Alternative approaches in digital era to handle undergraduate physics (mechanics) laboratory: a case study of moment of inertia of a flywheel experiment

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Abstract. With the invasion of Digital Era on all activities of life, alternative approaches are emerging to explore a single situation in many ways, offering new opportunities and insights about learning behaviour of the student. It is expected that this is going to impact traditional laboratory practices in different ways. The moot question is: can these alternative explorations be used for enhancing learning experiences of the learners, make laboratory a more engaging place and tuning learners' alternative conceptions with the conceptions of an expert. In this case study, we present three ways to perform an experiment to calculate the moment of inertia of a flywheel in a typical undergraduate Mechanics (Physics) laboratory: (i) the traditional way using a stopwatch and a meter rod as basic measuring tools, (ii) by using a video analyser of a typical setup of the experiment and (iii) a modelling software available in a web-based virtual laboratory. The physics education research strategies are applied to observe the pedagogical value of performing the same experiment in three ways together. To go ahead with this approach, implemented through pre-post-test methodology, a concept inventory has been devised to identify the alternative conceptions around the moment of inertia, theorems of the moment of inertia and flywheel as a mechanical device to control rotational motion in a daily life. An effort has been made to address the alternative conceptions during the performance of the same experiment in three distinct ways. Finally, a perception survey was also carried out to know about this multi-representational approach's (a) pedagogical effectiveness, (b) effect on laboratory climate, (c) expectations of students, (d) laboratory engagement and (e) instructor-student relationship.

1. Introduction

Over the past couple of decades, physics education researchers have studied the effectiveness of existing teaching and learning practices: conceptual understanding, transfer of information and ideas, beliefs about physics and problem solving in physics. Effective experimentation ways have always been remained as an important part of an undergraduate (UG) physics course. Research has shown that lab courses have a strong impact on students' learning outcomes [1-2] and it is laboratory experiences that "make science come alive" [3]. However, it has been noticed that important place, which laboratory should have in undergraduate classes, is being relegated to derivation based learning of physics. One of the reasons can be attributed to non-availability of resources to faculties, for laboratory enhancement and maintenance. However, it is important that way out from such a situation should be there, so that students master necessary experimental skills to compete once they go out and face real life. Moreover, studies have also shown that in order to increase students' success, new strategies and education programs must be developed and it is stressed that interactive multi-media and simulations prepared in accordance with learning objectives can play a crucial role in conceptual learning [4-6].

Nowadays, information and communication technologies have invaded science education in all directions and have changed the laboratory landscape by the introduction of simulated labs (also called virtual labs), and remote labs [7-8]. By definition, virtual laboratory (VL) is a computer simulation, which supports important functions of laboratory experiments to be carried out, on a computer. Primarily in a virtual lab, a computer model replaces and imitates a real experiment. With the help of virtual environments and computer simulations, there is a possibility to teach the difficult or even out of bound things to students. Simulations make students learn through trial and error and encourages them for the search of solution methods or the problems. With the use of virtual instrument, one can show students instantly how changing one particular value of a parameter in mathematical equation would change the result. Thus allowing them to gain a greater understanding of how the theory relates to the experiment and the effect of changing input information. Once they have gained the knowledge base they are better equipped to predict, discuss and perform real experiment [9-11].

In 2009, Government of India launched a National Mission project to build Virtual Labs (VL), targeting more than thousand experiments mapped to the under graduate and postgraduate curriculum. In this case study we present three ways to perform an experiment, to calculate the moment of inertia of a flywheel in a typical undergraduate Mechanics (Physics) laboratory: (i) the traditional way using a stopwatch and a meter rod as basic measuring tools, (ii) a modelling software available in a web-based virtual laboratory and (iii) by using a video analyser of a typical real setup of the experiment.

2. Research Questions

Following research questions were posed in the study:

1. How do performance of students compare in learning concepts using virtual laboratory, hands on laboratory and tracker software?
2. Does use of alternative approaches increase the learning gain?
3. Are virtual labs as effective in learning as hands on laboratory?

3. Sample and Methodology

The sample group consisted of 34 students studying in first year of B.Sc. physics at a women college Shimla, India. The steps used in the process were (Figure 1)

Step 1: The sample group was given instructions with traditional lab applications. The theory and the procedure of the experiment using traditional methodology in real lab was explained to them. They performed the experiment, collected data and wrote a lab report. The lab report was graded using rubric.

Step 2: A summative assessment tool, consisting of ten multiple-choice questions, based on the concept of moment of inertia was designed. (Appendix A) and administered to students in the form of pre-test.

Step 3: Same set of students were given instructions with virtual lab application and they performed the experiment in the virtual lab by using input parameters the same as that of real experiment, collected data and analysed it. They calculated moment of inertia of the flywheel and wrote the lab report, which was again graded using rubric.

Step 4: Students took a video clip of the experiment and tracked it in the Tracker software, which converted a video-graphed observation to data to further calculate the moment of inertia. Which was again graded using the developed rubrics. Finally, students took the summative assessment test as post-test.

Step 5: The perception of the students about the use of these alternative approaches was found out using a perception survey consisting of six statements compared to real lab experiment.

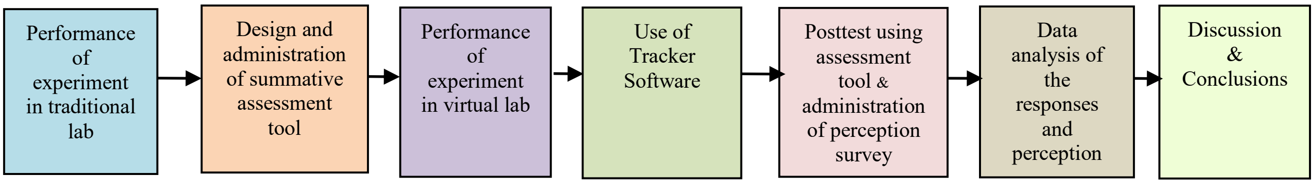


Figure 1: Sequential research design for flywheel experiment

4. About the experiment of moment of inertia of flywheel

4.1. Learning objectives of moment of inertia concept

First, the learning objectives of the moment of inertia concept were defined. After performing the experiment learner should be able to

- distinguish between inertia of translational motion and inertia of rotational motion.
- understand that moment of inertia of a body depends on both mass and distribution of the mass about axis of rotation.
- identify flywheel as a disc, and derive its moment of inertia about an axis perpendicular to its plane and passing through the centre.
- identify flywheel as a device to store energy, which it can supply when the driving energy is not available.
- state and apply theorems of parallel and perpendicular axis of moment of inertia.
- explain that if position of the axis of rotation changes moment of inertia changes.
- apply theorems of perpendicular and parallel axis to calculate this change.
- apply law of conservation of energy to calculate expression for finding the moment of inertia of the flywheel mounted on the wall and initiated rotation by a falling body hung on the axle by a coiled thread.
- understand that moment of inertia of the flywheel will be different on different planets calculated by the method used.
- identify machines and devices in day today life where fly wheel is used (such as in sewing machine, car, aeroplanes, floor grinders, washing machine etc.) and see its benefits.

4.2. Traditional laboratory method

This experiment is performed to teach students the concept of moment of inertia and the law of conservation of energy. In the flywheel experiment when the mass is allowed to fall, the potential energy partly gets converted into kinetic energy and partly into rotational energy of flywheel.The flywheel is set with the axle of the flywheel horizontal. The vernier calliper is used to measure the radius r of the axle at different points and then mean is taken. A mass m is attached to the axle of flywheel by a string, which is wrapped n times round the axle to have potential energy to rotate a flywheel. The height h of the mass from the ground is measured. The mass is released and as soon as the mass hit the ground, stop watch is started. Number of revolution made by the wheel (n_1) before coming to rest is counted and time is noted Figure 2 (a). The experiment is repeated for at least 3 times and the mean time of the falling is obtained. By using theoretical relation (1), equating the potential energy to the kinetic energy of the flywheel and the friction losses in the bearings the students calculate the moment of inertia. Two variables they need to find are the maximum speed of the flywheel and the number of rotations that the flywheel makes.

$$I = \frac{2mgh - m\omega^2 r^2}{\omega^2\left(1+\frac{n}{n_1}\right)} \qquad (1)$$

Where g = acceleration due to gravity

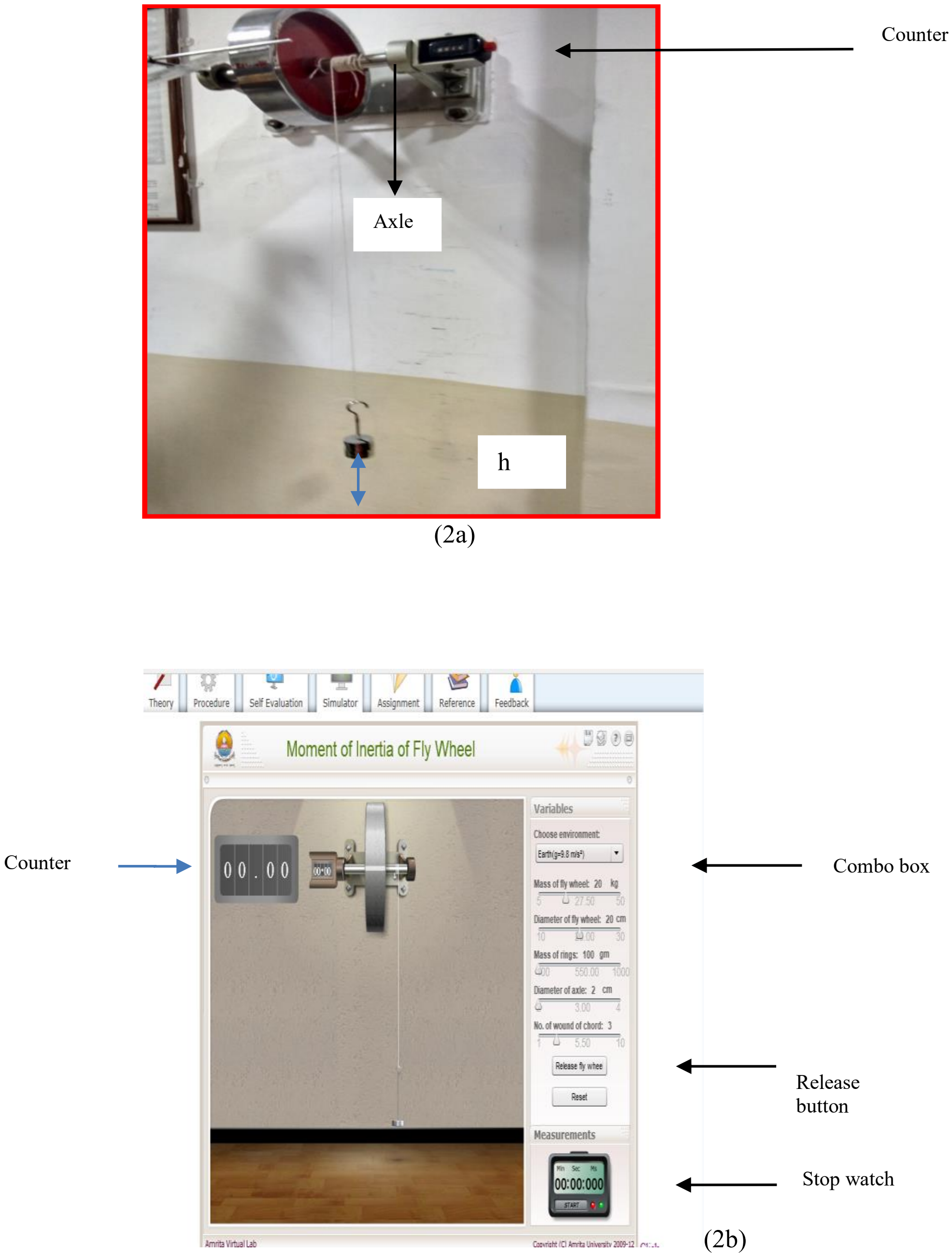
r = radius of flywheel axle

m = mass suspended through string / thread.

n = number of turns of string wrapped on axle

n_1 = Number of oscillation up to flywheel stopped after detaching the mass.

t = time of oscillation



(2a) (2b)

Figure 2: (a) Flywheel used in Traditional way and (b) Flywheel used in virtual lab

4.3. *Virtual laboratory method*

The Virtual Instrument (VI) Figure 2 (b) for the above experiment was used from Virtual and Accessible Laboratories Universalizing Education (VALUE @ Amrita) Virtual Labs Project [12]. Students on an individual basis performed virtual lab assignment. Students were supposed to read the background information and procedures contained in that exercise and complete the data tables. The steps used were:

i. *Introduction*

In this section, the students were given an overview of the experiment to be undertaken, an animation showing how it worked, what was being measured and how it related to real life situations. Students were supposed to take following steps

i. Choose any desired environment by clicking on the 'combo box'
ii. Adjust the sliders to have suitable dimensions for flywheel arrangement.
iii. Click on 'Release fly wheel' to start the experiment.
iv. No of revolutions (N) of the flywheel, after the loop slips off from peg is indicated on the side of axle.
v. The time taken by flywheel to come to rest is noted from stop watch.
vi. Repeat the experiment for different values of variables.

ii. *Procedure and Data logging*

In this part, students performed the experiment and observed the data logged.

iii. *Theory and Calculations*

In this section, the students worked through their calculations manually and calculated the result being sought from the experiment. They then entered their own values into the computer and received immediate feedback of how these compared to the automatically calculated values from the VL.

4.4. *Video analysis of the experiment*

Following steps were used in this process:

i.Installation of Tracker

Tracker, a video analysis and modelling tool, built on the Open Source Physics (OSP) Java framework, which is an extremely useful tool to use in the study of objects in motion, from both kinematic and dynamic perspectives was installed [13]

ii. Making of a Video

A camera was used to capture the real time video of the rotations of the flywheel from the time of release of the mass until the flywheel comes to rest.

iii. Tracker Analysis

The above-recorded video was opened in Tracker software. A scale and reference frame for position data were established. The video was examined and tracked frame-by-frame with a mouse. The data generated by these tracks wasanalysed by plotting graphs, fitting curves, and observing graphical overlays and transformed views of the video. It was also shown to students that data could also be exported to spreadsheets or other programs for doing further calculations.

5. Discussion and Analysis

A. Pre-Post Comparison of Summative Assessment Tool

To check the conceptual understanding of moment of inertia of students an assessment tool consisted of ten questions was administered in the form of pre and post-test. Figure 3 shows a comparison of students responding correctly to each question.

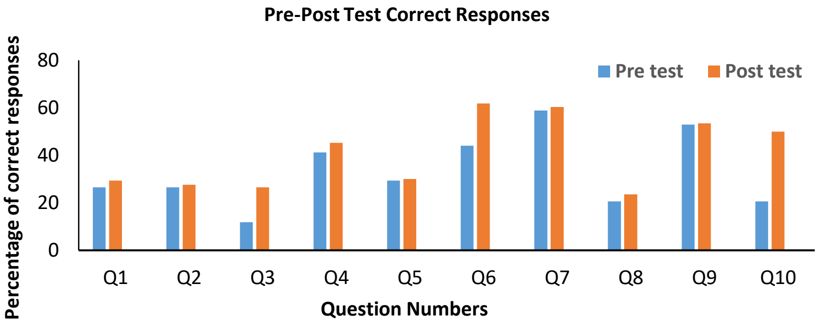


Figure3: Percentage of students responding correctly in pre and posttest

B. Normalized Gain

Normalized gain (g) was calculated using the formula

$$g = \frac{(\%posttest - \%pretest)}{(100 - \%pretest)}$$

The result obtained is given in the table 1

Table1: Normalized gain obtained in summative assessment tool

Q.No	%Pretest	%Posttest	gain (g)
1.	26.5	29.4	0.039
2.	26.5	27.6	0.015
3.	11.8	26.5	0.160
4.	41.2	45.3	0.07
5.	29.4	30	0.008
6.	44.1	61.8	0.317
7.	58.8	60.4	0.039
8.	20.6	23.5	0.037
9.	52.9	53.5	0.013
10.	20.6	50	0.37

By using the criteria established by Hake, the gain was interpreted [14]. Overall, in all the questions, there was a normalized gain shown by the students, indicating slight improvement in the conceptual understanding of moment of inertia. In Q1, Q2, Q3,Q4,Q5, Q7, Q8and Q9 the normalized gain was low (<0.3), only in Q6 and Q10 the normalized gain was found to be medium (<0.7)

C. Lab Reports Evaluation by Rubrics

The lab reports for both traditional and virtual labs were graded analysing the observational skills, manipulative skills, and reporting skills of students using rubrics to observe that whether learning objectives defined above have been met or not. It was observed that students found it easy to perform the experiment in virtual lab (simulation) as compared to in traditional lab, where using the real environment provided an unautomated task management and skill. The mean score obtained by students in real lab and virtual lab is shown in Table 2. We observed that the mean score of students enhanced when they performed the experiment in virtual lab.

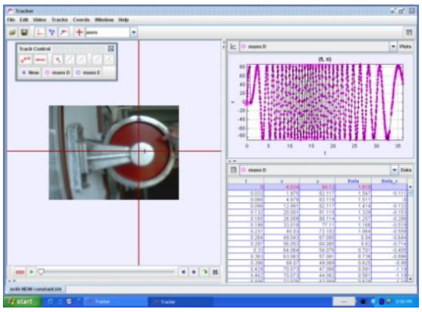
Table2: Mean score obtained in evaluation of lab report using rubric

Mode	Mean Score (18)	Standard Dev
Real Lab	12.52	1.54
Virtual Lab	14.38	1.62

D. Analysis using Tracker software

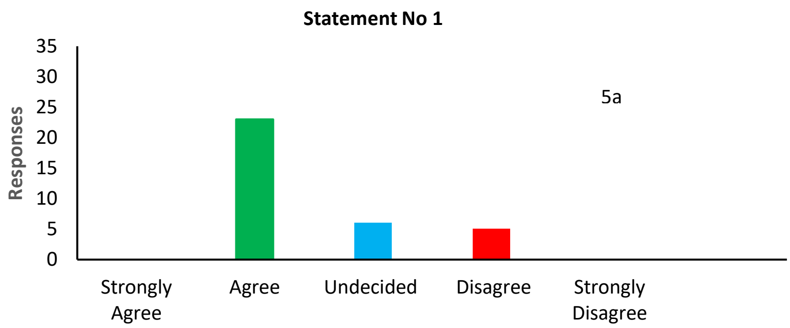
Video of flywheel experiment was captured and was tracked in the Tracker software Figure 4. In tracking the reference, point it was observed and demonstrated to students that flywheel gains angular velocity from 0 to ω_{max} in n_1 rotations and loses velocity from ω_{max} to 0 during the next n_2 rotations.The graph of x vs. t with origin of the axis placed at the centre of the flywheel is sinusoidal.

Figure 4: Screen shot of flywheel experiment using tracker software

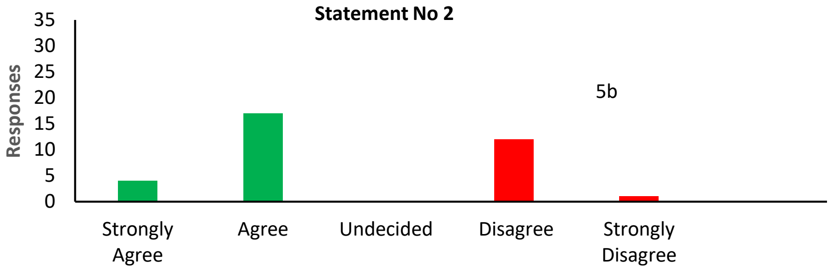


E. Perception Survey Result

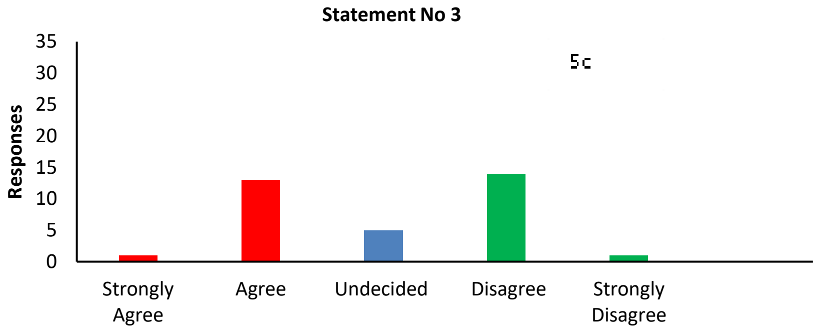
Students perceptions on using virtual lab were evaluated by using a survey, which was based upon six questions on a five point Likert's Scale, from 1 (strongly disagree) to 5 (strongly agree). They completed this survey anonymously, at the end of their laboratory course, to determine which form of laboratory they preferred and felt to be the most enjoyable and effective. Results are illustrated by bar graphs in Figure 5 (a-f). In each of these figures, perceptions were converted into percentage by dividing student response numbers for each statement by total number of responses. The green colour indicates that this choice was the choice of experts as well.



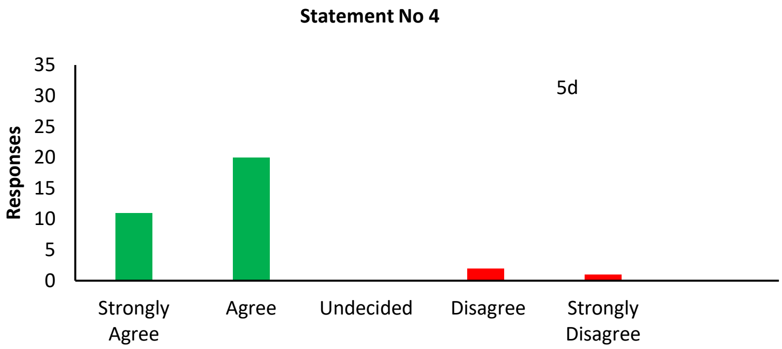
Statement No. 1: I think I learned more clearly the concept of moment of inertia by participating in virtual lab and using Tracker software compared to traditional lab



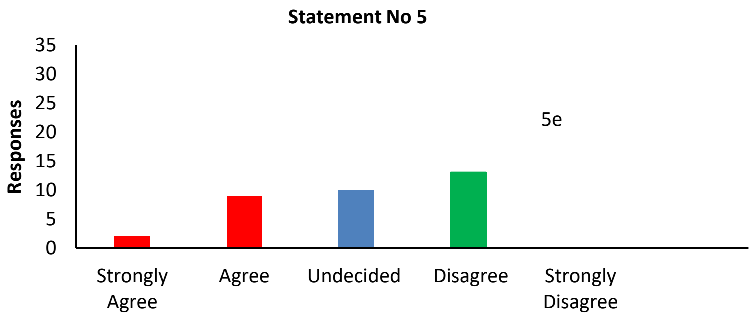
Statement No. 2: I think I learned more about how to perform physics laboratory procedure of flywheel experiment in virtual lab compared to traditional lab



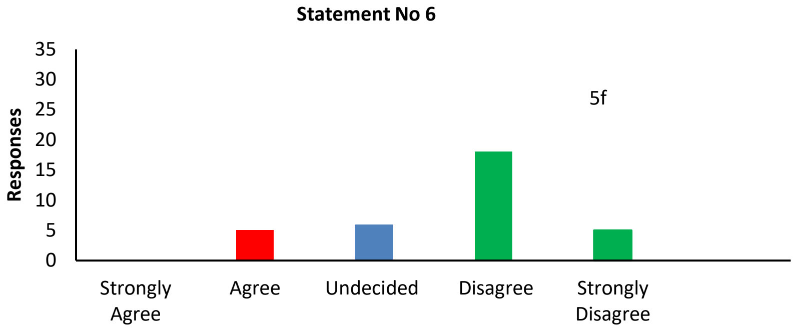
Statement No. 3: I think I learned more about how to use physics laboratory equipment of flywheel experiment by participating in virtual lab compared to traditional lab.



Statement No. 4: I think virtual labs are more user-friendly and less time consuming than traditional lab.



Statement No. 5: I would prefer to participate in virtual labs compared to traditional labs.



Statement No. 6: I think virtual labs can replace real experimental (traditional) labs

Figure 5(a-f): Response of students on perception survey

Students responded that the use of virtual lab has benefited them as they have learned more physics concepts and clarity of procedure of the experiment by participating in the virtual labs, as compared to traditional labs. They also reported that they had enjoyed the virtual laboratories, as they were user friendly and an easy way. However, they also revealed that to learn how to use lab equipment they would prefer traditional lab. Overall students' feedback was encouraging that the use of virtual laboratories and Tracker software has increasedstudents' motivation, facilitated self-learning attitudes, enhanced theoretical understanding, and acted as pre-real laboratory demonstrator.

6. Conclusions

Alternative instructional approaches in physics laboratory that involves technology were used in the present study with an aim to provide an effective learning environment for the students. One of the tool used was virtual lab (an e-learning tool). Undoubtedly, this powerful tool can be used for learning physics concepts and developing skills. The effectiveness of the virtual laboratory and traditional hands on laboratory implementation was observed through students studying physics. It was observed that students need to have some minimum skill to handle real equipment with emphasis on precautions to be taken while handling the actual equipment. There were some differences in the experiences of the performers, but it was not found that one format was superior or inferior to other.

In fact, all types of laboratories offer certain advantages. However, we think that coupling of different modes can provide an enriched learning environment.A virtual instrument of the experiment can be used either prior or during hands on experiment in the same way as pilots' aretrained to fly aero planes on a simulator before the actual flight runs. This can enable students to understand what they have to do and why they are doing it. This approach can help the student perform a more comprehensive analysis of the theory and then to gain a better understanding of the relevance of the topic, to be learned. Thus, allowing them opportunities to learn in many different ways by filling in the gaps left missing from lectures and textbooks [15]. They can be benefitted by availing a learning tool, which allows them the freedom to learn at their own pace along with the video and animation clips that can make them visualize complex concepts. One important issue that crops up in this study usingthe virtual lab is that computer simulations alone do not seem to be sufficient to properly train the students to use specific laboratory equipment. Instead, traditional labs are found to be more effective pedagogical techniques in terms of teaching them how to use physics lab equipment. This study provides a model that can be used for further investigations.

The video analysis of a motion using interactive Tracker software was also found to be an excellent teaching strategy, which made physics more interesting for the learners. It gave students a simple and easy way to understand the process of movement and fundamental concepts such as position, trajectory etc. Learners could easily understand principle and phenomenon involved more deeply.Thus, we can conclude that by coupling the demonstration of an experiment with a video data analysis and modelling tool such as Tracker, we can provide learners an opportunity to observe a connection between the video (real life) and the graphs, which normally they do not see together. Present days almost everyone possesses a cell phone, which has a camera in it. A video of any type of motion can be recorded and analysed by using this software. One can use this gadget to link concepts of physics with real life such as projectile motion, one dimensional, two-dimensional motion etc.

Virtual labs reduce equipment needs, and thus cost, by providing ‘‘virtual access’’ to equipment and accompanying materials and can act a boon especially for remote area and economically weak institutes. It can provide a new perspective to students that they never would have thought of. For example in flywheel, experiment students can do the experiment not only in earth but also in using virtual lab, they can do the experiment in various planets.

Virtual lab experiments blended with hands-on experimentations can contribute to the students' more motivation for learning and strengthen their understanding of the basic physical concepts taught in the classrooms, and allows them to relate theoretical concepts to real world examples. However, it should not be used as a substitute for hands-on lab experiments and teachers in the classrooms. As mentioned by some of the students that they need assistance when having difficulties in performing the real experiment. Authors propose to carry this work further to extend this pilot study to perform a set of mechanics experiments through both virtual lab and traditional lab, with a focus on identification of learning gaps.

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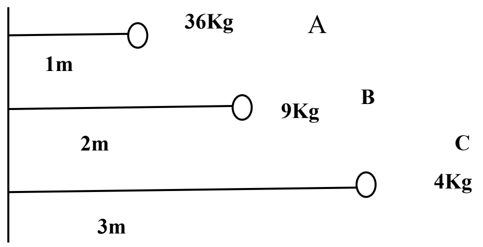
APPENDIX A

Multiple Choice Questions on Flywheel Experiment

Q1: The figure A1 shows three small spheres A, B, C that rotate about a vertical axis. The perpendicular distance between the axis and center of each sphere is given. What is the relation of their moment of inertia?

a. $M.I_A > M.I_B > M.I_C$
b. $M.I_B > M.I_A > M.I_C$
c. $M.I_C > M.I_B > M.I_A$
d. $M.I_A = M.I_B = M.I_C$

FigA1



Q2: There are two spheres of equal masses, one is solid and the other is hollow. Which statement is correct about the relationship between their moment of inertia?

a. The moment of inertia of solid sphere is more
b. The moment of inertia of hollow sphere is more
c. Both the spheres have equal moment of inertia
d. The moment of inertia cannot be defined for both the spheres

Q3: Two lenses of same mass and same radius are given. One is convex and the other is concave. Which one will have greater moment of inertia, when rotating about an axis perpendicular to plane and passing through the center?

a. Concave Lens
b. Convex Lens
c. Both the lenses will have equal moment of inertia
d. Moment of inertia of concave lens will be half of convex lens

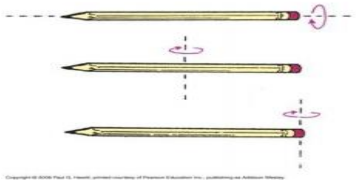


Fig A2: (Image source is "*University Physics*" 12th Edition)

Q4: Consider three axes of rotation for a pencil: along the lead (A); at right angles to the lead at the middle (B); at right angles to the lead at one end (C) Fig A2. Rate the rotational inertias about each axis from small to large.

a. $I_A < I_B < I_C$
b. $I_A < I_C < I_B$
c. $I_B < I_A < I_C$
d. $I_C < I_A < I_B$

Fig A3: (Image source is common creative)

Q5: A pool cue is a wooden rod (used to strike a ball in pool or billiards) with a uniform composition and tapered with a larger diameter at one end than at the other Fig A3. Use the theorem of parallel axis to decide whether a pool cue has a larger M.I

a. For an axis through the thicker end of the rod and perpendicular to length of the rod
b. For an axis through the thinner end of the rod and perpendicular to length of the rod
c. Will remain equal for thinner and thicker end
d. Cannot define

Q6: A flywheel is a solid disc used in internal combustion engines of cars. The main function of it is to:

a. Match the input energy to the engine at constant revolution per minute
b. Smoothen cyclic variations of speed of the engine
c. Smoothen cyclic variations of energy output from the engine
d. Maintain constant uniform speed of the engine

Q7: A flywheel is a rotating mechanical device having inertia of rotational motion known as moment of inertia and stores energy in the form of

a. Rotational potential energy b. Translational kinetic energy
c. Rotational kinetic energy d. Both rotational kinetic energy and rotational kinetic energy

Q8: A flywheel is rotating with a constant angular velocity. A point on its rim has a

a. Tangential acceleration b. Radial acceleration
c. Both tangential and radial acceleration d. Zero acceleration

Q9: A body rotates about an axis AB (Fig A4) with an angular velocity ω then all its particles have

a. The same angular velocity but different linear velocities
b. The same linear velocity but different angular velocities
c. The same angular velocity and linear velocity
d. The same angular velocity but zero linear velocities

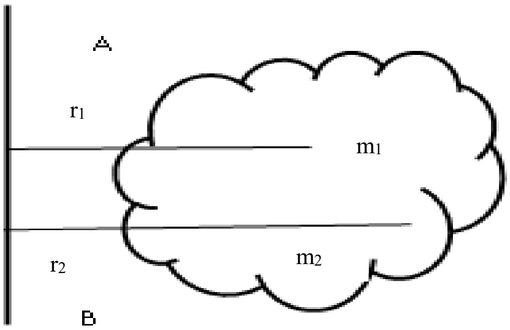


Fig. A4

Q10: A Flywheel cannot be used in

a. Aeroplanes b. Washing machine
c. Electric cars d. Floor grinders