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A Physics Lab Course in Times of COVID-19

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ABSTRACT

Due to the coronavirus lockdown, home experiments were devised for our first-year physics lab course. In this practitioner contribution we elaborate on the guided inquiries that were set up. Students could carry out the experiments with standard tools available at home, including sensors mobile phones are equipped with. Various design principles stemming from the literature were used that are meant to encourage the development of inquiry skills. The switch from prescribed to more open experiments allowed us to focus on the quality of the inquiry rather than judging the quality of the final report alone. Students tried to produce sound research but often did not make optimal choices. We were not able to provide adequate feedback during their investigations. How students carried out the experiments shows that the current course does not adequately develop the highly valued inquiry skills to set up an independent scientific experiment. We expect the design principles to be transferable to other science subjects and can be used by other practitioners when students have to stay at home.

Introduction

The first-year physics lab course (FYPLC) at the University of Technology Delft was running the last three, of eight, half-day experiments when the COVID-19 lockdown forced us to end the on-campus experiments. To continue education, the director of education asked teachers to come up with solutions for distant learning. Although, for theoretical courses, many online options are available, the prescribed experiments in our FYPLC require special lab equipment and cannot be carried out easily outside the classroom. Consequently, new inquiries were devised that required only everyday tools. This paper is a practitioner contribution in which we elaborate the ideas and design principles, stemming from the literature, used to come up with fully-fledged first-year physics experiments that can be done at home. Furthermore, we describe our experience with this type of teaching and reflect on the design principles.

Design Principles

In general, the FYPLC has a focus on developing conceptual knowledge. In typical experiments, conducted on campus, students determine a variety of physics concepts such as the wavelength of sodium or mercury, the Boltzmann constant using the (V,I)-characteristic of a diode, or the dissolution enthalpy of salt. As these, and other content focused experiments, require specific lab equipment, the first design principle is to *focus on the development of inquiry skills*. This is in accord with the recent calls to shift the goals of laboratory instructions (Kozminski et al., 2014).

Developing inquiry skills requires that students take agency and devise procedures, choose instruments, take adequate measures to reduce measurement uncertainty, etc. (Hodson, 2014; Millar, 1997). In a continuum of levels of inquiry, shown in figure 1, *guided* and *open inquiry* offer these possibilities (Tamir, 1991). In guided inquiry, the problem is given while the procedure is decided by the students and the conclusion is, at the outset, unknown. During open inquiry, students come up with their own research question. However, if students are not trained in posing researchable questions, it is likely that many students will have difficulty during the initial phase, when they identify interesting problems and formulate researchable questions at an adequate level. Therefore, the second design principle is the *use of guided inquiry*. Students are provided a research question but must devise, on their own, the experiment that allows them to answer it convincingly.

	Problem	**Procedure**	**Conclusion**
Confirmation	given	given	given
Structured inquiry	given	given	open
Guided inquiry	given	open	open
Open inquiry	open	open	open

Figure 1. The levels of inquiry and corresponding amount of information provided by the teacher (Tamir, 1991).

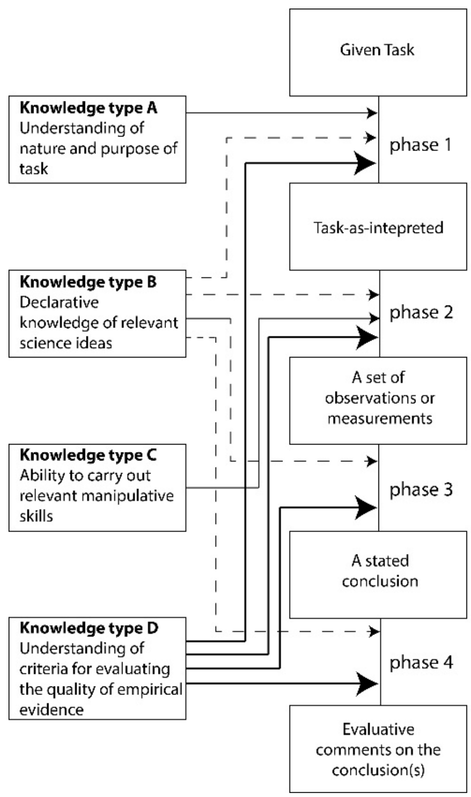

Figure 2. The PACKS model indicates what types of knowledge influence the decisions made in various phases in an inquiry (Millar et al., 1994).

A focus on developing inquiry skills is closely related to the development of *understandings of criteria for evaluating the quality of empirical evidence*, knowledge type D in the *Procedural and Conceptual Knowledge in Science (PACKS)* model (Figure 2) (Gott & Duggan, 2007; Millar, Lubben, Gott, & Duggan, 1994). This model illustrates what types of knowledge influence decisions made in various inquiry phases. Millar et al. (1994) concluded that especially knowledge type D influences the overall quality of a scientific inquiry. To focus on the development of this knowledge type and to reduce the chance of cognitive overload (Johnstone & Wham, 1982; van den Berg, 2013), students should have already sufficiently acquired the other types of knowledge. This means that students understand the purpose of the given task (knowledge type A), understand the physics content (knowledge type B) and are familiar with the equipment (knowledge type C). The third design principle is *the reduction of knowledge demands* other than type D.

The Experiments

Our 52 students were expected to carry out two experiments, hand in their lab journals for both the experiments, and submit a science report of the second experiment. Students were urged to *use a scientific approach and maintain scientific standards.* As it was the first time that students had to devise their own methods, two options for simpler research tasks were given so that students at least felt capable of answering the research question:

1. Determine the speed of sound through air using a PVC tube with a maximum length of 40 cm.

2. Determine the gravitational acceleration g, not using a simple pendulum.

The tasks are clear and easily understood (knowledge type A), students are familiar with the content (knowledge type B) and, as an aid, students were directed to the phone application Phyphox. The app allows to acquire data from the many sensors available in mobile phones (Staacks, Hütz, Heinke, & Stampfer, 2018). We expected the students to be familiar with their phones and that they could use the apps without problems (knowledge type C). After conducting the experiments, we evaluated their logbooks and provided feedback on their methods and assessed the quality of the inquiry. It took the teacher about eight hours to review the 25 logbooks and provide feedback.
The second inquiry (Figure 3) was described in more detail so that students began with a clear idea of what to do.

Make a small hole in the bottom or at the side of a milk carton. Fill the carton with water, hold your finger on the hole. Removing your finger will cause the water to spray from the bottom or side. Pick one of the following tasks, or think of a third on your own:

1. Determine the relation, if any, between the horizontal position of the water jet at a fixed vertical position and the water level.
2. Determine the relation, if any, between the flow rate and the water level.
3. Think of a research question yourself.

Make a physical model first, carry out the study. Compare your model with the empirical data. Provide explanations for differences.

Figure 3. Instructions for second inquiry.

Again, the demand on knowledge type A is limited as the problem is clearly described, the content required for making a simple model is covered at pre-university level (knowledge type B). Instruments can be found in the kitchen and at every desk (knowledge type C). The quality of the inquiries were assessed using the Assessment Rubric for Physics Inquiry (Pols, Dekkers, & de Vries, 2020a, 2020b). As shown in Table 1, the rubric specifies ideas about evidence that the researcher holds. These ideas are operationalized during an inquiry. In the rubric three levels of competence are specified but scoring in between levels is allowed. Teaching assistants (senior physics students) used the lab journals and reports to assess the quality of the inquiry.

Table 1. *An Example of an Understanding of Evidence from Pols et al. (2020a) with Indicators for Three Levels of Competence*

Researcher understands that:	Understanding is demonstrated by:	Lowest level	Intermediate level	Highest level
(Human) Errors may occur and precautions are needed to minimize or avoid them, ensuring reliability.	Identifying sources of uncertainty and error and taking justifiable precautions.	Fails to identify sources of uncertainty and error.	Takes precautions to minimize effects of some but not all sources of uncertainty or error or fails to practically implement the precautions.	Takes all relevant causes of uncertainty and error into account and develops or augments procedures to minimize them.

Findings

Teacher's Perspective

Experiment 1.1.

When blowing over a PVC tube, the produced frequency is described by $f = \frac{nv}{2L}$ for a tube that is open on both sides and $f = \frac{(2n-1)v}{4L}$ for a tube that is closed on one side. In these equations, *n* is the order, an integer multiple of the fundamental (lowest resonance, *n*=1) frequency, *L* is the length of the tube (though a small correction should be applied) and *v* the velocity of sound in air. We were pleasantly surprised by the different approaches students used to determine the speed of sound using resonance. Some students used a sweep frequency and determined overtones ($f(n, L = const.)$), others reduced the length of the tube and measured the fundamental frequency ($f(L, n = 1)$). There were students using an open-open system, and others using an open-closed system. Some students were using their ears to determine the resonance frequency, others used two mobile phones, one to generate and the other to measure the frequency and amplitude. By applying a correction to the length of the tube, students demonstrated that they investigated the theory deeply. This small description illustrates that students devised their own methods. Though the task was the same to all, much freedom was given in how the inquiry was set up, which variable was chosen to be the independent, and which system (open or closed) was used.

Experiment 1.2

The usual way to determine the gravitational acceleration (g) is to let a heavy object fall from a known height (H) and measure the time (Δt) before the object hits the ground very accurately ($g = \frac{2H}{\Delta t^2}$), although other ways in which an object accelerates due to gravity can be used as well. One pair determined the gravitational acceleration by determining the acceleration of a marble rolling down an incline. All other pairs determined the gravitational acceleration by dropping a heavy object. Different methods were applied though. One pair video-recorded the fall and used the app *tracker* to determine the acceleration. Other pairs used an acoustic chronometer. The sound of either shouting at the moment of release or, further reducing measurement uncertainty, puncturing a balloon to which the object was attached, started the timer. The sound of the object hitting the ground stopped the timer. However, often the time required by the sound to travel from the ground to the phone was forgotten.

Experiment 2

Each pair was able to take a reasonable amount of measurements in the second experiment to do a full analysis, see figure 4. However, the quality of the data could be improved in most cases. Students had difficulties in choosing optimal procedures and instruments to reduce errors, e.g., using paper rulers on the inside of the carton to measure the water level where a kitchen scale could lead to a more accurate measurement. In the discussion section of the reports, students assessed the reliability of their measurements and compared the empirical data with the theoretical model. They often elaborated on effects that are too small to explain the differences. Rather than abandoning the oversimplified model, students doubted their own methods. One TA commented: ‘Students come up with great ideas which can be implemented so easily, that one wonders why they did not do this in the first place.’

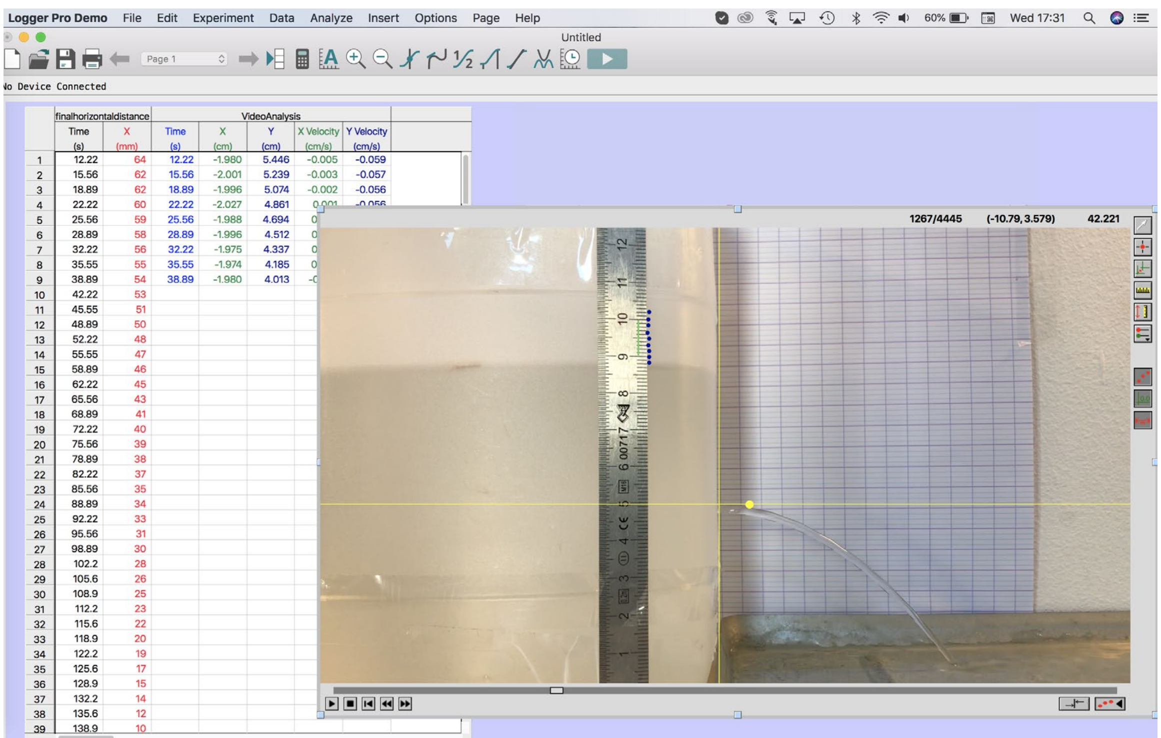

Figure 4. These students used video recordings to obtain highly accurate measurements of the water level (blue dots) and the horizontal travelled distance of the water jet (yellow dot).

Because of the lockdown, we were not able to supervise students directly and did not have any timely deliberations with students. They carried out their inquiries without any feedback during the investigations, carrying it out as they seem fit. We were only able to assess in retrospect what was done. A second cycle would probably improve the inquiries and help students in developing inquiry skills.

Students' Perspective

We asked students to provide feedback in which they compare the open experiments at home to the prescribed experiments on-campus. Though not many students provided feedback, we want to present one of the letters in full (translated by author and an independent native speaker).

> Personally, I thought the home-experiments were great, precisely because of the real freedom of choosing what to study and how to do it. I think this pushes you to learn more about how to do research because you have to reflect on complicating factors that might influence your measurements, as opposed to the standard lab-experiments before the quarantine where most of the issues had already been dealt with.
>
> Making a model first was fun because you dug much deeper in the theory than during the regular experiments. Through creating the physical model, you better understand the underlying physics and learn about factors that influence the results as well. To give some examples, we learned a lot about the coefficient of discharge, velocity, and contraction.
>
> On the other hand, the equipment limitations pose a difficulty, though this conversely means you have to think harder about your experimental design so that you can manage to obtain precise results despite using imprecise equipment.
>
> In short, I've found the home-experiments to be a really fun and educational way to do lab assignments. I don't know whether it is a real replacement for the regular experiments as we ought to learn to work with equipment as well, but I believe that the amount of freedom motivates students and teaches about setting up a scientific inquiry.

The letter illustrates that the learning goals we were aiming at are mentioned and recognized by the student. Another student suggested the idea of new experiments were quickly and professionally implemented. He commented that the intervention would benefit from an in-between evaluation of the method, as already suggested in the teacher's reflection.

Development of Inquiry Skills

Developing inquiry skills requires that students take agency of their inquiries, devise a method, collect data, analyse them, draw conclusions, potentially fail in doing each in some way, reflect and evaluate, and do it all over again. Except for the latter, we can say that the experiments were successful. The intervention reveals students' approach and what they know about setting up a scientific inquiry. The fact that not all students are able to produce reliable inquiries, indicate shortcomings of the current FYPLC. Students are switching too quickly to data collection, where a more scientific approach would have them reconsider their devised method and pay more attention to the quality of the data. As soon as students are allowed to return to campus, we will focus our FYPLC towards developing inquiry skills so that they are able to do more complex and independent research in later years of the applied physics program.

Reflection

Due to COVID-19 lockdown, new experiments for the first-year physics lab course were devised using design principles stemming from the literature. These principles were helpful in quickly setting up experiments focusing on developing inquiry skills that could be carried out at home, requiring no additional time for the teacher. As the experiments were carried out as intended and reveal what students know about setting up a reliable inquiry, we infer that the design principles have a predictive value. That is to say, the expected outcomes have been met and the learning objectives have been attained. As the principles are subject-independent, we expect these to help other practitioners to set up similar experiments in other subjects. If anything positive can be said about the pandemic for our lab course, it is that the intervention revealed shortcomings of the current course, which will lead to an enhanced lab course in the near future.

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References

Gott, R., & Duggan, S. (2007). A framework for practical work in science and scientific literacy through argumentation. *Research in science & technological education, 25*(3), 271-291.

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education, 36*(15), 2534-2553.

Johnstone, A. H., & Wham, A. (1982). The demands of practical work. *Education in chemistry, 19*(3), 71-73.

Kozminski, J., Lewandowski, H., Beverly, N., Lindaas, S., Deardorff, D., Reagan, A., . . . Hobbs, R. (2014). AAPT recommendations for the undergraduate physics laboratory curriculum. *American Association of Physics Teachers*, 29.

Millar, R. (1997). Student's understanding of the procedures of scientific enquiry. *Connecting Research in Physics Education with Teacher Education.*

Millar, R., Lubben, F., Gott, R., & Duggan, S. (1994). Investigating in the school science laboratory: conceptual and procedural knowledge and their influence on performance. *Research Papers in Education, 9*(2), 207-248.

Pols, C. F. J., Dekkers, P. J. J. M., & de Vries, M. J. (2020a). Assessment Rubric for Physics Inquiry. In http://doi.org/10.5281/zenodo.3778087 (Ed.): Zenodo.

Pols, C. F. J., Dekkers, P. J. J. M., & de Vries, M. J. (2020b). *The Construction and Validation of an Assessment Rubric for Physics Inquiry.*

Staacks, S., Hütz, S., Heinke, H., & Stampfer, C. (2018). Advanced tools for smartphone-based experiments: phyphox. *Physics education, 53*(4), 045009.

Tamir, P. (1991). Practical work in school science: an analysis of current practice. *Practical science*, 13-20.

van den Berg, E. (2013). The PCK of Laboratory Teaching: Turning Manipulation of Equipment into Manipulation of Ideas. *Scientia in educatione, 4*(2), 74-92.