducted at the school level and undergraduate level using the same experimental set up described above. The number of oscillations are counted for a given period of time. The total time taken by bob for n oscillations is determined. And for this the time for one oscillation that is the time period is determined. In this way counting the number of oscillations helps to determine g.

Time period of a simple pendulum for oscillations of small amplitude is given by the relation

$$T = 2\pi\sqrt{L/g} \qquad (5)$$

Using tracker software we can determine the time period of a simple pendulum easily. For this we make a simple set up by attaching a spherical bob of mass to a light string of length 0.46m from a rigid support at the wall. The pendulum is released at an initial angle of 10°. Using a high speed camera the bob oscillation is recorded at a frame rate of 25 fps. The video from the experiment is then examined in the tracker to study the motion of the simple pendulum. Auto tracking function available in tracker is used to track the displacement of the bob.

The motion of the pendulum shown in Figure 7 is sinusoidal and using the fit equation shown in the figure we obtain:

$$x = A\sin(Bt+C) \qquad (6)$$

here the constant A represents the amplitude, constant B represents the angular frequency ω and C represents phase of the wave.

So we get

ω= 4.61

Using the value of ω the time period of the pendulum is obtained as T= 1.36s.

Using equation (5) we can also calculate g which comes out to be 9.77m/s^2.

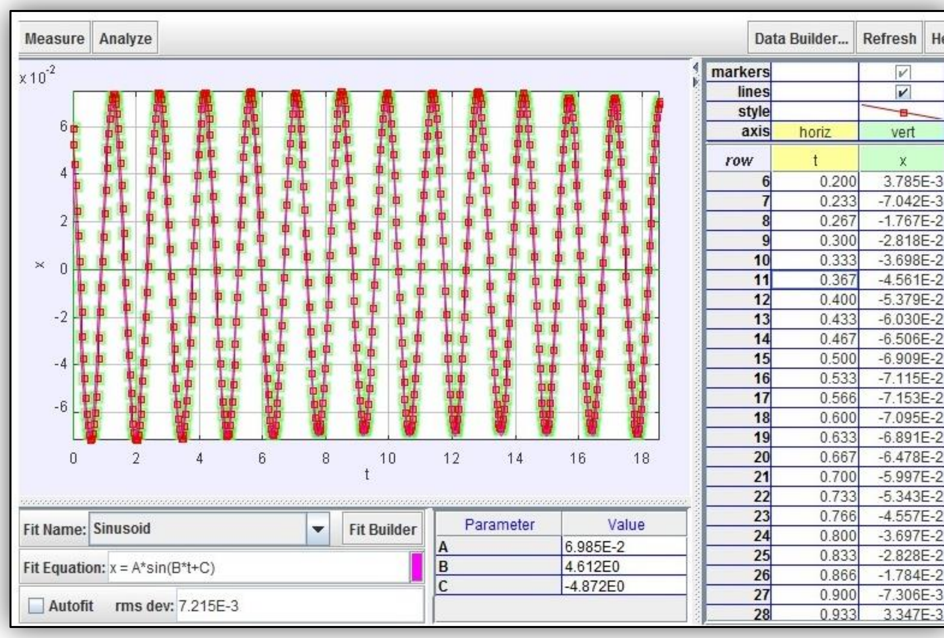

Figure 7: Analysis of the oscillation of the simple pendulum using curve fitting in tracker

A similar graph is obtained from coding simulations as shown in Figure 8

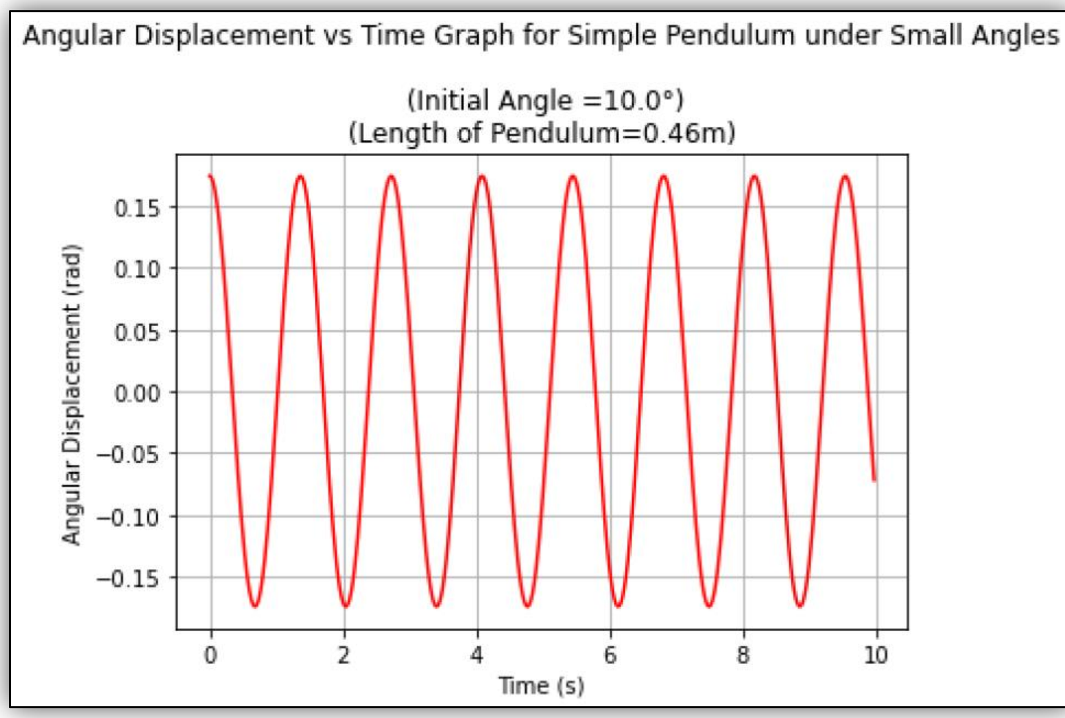

Figure 8: Analysis of the oscillation of the simple pendulum using coding with python

Results and Discussion

Before the experimental study, the pre-achievement test was administered to the two groups to find out their achievement in selected experiments of mechanics as given in section 3. The pretest comprised of multiple choice questions related to concepts of mechanics.

During the period of study, the experimental group was exposed to the video analysis and coding as discussed in section 3.

The t- test was used to determine if there was difference between the experimental and control groups in their:

a) Pre-achievement scores in mechanics
b) Post-achievement scores in mechanics

The pre-achievement test was conducted to find out if both groups of respondents possess the same cognitive level before the conduct of the study. The t ratio of 1.607 has an associated probability of .122. The obtained t value is less than table t value at 0.05 level of significance. Hence, there is no significant difference between the pre-test mean scores of the two groups of respondents. This only means that the two groups had the same cognitive level before the study was conducted.

After the study, the effectiveness of video based analysis and coding in learning selected topics of mechanicswas determined. The scores of the two groups were used for the study.

Technique	Test	Group	Mean	SD	df	t	p
Traditional experiments	Pre test	Control	26.67	3.284	50	1.607	.122
	Pretest	Experimental	24.31	3.987			
Video Analysis	Post test	Control	17.23	6.070	50	5.636	.000
	Post test	Experimental	25.44	3.787			
Coding	Post test	Control	19.95	5.744	50	4.134	0.000
	Post test	Experimental	25.50	3.419			

Table 1: Independent sample t test results of control and experimental group

As shown in the table, the students exposed to video analysis and coding had a post-test mean score of 25.44 and a standard deviation of 3.787 while the group exposed to traditional experiments had a mean score of 17.23 and a standard deviation of 6.070. The t ratio of 5.636 has an associated probability of .000. The t value obtained is greater than the table t value at 0.01 level of significance. Hence, there is a significant difference between achievement scores of the two groups after the study. Similar results were obtained for coding.

After the treatment, the two groups of study varied statistically in terms of their learning achievement. Hence we can say that both the methods were effective in learning selected topics of mechanics as compared to the traditional approach.

Conclusion and Implications of the study

It is clear that our demonstration displays the feasibility for practical uses of the apparatus and Tracker in undergraduate laboratories. The complete setup can be simply built from inexpensive materials and Tracker is freeware.

It can be concluded that daily life problems in physics can be easily solved by performing simple experiments. Data can be easily collected using a digital camera and the information in the recorded movie can be easily analyzed using the Tracker software. The experiments shown in this paper using the freeware software Tracker can be easily built up using inexpensive materials. They demonstrate the feasibility of the practical uses of the setup and Tracker can be easily used in the undergraduate laboratories. The study can be extended to other areas like projectile motion, stokes law, rotational motion of bodies, coupled oscillations etc. Coding simulations presented in the paper helped to visualize the ideal situations.

References:

AdliHaron and K A Ismail, IOP Conf. Ser.: Materials Science and Engineering 36, 2012

ThammarongEadkhong, R Rajsadorn, P Jannual, S Danworaphong, Rotational dynamics with Tracker, European Journal of Physics 3355(33):pp. 615—622, 2012

GözdeOkali, BekirYildrim, SerkanTimur, The Effect of Coding Education on 5th, 6th and 7th Grade Students' programming Self- Efficacy and Attitudes About Technology, Educational Policy Analysis and Strategic Research, V 15, N 2, 2020.

Lekan, Akinode John and Abiodun,Oloruntoba Samson, Children Perceptions of the Effectiveness of Online Coding as a Supplement to in-person Boot Camps, International Journal of Scientific Advances, Volume: 1, Issue: 3, Nov -Dec 2020