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Research Article

Division II: Pure and Applied Science, Environment, and Agriculture

Using diffraction to measure hair diameter: An evidence-based evaluation of an alternative Physics laboratory activity in Biophysics

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Abstract

A ruler is a common instrument of measurement that displays in inches, centimeters, and millimeters, but not in micrometers. Since the smallest unit of measurement on a ruler limits accuracy, it might not be the best instrument for tiny things; however, it is adaptable and can be used to measure steps, depth, and diameters both inside and outside. This study aimed to measure the thickness of a hair strand without using any conventional method, but by using a steel ruler. This research investigated comprehension of laboratory experiments and the enhancement of scientific process skills among BS Biology students taking Biophysics course. 91 students participated in the survey using a 5-point Likert Scale, ranging from "No Understanding" (0) to "Complete Understanding" (4). Findings showed that 100% of students demonstrated strong comprehension of the lab's objectives and concepts, while 85.7% reported a strong grasp of the procedures. One student (1.1%) indicated minimal comprehension of the concepts prior to the lab. Additionally, 94.5% reported that laboratory experiments greatly enhanced their comprehension of concepts. Students dedicated 30 minutes to discussing the lab afterward, and 91.2% invested 1 hour in preparing their lab reports. Moreover, participants regularly performed important laboratory tasks, including preparing materials, organizing experiments, demonstrating the activity design, and adjusting to conditions during laboratory tasks. The statistically significant results for both Q3 and Q5 support the conclusion that the developed laboratory activities fostered strong student engagement and conceptual understanding, aligning with best practices in active, inquiry-based science education.

Keywords: measurement, digital laboratory, student engagement, alternative physics lab

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Introduction

A ruler is a common instrument of measurement used to have versions that display in inches, centimeters, and millimeters but not in micrometers. The smallest unit of measurement indicated on the ruler determines how accurate your measurement will be. Getting an accurate measurement can be difficult if the object is noticeably bigger or smaller than the ruler just like the case of getting the diameter of a hair strand.

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Although they can be used to measure small exterior diameters, micrometers—also known as micrometer calipers or screw gauges—are incredibly accurate measuring instruments for external measures, most notably thickness. A useful instrument for measuring the diameters of various things, including pipes, wires, screws, and the separations between small places, is a pair of calipers. They are an adaptable instrument that may be used to measure step, depth, and diameters both inside and outside.

Young's Double Slit Experiment, a diffraction and interference technique, can be used to measure these objects. It focused on the pattern of light impinging on two small, apart slits, but the same technique may be used on any small-diameter object. where the diameter is within a factor of ten of the laser light's wavelength.

Laboratory experiences play a substantial role in most science courses, specifically BS Biology, and many teachers believe the number of labs they offer is a measure of the quality of their curriculum. While some teachers believe labs are meant to confirm concepts taught during lectures, others feel labs should address students' everyday beliefs about the world. Still other teachers emphasize learning of the scientific method and laboratory techniques (Hoffer et al., 1996). Hands-on activities included in laboratory experiments and exercise further develop scientific skills as it provides students with opportunities for authentic and firsthand learning experiences. However, challenges arise due to inadequate resources for laboratory activities and experiments (Duban et al., 2019). As a result, educators search for alternatives to apparatus and equipment or focus only on experiment demonstration, considering them as substitutes, eliminating the crucial experiential learning component in Physics.

According to McFarlane (2013), to enhance students' interest in learning science subjects, there is a need for a more dynamic and activity-based practical approach that provides students with opportunities to engage with science, as science subject has long been taught and learned as a mono-methodological branch of knowledge. This attitude needs to change through the practice of embracing more student-centered approaches in science learning. Therefore, practical work is one of the most distinctive features of science that may ignite students' interest in learning this subject (Allen, 2012; Sorgo & Spernjak, 2012).

The purpose of this study is to use the developed alternative laboratory experiments in the topic, Measurement for the subject Biophysics of BS Biology students by measuring the thickness of a hair strand by not using a micrometer caliper or any conventional way of measurement but by using a steel ruler and laser beam. It also aims to highlight the fact that, when used in conjunction with another diffraction-based technique, it is possible to determine the laser light's wavelength by utilizing a regular ruler as a reflection grating. After which the learners will be assigned the engaging task of measuring a hair's diameter with a steel ruler. Laser light can be sprayed over hair to determine its diameter, we can also do this to the diameter of a thin string or electrical wire. Merely measuring the distance between the hair and the projection screen and the distance from the centre to one of the dark spots, the diameter of the hair can be calculated reveals that the scattering produces a diffraction pattern that consists of a line of light and dark patches.

To evaluate students' engagement and learning effectiveness in laboratory activities, the following hypotheses were formulated:

Hypotheses for Q3 (Understanding of Lab Procedure):

There is no significant difference between students' perceived understanding of the lab procedure and the neutral midpoint score of 2.5 on the Likert scale.

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Hypotheses for Q5 (Labs Helped in Understanding Concepts):

There is no significant difference between students' perceptions of how much laboratory experiments helped them understand scientific concepts and the neutral midpoint score of 2.5 on the Likert scale.

Methods

Research Design

To analyze the survey responses of the 91 participating BS Biology students, the following statistical procedures were employed: Means, standard deviations, and percentages were calculated for each questionnaire item to summarize students' self-reported levels of understanding, engagement, and involvement in laboratory activities; One-Sample t-Tests to determine whether students' average ratings significantly exceeded the neutral benchmark value (set at 2.5 on a 0–4 Likert scale); one-sample t-tests were conducted for key items such as: Understanding of lab procedure (Q3) and Helpfulness of labs in understanding scientific concepts (Q5). These tests assessed whether the observed mean ratings were statistically greater than the neutral point, indicating significant student engagement and learning gains. All inferential tests were evaluated at an alpha level of 0.05. P-values less than 0.05 were considered statistically significant.

Participants

The participants of the study were 91 BS Biology students taking Biophysics course served as respondents in the study.

Instrument

Data were collected using a structured questionnaire employing a 5-point Likert scale ranging from 0 ("No Understanding") to 4 ("Complete Understanding"). The predictors provided information on students' ratings of the effectiveness of labs in improving their understanding of physics concepts.

The format and content of the questionnaire were informed by themes from previous studies on science education and laboratory engagement (Harlen, 1999; Mirana, 2019; Sorgo & Spernjak, 2012). The items were designed to assess students' perceived understanding, involvement, and skill development during laboratory activities. Additionally, the questionnaire structure aligns with established formative assessment frameworks such as knowledge surveys and Classroom Assessment Techniques (CATs), which utilize student self-ratings to monitor comprehension and inform instructional decisions (Cross & Angelo, 1988; Nuhfer, 2003). It also mirrors elements of validated instruments like the Student Understanding of Science and Scientific Inquiry (SUSSI) and the Colorado Learning Attitudes about Science Survey (CLASS), both of which employ Likert-scale items to evaluate students' confidence and attitudes toward laboratory-based scientific inquiry.

About the experiment

Just a laser diode with a wavelength of 630–630 nanometers, a plastic ruler, a tape measure, some bond paper, and scotch tape are required pieces of equipment.

The experiment is appealing to both student and teacher for the following reasons:

1. It sounds like Mission Impossible, which immediately grabs the students' interest;
2. It is truly beautiful physics which is, nevertheless, easy to understand and well described in standard undergraduate physics textbooks;

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3. At its simplest level, the experiment is straight forward to carry out, and the experimental data is easily processed to yield the required result;
4. At deeper levels, for those who wish to explore them, there is more and more to be learned about diffraction, about experimental design and scientific method, and about the processing of experimental data and the treatment of errors.

Procedure for the experiment:

The students reflect the undiverged laser beam off the 1/64 in or 1.2 mm divisions of the rule at near grazing incidence in order to estimate the wavelength of the laser light using the plastic ruler. Ten diffracted orders can usually be seen at a distance from the rule on a paper screen. The diffracted maxima's locations can be found using the equation:

$$d(\sin\theta m - \sin\theta i) = m\lambda,$$

The experiment is well-suited as a student exercise, where the students determine hair thicknesses of everyone in a class. How does the thickness vary with sex, race, ages and hair color? One can begin by measuring the thickness of a thin metal wire with a known diameter, such as a 0.1 mm metal wire, to see if the method is effective. The students can then assess their understanding of how to accurately execute the measurement.

It is recommended to conduct the presentation on hair types on both straight and curly.

Laser light diffraction can also be used to measure the sizes of other objects, such as blood cells or pollen, as detailed in the references.

It is important to take multiple measurements when varying the angle of the scattered laser light. This will demonstrate that straight hair is more round in the cross section, but curly hair is more oval!

Laser light diffraction can also be used to measure the sizes of other objects, such as blood cells or pollen, as detailed in the references.

Procedure:

1. As indicated on the front table, set up the experiment.
2. To use the paper as your target, tape it to an apple box.
3. To view the first and second maxima, position the target away from the grating. (Be sure to gauge the separation between the paper and the grating). Let's call this number x.
4. Check that your goal and the grating are parallel to each other.
5. Through the grating, shine the laser beam. Verify that the bean is positioned perpendicular to the grating. Important: Avoid staring at the laser beam or its reflection directly. It will damage your eyes. Nor should you tinker with the laser.
6. Verify that the zero maxima (the center dot) is surrounded by two maxima (two red dots). In other words, you should have five red dots on your paper.
7. Using a pencil, indicate where each dot's center is. Verify that you can identify which dot is in the center.
8. When you're finished, turn off the laser.

The experiment was designed such that 50 students may participate simultaneously, each working in a group of five. A typical experimental grouping in a laboratory.

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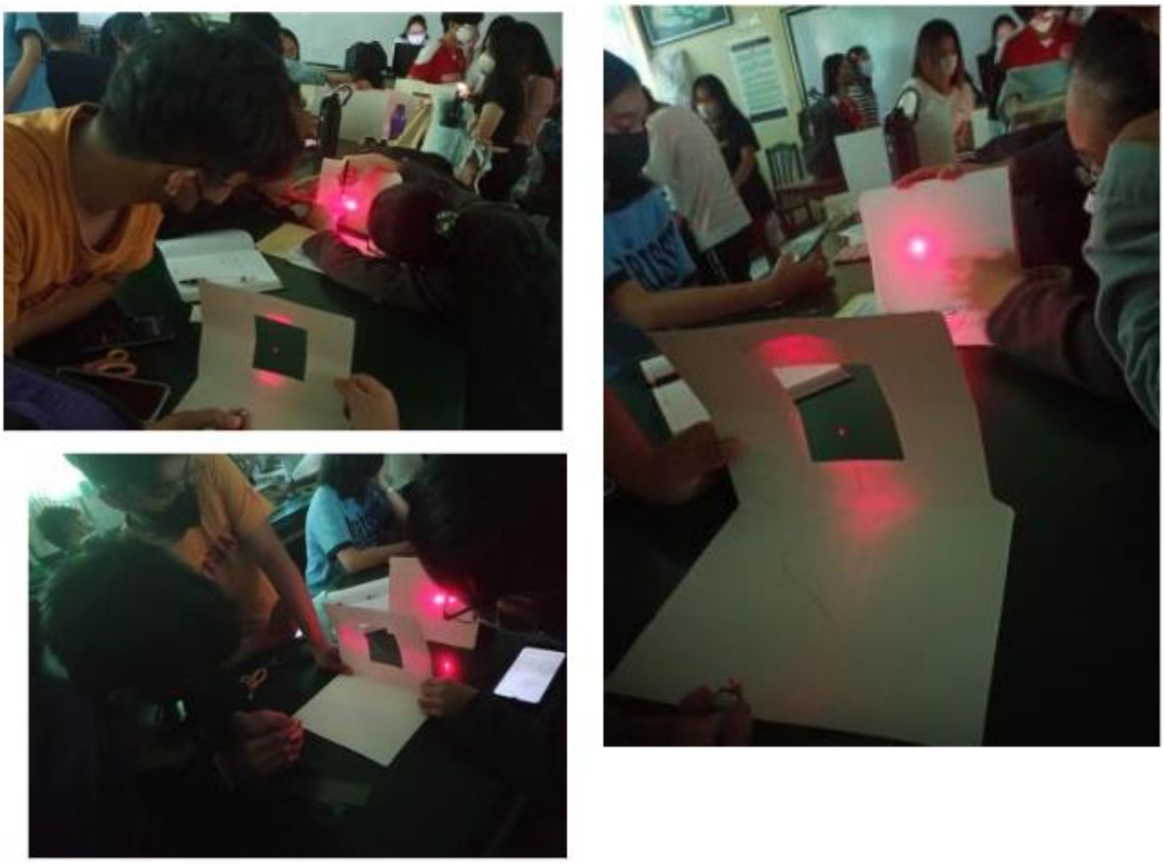

Figure 1. Students doing the experiment "Using Diffraction to Measure Hair Diameter"

Results and Discussion

The responses to questions assessing student comprehension and involvement serve as valuable indicators of the effectiveness of the diverse pedagogical methods employed by the Biophysics professor. These findings suggest that the combination of hands-on laboratory activities, guided discussions, and structured report writing collectively contribute to enhancing students' conceptual grasp and practical skills. By actively participating in well-designed experiments and reflective discussions, students were able to deepen their understanding of complex biophysical concepts, highlighting the success of the instructional strategies in promoting meaningful learning outcomes. The results revealed that BS Biology students enrolled in the Biophysics course demonstrated a high level of understanding and engagement with the laboratory experiments.

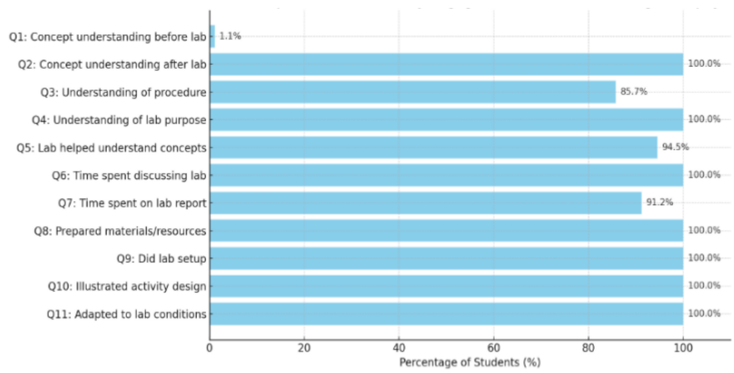

Figure 2. Student Responses on Laboratory Engagement and Understanding in an Alternative Lab Experiment in Biophysics

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On a self-assessment scale ranging from "No Understanding" (0) to "Complete Understanding" (4), all students reported a strong or complete understanding of the purpose of the lab activity (Q4) and the concepts learned after the laboratory session (Q2). Additionally, 85.7% (78 out of 91 students) indicated a strong or complete understanding of the experimental procedures (Q3). These results suggest that the laboratory activities were effective in clarifying both the theoretical and procedural components of the lesson. Interestingly, only 1 student (1.1%) expressed minimal or no understanding of the concepts before the lab (Q1), which highlights the instructional value of the laboratory in bridging conceptual gaps.

Student perceptions of the laboratory's educational impact were further confirmed by the 94.5% (86 students) who stated that the experiments significantly helped them understand the underlying scientific principles (Q5). Furthermore, the entire sample participated in a 30-minute discussion post-laboratory (Q6), and 91.2% (83 students) dedicated an hour to preparing lab reports (Q7), demonstrating high levels of cognitive engagement and reflective practice.

In terms of science process skills, all students affirmed their consistent involvement in core experimental tasks such as: Preparing materials and resources (Q8); Executing laboratory setups (Q9); Illustrating activity designs (Q10), and Adapting procedures based on situational requirements (Q11).

Table 1. T-test for Understanding of the lab procedure (Q3) and Lab helped in understanding concepts (Q5)

Question	Description	Sample Size (n)	Mean ($\bar{x}$)	SD (s)	Hypothesized Mean (μ_0)	t-value	df	p-value
Q3	Understanding of lab procedure	91	3.6	0.6	2.5	17.48	90	< .001
Q5	Labs helped in understanding concepts	91	3.9	0.4	2.5	33.41	90	< .001

A one-sample t-test was conducted to evaluate whether students' self-reported engagement and understanding scores (on a 0–4 Likert scale) were significantly higher than the neutral midpoint value of 2.5. Students reported a mean score of 3.6 (SD = 0.6) on for Understanding of Lab Procedure (Q3), indicating strong perceived understanding of laboratory procedures. The results of the t-test showed that this mean was significantly higher than the neutral value, $t(90) = 17.48$, $p < .001$. This result provides strong evidence to reject the null hypothesis, confirming that students felt confident in their procedural understanding—an indicator of high laboratory engagement. For Labs Helped in Understanding Concepts (Q5), students rated the effectiveness of labs in helping them understand concepts with a mean score of 3.9 (SD = 0.4). A one-sample t-test also revealed a statistically significant difference from the neutral midpoint, $t(90) = 33.41$, $p < .001$ The null hypothesis was again rejected, indicating that students perceived laboratory activities as highly effective in supporting conceptual learning.

Mirana (2019) reiterated that if these skills are not acquired, students will find learning difficult; they could not get meaningful learning experiences. The latter's absence contributes immensely to the decline in interest and the negative attitude toward science. As a result, scientific education should support the development of science process abilities in schools by providing the required learning environment, such as active engagement, life integration, and meaningful learning. Harlen (1999) claimed that students' ability to acquire SPSs at a required level is critical and that pupils who cannot do so will be unable to perceive the world and make vital connections. As a result, it is reasonable to infer that science process skills and subject

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understanding are complementary (Bulent, 2015). Students' acceptance of the alternative laboratory experiments in the Measurement topics for Biophysics is prepared for use in the classroom or at home. Students pursuing a BS in Biology with a Biophysics course used this experiment with remarkable success.

Conclusion

A laser beam (from for instance a laser pointer) is directed towards a piece of hair. This creates a diffraction pattern, from which the diameter of the hair can be measured using a ruler. A one-sample t-test comparing students' self-reported understanding of the lab procedure (Q3) against the neutral midpoint of 2.5 revealed a statistically significant difference, $t(90) = 17.48$, $p < .001$. The mean score of 3.6 ($SD = 0.6$) indicates that students perceived themselves as having a strong to complete understanding of the lab procedures, suggesting high procedural engagement during laboratory activities. Results from a one-sample t-test for Q5, which asked whether laboratory experiments helped students understand concepts, yielded a mean score of 3.9 ($SD = 0.4$), significantly above the neutral value of 2.5, $t(90) = 33.41$, $p < .001$. This provides robust evidence that students found the laboratory sessions highly effective in deepening their conceptual understanding, reinforcing the instructional value of hands-on learning. Overall, the data suggest that the alternative laboratory method used in this study successfully promoted deep learning, scientific inquiry, and engagement—hallmarks of effective science education in the 21st century.

The findings of this study reveal that the integration of alternative laboratory experiments—specifically those involving laser diffraction techniques for measuring hair diameter—significantly enhanced student understanding and engagement in the Biophysics subject. The experiment was a success and was able to deliver the objectives of the activity. The results indicate that BS Biology students in Biophysics gained solid understanding and actively engaged in lab activities, demonstrating the effectiveness of the professor's varied pedagogical approaches.

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