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Students' report on an open inquiry

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Abstract

As part of the final projects of our introductory lab course, students conceived experiments related to the umbrella topic of 'Physics of toys and sports' and carried out the experiments at their homes. This paper revisits two of these experiments described by student teams and illustrates how self-conceived experiments provide opportunities to truly engage students in *doing science.*

Keywords: practical work, introductory lab course, first year physics

1. Introduction

As a final project of our first year introductory lab course, students carry out a self-conceived physics inquiry. They apply the knowledge they have acquired in the preceding weeks, and assume a role with more initiative, responsibility and freedom than in the previous experiments. This provides more opportunities to think like a physicist as many of the cognitive tasks are carried out by the students [1, 2].

This year's central topic *physics of toys or sport* was chosen as we assumed that this topic was interesting to students and often involves interesting physics [3, 4]. Due to COVID restrictions, we slightly adapted our assignment, as was done in many other practical courses [5–9]. Students were expected to use the materials available at home foremost, but could borrow some equipment when required. Either way, they were tasked to produce an as scientifically as possible inquiry. This resulted in a lot of improvisations. Yet there were some amazingly creative ideas from the students.

Rather than providing the teachers' view on the experiments and the process, two teams of students present their experiment and review what they have learned. To keep a concise paper we omit the textbook theory and some of the data.

2. Team 1: the inductance of a slinky

As a slinky—a large insulated spring with a metal core in the shape of a helix—resembles a coil, we wanted to establish the inductance of a stretched and unstretched slinky. To study this electrical feature of the toy, a serial circuit with a 220 Ω

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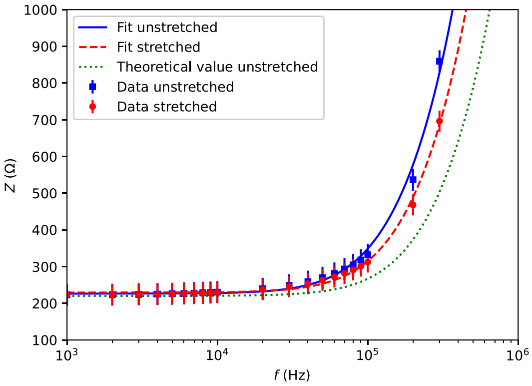

Figure 1. The established impedance Z of the RL-circuit as function of the source frequency for the stretched and unstretched slinky together with the theoretical value.

resistor, R, was built (see [10] for the circuit and an elaborate theoretical background). We measured the voltage across the slinky using a borrowed oscilloscope/function generator (Rigol DS1104) within a frequency range, f, of 10^3–10^5 Hz using a 2.5 V AC supply voltage. The established impedance, Z, of the circuit is shown in figure 1, where we fitted the results using the theoretical model:

$$Z = \sqrt{(R + dR)^2 + (2\pi f L)^2}. \tag{1}$$

dR represents the sum of the resistance of the slinky and other resistances e.g. that of the wires. dR takes into consideration that there is a tolerance in the used resistance as well.

The results yield an inductance, L, of 0.4 ± 0.2 mH and 0.3 ± 0.1 mH for the unstretched and stretched slinky respectively. The theoretical inductance of the unstretched and stretched slinky, calculated using

$$L = \frac{\mu_0 \pi r^2 N^2}{l}, \tag{2}$$

with μ_0 the magnetic permeability in vacuum, $r = 3.8 \pm 0.1$ cm radius, $N = 79$ number of turns, and $l = 15.5 \pm 0.1$ cm length of the unstretched and $l = 18.5 \pm 0.1$ cm for the stretched slinky was respectively 0.23 ± 0.01 mH and 0.19 ± 0.01 mH. Our experimental values are in agreement with the theoretical values. However, this is largely due to the associated uncertainty in our values—implying that we have to improve our methods.

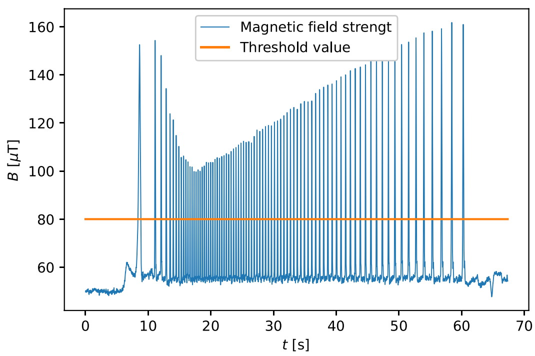

Figure 2. The raw data recorded using the Phyphox app, magnetic field strength as a function of time.

Furthermore, as can be seen in figure 1, our results systematically yield a higher impedance than the theoretical value. Although this requires investigation, it is our assumption that a slinky is not an ideal coil after all.

3. Team 2: the drag coefficient of a cyclist

Our experiment was an attempt to determine whether the drag coefficient of a cyclist in an upright position are higher than those of a cyclist in a bent-over position. Thereto the same cyclist accelerated to a velocity of ~25 km h^{-1} after which he stopped pedakling. We then tracked the velocity during the deceleration and related this to the theoretical model for air resistance:

$$F_d = \frac{1}{2}\rho A C_d v^2. \tag{3}$$

in which ρ is the air density, A the frontal area of the cyclist, C_d the drag coefficient and v the velocity of the cyclist. To determine the travelled distance a magnet was attached to the rear wheel of a bicycle and a phone to its frame. The phyphox app [11] and a self-written algorithm allowed us to convert the raw data, see figure 2, into a meaningful distance-time graph, see figure 3.

A series of four repeated measurements was performed for four situations; straight downwind, straight upwind, bent-over downwind, bent-over upwind. To fit the data a theoretical model was used where only drag force was taken into account:

$$\frac{d^2x}{dt^2} + \alpha\left(\frac{dx}{dt}\right)^2 = 0, \tag{4}$$

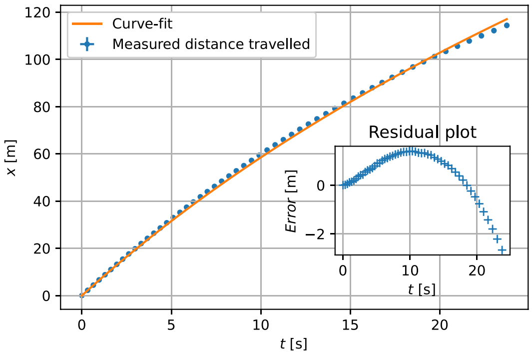

Figure 3. A distance-time measurement fitted using the theoretical model. An analysis of the residuals indicates that the rolling resistance cannot be neglected.

with $\alpha = \frac{\rho A C_d}{2m}$, where m is the mass of the cyclist and the cycle. Using the and the initial conditions $x(0) = 0$, the solution of this boundary value problem is

$$x(t) = \frac{ln(v_0 \alpha t + 1)}{\alpha} \quad (5)$$

where the initial velocity v_0 is calculated using the first three datapoints. The frontal area was calculated by using a photograph of the cyclist, software to count the amount of pixels and proportional scaling using the bicycle's features. Figure 3 presents a measurement alongside the fit using equation (5), showing that theory and practice are to a large extent in agreement. The average of α for up- and downwind measurements was used with the aim to cancel out wind effects. $C_d = 0.83 \pm 0.02$ for the straight up cyclist, and $C_d = 0.97 \pm 0.02$ in the bent-over case. This, initially, surprising result (a straight up cyclist is more streamlined than a bent-over cyclist) was further investigated by taking the frontal area into account. This gives the following values for the straight and bent-over cases, respectively: $AC_d = 0.804 \pm 0.004$ m^2 and $AC_d = 0.946 \pm 0.004$ m^2. This still implies that one experiences less drag when cycling bent-over.

4. Students' review

The final project allowed us (the students) to apply our acquired knowledge in a self-conceived experiment. Designing your own experiment is challenging in a whole different way than just executing a pre-made assignment. The most important lessons were learning to deal with unforeseen circumstances and finding inventive solutions to problems that inevitably arise when a group of first-year students come up with an experiment.

5. Teachers' review

The students' descriptions illustrate that they dealt with theory at a more advanced level than is covered in theoretical lectures: In their projects, the students encountered physical phenomena in non-idealised situations. Moreover, they set up and solved differential equations in a way and at a level that was not covered in mathematical courses yet.

From their descriptions, one can also imagine that they encountered various problems. Without our instant help at their disposal, they had to deal with these themselves. This approach does not always yield scientific acceptable outcomes, but engages students in more complex and authentic problem solving. To quote one of our students: 'It probably provides a more honest image of doing real inquiry, most of the time it does not work and you have to figure out why.' We hope to have provided a clear picture of what students can achieve and learn when we allow them to conceive and carry out their own physics experiments.

Data availability statement

No new data were created or analysed in this study.

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Freek Pols was a physics teacher for ten years and is now the first year physics lab course coordinator at the faculty of Applied Physics, Delft University of Technology. His research focusses on practical work in physics and teaching scientific inquiry at both secondary school and academic level.

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