THE SIGNIFICANCE OF VERNIER SENSORS IN ENHANCING THE EFFECTIVENESS OF PHYSICS LABORATORY EDUCATION

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Abstract. *This scholarly article meticulously examines the innovative methodologies associated with the integration of Vernier technologies aimed at significantly improving the overall effectiveness and educational value of physics laboratory sessions specifically within the context of Presidential schools. The strategic implementation of these advanced technologies during laboratory work not only facilitates considerable time-saving endeavors but also enhances the visualization of data, while concurrently simplifying the execution of intricate and complex experimental procedures that are often encountered in the physics curriculum. Furthermore, compelling evidence derived from the comprehensive study substantiates the assertion that the incorporation of Vernier technologies not only heightens students' interest and engagement in the subject matter but also effectively serves as a crucial bridge that connects theoretical knowledge acquired in the classroom with its practical application in real-world scenarios.*

Keywords: *vernier technologies, Vernier Graphical Analysis, Physics Education, Digital Transformation, Laboratory Experiments, Educational Technology.*

Introduction

In the contemporary world of rapid digital transformation within the educational sector, the strategic integration of classical instructional methods with innovative technological frameworks has become increasingly vital. Specifically, the organization of physics laboratory sessions through the utilization of advanced digital instrumentation – exemplified by Vernier sensors – plays a crucial role in reinforcing students' theoretical understanding while simultaneously nurturing their experimental and research capabilities. These digital sensors provide extensive functionalities for recording physical variables with high precision, allowing for immediate analysis and clear visualization through dynamic tables, graphs, and multidimensional diagrams. [1]

The Experimental Nature of Physics

Physics is fundamentally an experimental science, requiring the rigorous study of natural phenomena and physical laws through direct empirical research. Therefore, upgrading the educational infrastructure with interactive tools and innovative laboratory equipment is a key determinant in ensuring the excellence of the learning process. The application of Vernier sensors in physics laboratories does more than just modernize the classroom; it actively stimulates student engagement with current technological advancements and facilitates the development of essential competencies such as critical thinking, meticulous observation, and the synthesis of complex datasets.

Didactic Foundations and Learning Outcomes

This article provides an in-depth analysis of the didactic foundations and contemporary methodical strategies for incorporating Vernier sensors into the physics curriculum. It explores

how these innovative technologies not only elevate the quality of student outcomes but also foster a more positive and proactive attitude toward the subject matter. Research consistently demonstrates that sensor-integrated laboratory environments and computer-based experimentation significantly enhance the level of cognitive mastery among learners. [2]

The technology's capacity for automatic, real-time data acquisition redirects the student's cognitive load away from the tedious manual tasks of technical measurement and toward the conceptual essence of the physical processes being studied. This shift allows students to engage in higher-order thinking, significantly boosting the efficiency of the lesson and strengthening student motivation through immediate feedback loops.[3]

Practical Implementation and Software Requirements

Operating Vernier sensors effectively necessitates that students first install the specialized Vernier Graphical Analysis software on their computing devices and cultivate the technical proficiency required to navigate its features. This digital platform functions as the primary vehicle for visualizing experimental outcomes and formulating conclusions regarding physical laws. By providing a user-friendly interface for curve fitting, statistical analysis and data sharing, the software helps students bridge the gap between raw data and scientific theory. [4]

Below, we outline a practical example demonstrating the application of Vernier sensors within a standardized laboratory setting to illustrate these principles in action.

Investigation of the Law of Conservation of Momentum in Collisions

Student may have learned that a moving object possesses kinetic energy. Momentum is another property of an object, related to its mass and velocity, that is useful to describe its behavior. Momentum, p, is the product of the mass and velocity of an object, $p = m \bullet v$.

They may have learned an external force produces a change in the momentum of an object. If we consider as our system two carts that undergo a collision, then any forces they exert on one another are internal to the system. In this experiment student will examine the momentum of both carts before and after collisions to see what effect, if any, these forces have on the momentum of a system. [5]

The objective of this experiment is to study the law of conservation of momentum during collisions. The necessary equipment includes a measuring tape, carts, a scale, two data logging devices, a switch, light gate, a small hammer, a 1 kg mass, as well as various clamps and boss. (Figure 1)



Figure 1 (The necessary equipments for laboratory)

Regarding safety regulations, it is essential to follow specific precautions during the procedure. When performing the experiment on a special table, you must check that both ends of the track are secured with protective barriers to prevent the carts from falling and damaging the floor or causing personal injury. Additionally, you should be careful to protect your hands and fingers from being pinched or injured when a cart strikes a vertical barrier.

Experimental Procedure:

1. Measure a length of 1 m across the floor or a bench.

2. Measure the mass of two trolleys on the balance and record your results.

3. In the centre of the 1 m length, place the two trolleys back to back. Set up data loggers at either end of the 1 m space (0.5 m away from the back of each trolley, see Figure 2).

4. Set up the data logger to measure the velocity of each trolley as it passes through the light gate.

5. Hit the vertical release rod and record the velocity of each trolley as it passes through the light gate.

6. Repeat steps 2–5, adding different masses to one trolley.

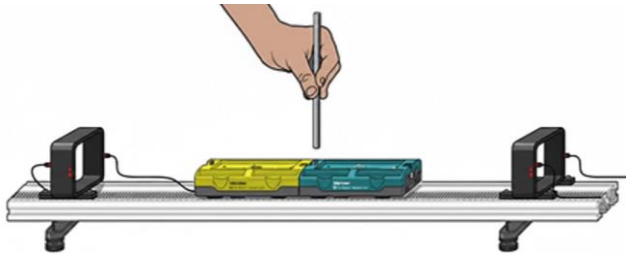


Figure 2 (Experimental set-up for investigating momentum in explosions)

How Velocity Measurement Works

Velocities are calculated by finding the time interval associated with the successive blocking of the two internal gates. This time interval is referred to as the pulse time. The ratio of the distance between the internal gates (2.0 cm) and the pulse time is reported as the magnitude of the object's velocity. An object that first blocks Gate 1 then blocks Gate 2 will report positive velocities. An object that first blocks Gate 2 then blocks Gate 1 will report negative velocities. Velocity measurements can be displayed with units of m/s (default), cm/s. [6]

The default data-collection mode for Object Velocity is Time-based. While collecting data, velocities and their associated time values are recorded. The reported time value, referred to as the velocity mid-time, is determined by averaging the times used for the pulse-time calculation. Student can make multiple velocity measurements in the same data set; however, it may be necessary to adjust the experiment duration in order to collect student desired data.

Recording results

These results were recorded in the laboratory lesson during the learning process.

Average Momentum of Trolley A: $p_A = 0.238\,kgm/s$

Mass of trolley A / kg	**Velocity of trolley A / m/s**	**Momentum of trolley A / kg m/s**	**Mass of trolley B / kg**	**Velocity of trolley B / m/s**	**Momentum of trolley B / kg m/s**
0.253	0.722	0.182	0.253	- 0.738	- 0.186
0.379	0.638	0.241	0.379	- 0.659	- 0.249
0.505	0.575	0.290	0.505	- 0.579	- 0.292

Average Momentum of Trolley A: $p_B = -0.242\,kgm/s$

The total initial momentum of the system was zero (both trolleys were at rest). The total final momentum ($p_A + p_B$) remains approximately zero for each trial. These results confirm the Law of Conservation of Momentum, which states that the total momentum of a closed system

remains constant. The slight differences between p_A and p_B are likely due to external factors such as friction on the track or air resistance.

Uncertainty Analysis: The uncertainty is calculated based on the deviation of the total final momentum from the ideal value of zero.

The total momentum p_{total} for the three trials are -0.004, -0.008, and $-0.002\ kgm/s$.

Range of deviations: $0.008 - 0.002 = 0.006$

Absolute Uncertainty: $\frac{Range}{2} = \pm 0.003\ kgm/s$

Percentage Uncertainty is calculated relative to the average magnitude of momentum measured ($\approx 0.240\ kgm/s$)

Percentage Uncertainty: $\left(\frac{0.003}{0.240}\right) \times 100\% = 1.25\%$

The calculated percentage uncertainty of 1.25% serves as strong evidence for the accuracy and reliability of this experiment. Such a low percentage indicates that the random errors associated with the light gate timing and the measurement of trolley velocities were kept to a minimum across all trials. Furthermore, this high level of precision demonstrates that the experimental setup effectively controlled for external variables, such as track friction and air resistance, during the measured interval. Because the total final momentum remains remarkably close to the initial value of zero with very little deviation, the data provides a high degree of confidence in validating the Law of Conservation of Momentum. Ultimately, this minimal uncertainty confirms that the results are not only consistent but also a true reflection of the underlying physical principles being tested.

Conclusion

Based on the laboratory activity described above, it is clear that organizing physics experiments with Vernier sensors makes the learning process more engaging and easier to understand by demonstrating physical phenomena through real-world devices. Students learn how to operate electronic equipment and navigate specialized software, which motivates them to test their knowledge through technical projects. Furthermore, by analyzing their results and identifying potential errors, students significantly develop their creativity and problem-solving skills. Thus, this set of experiments complements guided-inquiry and Modelling Instruction classrooms. [6][7]

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