



Delft University of Technology

## Students' report on an open inquiry

Pols, Freek; Duynkerke, Lennard; Van Arragon, Jels; Van Prooijen, Kevin; Van Der Goot, Luuk; Bera, Bijoy

### DOI

[10.1088/1361-6552/ac27f8](https://doi.org/10.1088/1361-6552/ac27f8)

### Publication date

2021

### Document Version

Final published version

### Published in

Physics Education

### Citation (APA)

Pols, F., Duynkerke, L., Van Arragon, J., Van Prooijen, K., Van Der Goot, L., & Bera, B. (2021). Students' report on an open inquiry. *Physics Education*, 56(6), Article 063007. <https://doi.org/10.1088/1361-6552/ac27f8>

### Important note

To cite this publication, please use the final published version (if applicable). Please check the document version above.

### Copyright

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

### Takedown policy

Please contact us and provide details if you believe this document breaches copyrights. We will remove access to the work immediately and investigate your claim.

FRONTLINE • OPEN ACCESS

## Students' report on an open inquiry

To cite this article: Freek Pols *et al* 2021 *Phys. Educ.* **56** 063007

View the [article online](#) for updates and enhancements.

### You may also like

- [Demonstrating buoyancy in waterlogged ground](#)  
Stephen Hughes
- [Construction of an innovative, modern and affordable teaching tool in practical classroom activities using AS5600 encoder](#)  
R Essaadaoui, M El Hadi, A Ouariach et al.
- [Analysis of interference patterns using a simplified ripple tank, a smartphone camera and Tracker](#)  
Savrin Thy and Tsutomu Iwayama



**IOP | ebooks™**

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

# Students' report on an open inquiry

Freek Pols<sup>1,\*</sup> , Lennard Duynkerke<sup>3</sup> , Jels van Arragon<sup>3</sup>,  
Kevin van Prooijen<sup>3</sup>, Luuk van der Goot<sup>3</sup> and Bijoy Bera<sup>2</sup> 

<sup>1</sup> Science Education and Communication, Delft University of Technology, Delft, The Netherlands

<sup>2</sup> Chemical Engineering, Delft University of Technology, Delft, The Netherlands

<sup>3</sup> Applied Physics, Delft University of Technology, Delft



CrossMark

E-mail: [c.f.j.pols@tudelft.nl](mailto:c.f.j.pols@tudelft.nl)

## 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.

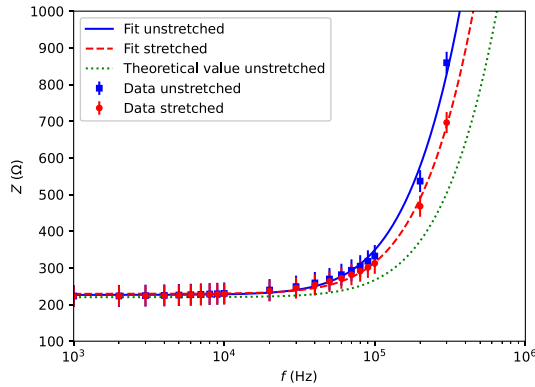
## 2. Team 1: the inductance of a slinky

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  $\Omega$

\* Author to whom any correspondence should be addressed.



Original content from this work may be used under the terms of the [Creative Commons Attribution 4.0 licence](https://creativecommons.org/licenses/by/4.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.



**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:

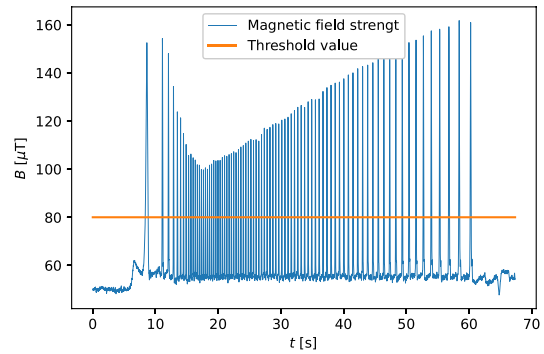
$$Z = \sqrt{(R + dR)^2 + (2\pi fL)^2}. \quad (1)$$

$dR$  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  $0.4 \pm 0.2$  mH and  $0.3 \pm 0.1$  mH for the unstretched and stretched slinky respectively. The theoretical inductance of the unstretched and stretched slinky, calculated using

$$L = \frac{\mu_0 \pi r^2 N^2}{l}, \quad (2)$$

with  $\mu_0$  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  $0.23 \pm 0.01$  mH and  $0.19 \pm 0.01$  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

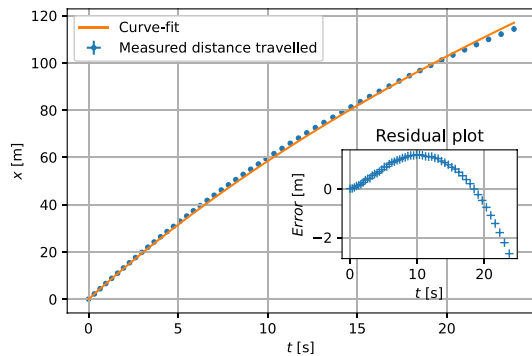
Our experiment was an attempt to determine whether the drag coefficient of a cyclist in an upright position are higher than those of a cyclist in a bent-over position. Thereto the same cyclist accelerated to a velocity of  $\sim 25$  km h $^{-1}$  after which he stopped pedaling. We then tracked the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

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

in which  $\rho$  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:

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



**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  $\alpha = \frac{\rho AC_d}{2m}$ , 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  $\alpha$  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:  $AC_d = 0.804 \pm 0.004 \text{ m}^2$  and  $AC_d = 0.946 \pm 0.004 \text{ m}^2$ . 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.

#### ORCID iDs

Freek Pols  <https://orcid.org/0000-0002-4690-6460>

Lennard Duynkerke  <https://orcid.org/0000-0001-6686-9970>

Bijoy Bera  <https://orcid.org/0000-0002-8626-3682>

Received 19 July 2021, in final form 7 September 2021

Accepted for publication 17 September 2021

<https://doi.org/10.1088/1361-6552/ac27f8>

#### References

- [1] Holmes N G and Wieman C 2018 Introductory physics labs: we can do *Phys. Today* **71** 1–38

- [2] Wieman C 2015 Comparative cognitive task analyses of experimental science and instructional laboratory courses *Phys. Teach.* **53** 349–51
- [3] Cross R 1999 The bounce of a ball *Am. J. Phys.* **67** 222–7
- [4] Featonby D 2005 Toys and physics *Phys. Educ.* **40** 537
- [5] Pols C F J 2020 A physics lab course in times of COVID-19 *Electron. J. Res. Sci. Math. Educ.* **24** 172–8
- [6] Bradbury F and Pols C F J 2020 A pandemic-resilient open-inquiry physical science lab course which leverages the maker movement *Electron. J. Res. Sci. Math. Educ.* **24** 7
- [7] Hut R, Pols C and Verschuur D 2020 Teaching a hands-on course during corona lockdown: from problems to opportunities *Phys. Educ.* **55** 065022
- [8] Klein P, Ivanjek L, Dahlkemper M, Jeličić K, Geyer M-A, Küchemann S and Susac A 2021 Studying physics during the COVID-19 pandemic: student assessments of learning achievement, perceived effectiveness of online recitations, and online laboratories *Phys. Rev. Phys. Educ. Res.* **17** 010117
- [9] Feenstra L, Julia C and Logman P 2021 A Lego® Mach-Zehnder interferometer with an Arduino detector *Phys. Educ.* **56** 023004
- [10] Nave C 2017 *RL Circuit* (Available at: <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/rlimp.html>)
- [11] Staacks S, Hütz S, Heinke H and Stampfer C 2018 Advanced tools for smartphone-based experiments: phyphox *Phys. Educ.* **53** 045009



**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.

**Lennard Duynkerke, Jels van Arragon, Kevin van Prooijen and Luuk van der Goot** are students of the bachelor program Applied Physics at Delft University of Technology.



**Bijoy Bera** is an assistant professor with focus on education. He teaches several courses within the TNW faculty such as: Transport Phenomena, Thermodynamics. His educational interest lies in personalizing learning activities in the context of individualized learning experience.