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Developing Inquiry Experience Through Curiosity-Driven Open Inquiry

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Various scholars^{1,2} recommend the use of open inquiry³ for good reason: As students make methodological decisions themselves and evaluate the quality of these, they gain a better picture of what doing science entails⁴ and learn more and better.⁵ However, simply asking students to come up with their own research question and methods and then to design their experimental setup poses insuperable difficulties for novices (note that PhD students and postdocs also receive guidance!). A gradual and segmented approach to teaching inquiry and to open inquiry seems therefore a more appropriate teaching strategy.⁶ Here we describe and review our approach to open inquiry—especially the final project in which students conceive their own experiment. To illustrate and evaluate this approach, one student team presents their experiment and reflects on their process and perceived learning gains. Through their experiences, we examine how our approach to open-ended experiments helps students develop expertise in the cognitive tasks of experimental physics while providing support as they navigate the challenges of inquiry-based experimentation.

The challenge of open-ended experiments

As described elsewhere in detail,^{6,7} our recently reformed first-year physics lab course (6 European Credit Transfer and Accumulation System credits = 168 h) introduces ~240 students to experimental physics. Using highly prescribed experiments, students in the first 5 months learn essential skills such as programming and data analysis⁸ (including measurement uncertainty and error propagation), learn to use precision instruments, and develop scientific communi-

cation skills by maintaining a lab journal and writing formal lab reports.

Although traditional cookbook-type experiments are excellent ways to attain some learning goals, engaging students only in this sort of “closed” activity might cause them to develop an incorrect image of how science works^{9–11}: science is not a linear process where the correct answer to the research question is always found by following a prescription. To the contrary, it is an iterative process where one has to deal with unforeseen circumstances and alter ambition levels when time (or money) is running out. Moreover, traditional cookbook-type experiments do not engage students in formulating relevant research questions, allow them to develop their own methods, or think deeply about ways of analyzing their data.^{2,5,12} To allow for such experiences, open-ended activities with more cognitive tasks for students to pursue inquiry learning are recommended.^{1,5,13}

Despite calls emphasizing the need to engage students in more open-ended experiments,¹⁴ reforms—moving away from prescribed, fixed experiments—are slow^{15,16} due to practical considerations. How do you supervise (with one teacher and ~20 student assistants) ~100 different experimental projects, where almost all groups deal with a variety of unknown factors (e.g., are the materials we need available?), all while being expected to reach experimental conclusions within just 4.5 weeks. Over the course of 5 years, the first author has conceived a format that is challenging yet feasible (outlined in Table I) to introduce such a large group to open-ended inquiry in the sixth month of the course. In the following, one student team (the second and third authors) elaborates on the process.

Table I. Both teacher and students run a tight schedule to finish the final project.

Week	Session 1 (4 h—Online)	Session 2 (4 h—On Campus)
1	Orientation on topic and research question	—
2	Trial measurements, testing, literature review, writing research proposal	Writing and handing in proposal
Christmas holiday break		
3	Processing feedback on proposal, outlining report, writing code for data analysis	Measurement day 1
4	Data analysis, optional additional measurements	Measurement day 2
5	Report writing, optional additional measurements	Report writing

Start of the project

For the final project of the first-year physics lab course, we had to conceive and conduct our own experiment in just 4.5 weeks (~36 h). We were given a set of topics, each with some basic setups, yet had freedom to choose a subject of interest. We opted for the subject of physical transport phenomena, specifically frictional flow, as it spoke the most to us, and we immediately had a creative idea. Where the standard experiment considered the determination of the viscosity of water, we decided to challenge ourselves and determine the viscosity of honey as function of temperature.

Proposal

After choosing a topic, we were meant to do a short literature study to help us specify the research question. We found that the viscosity of honey as function of temperature can be described by the Arrhenius equation¹⁷:

$$\eta = A_0 e^{-E_a/RT}, \quad (1)$$

where η is the viscosity, A_0 is the pre-exponential factor, E_a is the activation energy in joules, R is the gas constant ($8.314 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$) and T is the temperature in kelvin. Using this information, we decided to answer the following questions:

1. Is the Arrhenius relationship sufficient to describe the relationship between viscosity and temperature of honey?
2. What are the values of the pre-exponential factor A_0 and the activation energy E_a in the Arrhenius relationship?

Furthermore, we devised a research method and finished our research proposal, which was then approved.

Method

We faced the challenge that the standard setups were not suitable for (heating) honey, and we thus had to devise our



Fig. 1. A water bath was used to heat the honey uniformly.



Fig. 2. The ball falling through the honey. Video analysis was used to determine its terminal velocity.

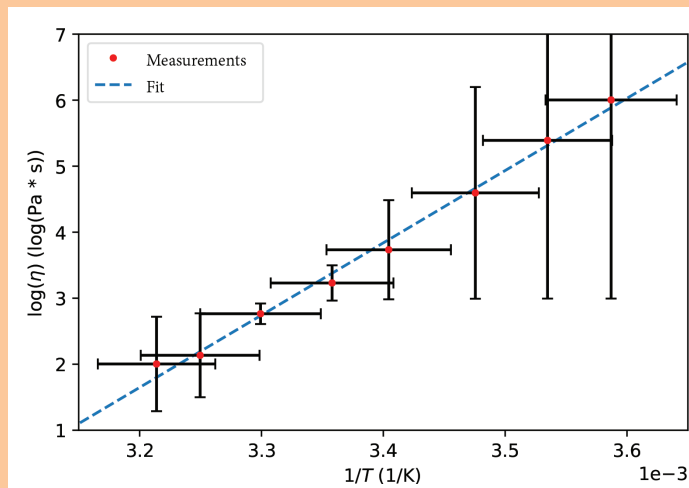


Fig. 3. The viscosity (log scale) as a function of the reciprocal temperature, confirming that the Arrhenius equation can be used to describe this relationship.

own setup using the available resources and equipment. With a little help, we were able to cool and heat honey in a measuring cylinder using a water bath (Fig. 1).

After taking the cylinder out of the bath, four spheres were dropped consecutively into the honey (see Fig. 2). A magnet was used to suspend each sphere while fully immersed in the honey, ensuring an initial velocity of zero. We used a video recording to determine the terminal velocity of each sphere. Using the equation for viscosity (Stokes's law),

$$\eta = \frac{D^2 g (\rho_b - \rho_h)}{18 v_t} \quad (2)$$

[where η is the viscosity, D is the diameter of the sphere, ρ_b is the density of the sphere, ρ_h is the density of the honey, and v_t is the terminal velocity], we determined the viscosity of honey at that specific temperature.

Results and discussion

Figure 3 shows the established viscosity as function of the reciprocal temperature, satisfying the Arrhenius equation. Using least-square fitting, we found an activation energy of $91 \pm 3 \text{ kJ/mol}$ and a pre-exponential factor of $3.2 \times 10^{-15} \text{ Pa} \cdot \text{s}$. These findings are the same orders of magnitude as determined by Saxena et al.,¹⁷ and we confirm that the viscosity of honey as function of temperature can indeed be described using the Arrhenius equation. As the uncertainty of the pre-exponential is the same order of magnitude as the value itself, follow-up experiments should be carried out to diminish this uncertainty. Therefore, we should stabilize and determine the temperature

better and use a wider cylinder so the effect of the sides is reduced.

Reflection

Conceiving and conducting your own experiment comes with various hurdles. For instance, it was difficult to find the right formula for calculating viscosity that was also applicable to our experiment. Initially, we worked with the Reynolds number (Re) and the drag coefficient (C_D), but we did not master the mathematical skills to deal with this complexity. Eventually, we discovered that viscosity could also be calculated using a different theory (Stokes's law). Additionally, toward the end of the project, we realized that the uncertainty for the pre-exponential factor was quite large. Next time, we would need to measure more accurately—that is, both temperature and velocity. We also had to be creative in finding a way to make the ball fall as close to the center of the measuring cylinder as possible. Tweezers did not reach deep enough, but using a magnet allowed the ball to be manipulated along the edge of the measuring cylinder by magnetic force. We thus encountered various problems that we did overcome (at least

most of them). We learned that it takes quite some time to set up a rigorous experiment. One needs time for studying the literature to understand the problem well enough and know what you are doing. We gained much experience and made mistakes that we will take into account a next time that we are supposed to conceive and conduct a physics experiment.

The final project in which you conceive and conduct your own experiment significantly differs from the prescribed experiments that we did earlier in the course. With the recipe-style experiments, we did not have to make test measurements; you only have to understand the theory and what you are going to do. You don't have to think about how to build your setup or how to improve it. In this project, we were very enthusiastic at the start, but then had doubts whether we could devise our own setup that would work. We were happy that all worked out and we could collect the data. We had stress when we were near the deadline and made a calculation error resulting in an invalid outcome at first. Finally, we were relieved when the report was handed in (and received a grade of 8.1/10).

What Amy and Xandesh's story tells us

Although we only described the journey of a single student team, the above story of Amy and Xandesh is illustrative for the experimental journey of most student teams when doing a self-conceived experiment in our first-year physics lab course.^{6,7,18} Many enjoy the given freedom and start with highly ambitious research projects—see Table II for a selection of this year's experiments. Rather than following a detailed recipe leading to a predetermined answer, they formulate their own research question, investigate existing knowledge, and integrate relevant insights into their experiment, all of which aligns with the objectives of this part of the course. However, they also encounter several challenges along the way, and their plans gradually become less ambitious but therefore more feasible.^{7,18}

Providing a list of topics, equipment, and ideas is sufficient to let students pick their own experiment and let curiosity drive their experiment. In doing an online investigation of the topic, students may stumble upon prescribed experiments leading to the correct answer to the question they themselves posed. We do not see this as a threat to the open-ended part

of inquiry, as most of the time the same materials are not available, requiring students to adapt their methods, reformulate their questions, or downsize their ambitious plans.

Another key observation from the students' report is that their understanding of physics is still developing. When searching for a formula relating viscosity to temperature, they found an article using the Arrhenius equation. However, had they explored the underlying concepts more deeply, they would have discovered that this equation is typically used to describe the temperature dependence of reaction rates in chemistry. In that context, the concept of *activation energy* has a clear physical meaning. When applied to viscosity, however, the Arrhenius equation serves only as an empirical model, and the so-called *activation energy* is better understood as a fitting parameter without a direct physical interpretation.

That said, we do not view this as problematic. The main goal of the open-ended experiment is for students to convincingly establish a relationship between two variables. Moreover, the students made a genuine effort to dig deeper into the literature—a commendable step, especially considering it was their first time reading scientific papers and they are non-native English speakers. Situating their findings within the broader framework of physics comes later in their education—an endeavor that certainly requires more than the 28 hours allotted for conceiving, conducting, and reporting on an experiment.

To conclude

Implementing open inquiry in a first-year lab course is not an easy task. As shown in Table I, both students and instructors work within a tight schedule. We make use of the Christmas holidays to review student proposals (by the teacher and four experienced student assistants), assess any safety concerns, and arrange for additional materials requested by the students (handled by the technicians). During the 4-hour lab

Table II. Amy and Xandesh's choice of topic is illustrative for the kind of inquiries students engage in.

Topics Students Chose for Research Projects
• Determining the diffusion coefficient using the Millikan experiment
• Testing Paschen's law by creating arcs at varying temperatures in atmospheric pressure
• Determining Planck's constant using LEDs
• Determining the refractive index of glass using a Michelson interferometer
• IV characteristics of diodes as function of temperature
• Analyzing the angle-drag relationship with an air track

sessions, one teaching assistant is typically responsible for supervising five to eight student teams. In the first session especially, students often need support with setting up equipment, gathering additional materials, and reviewing or refining their methods.

Four weeks and a day for preparation is just enough time to conceive and conduct an experiment, especially when little structure (list of topics and a mandatory research proposal) is provided. Yet, 4 weeks is short enough to not get frustrated about failures: Almost every team encounters unanticipated difficulties and problems that force the students to improvise, consult, and scale down the project. Many times, we had discussions where students stated that they have tried several things and nothing works, and asked whether their final idea is still sufficient to pass the course. Almost always, the reply is that they have undergone the difficulties experienced by real researchers and acted accordingly—they were truly engaged in the cognitive tasks of an experimental physicist. What more do we want as teachers?

References

1. D. Hodson, "Learning science, learning about science, doing science: Different goals demand different learning methods," *Int. J. Sci. Educ.* **36**, 2534–2553 (2014).
2. C. Wieman, "Comparative cognitive task analyses of experimental science and instructional laboratory courses," *Phys. Teach.* **53**, 349–351 (2015).
3. P. Tamir, "Practical work in school science: An analysis of current practice," in *Practical Science*, edited by B. E. Woolnough (Open University press: Milton Keynes, Philadelphia, 1991), pp. 13–20.
4. C. F. J. Pols, P. J. J. M. Dekkers, and M. J. de Vries, "Defining and assessing understandings of evidence with assessment rubric for physics inquiry: Towards integration of argumentation and inquiry," *Phys. Rev. Phys. Educ. Res.* **18**, 010111 (2022).
5. N. G. Holmes and C. Wieman, "Introductory physics labs: We can do better," *Phys. Today* **71**, 1–38 (2018).
6. C. F. J. Pols and P. J. J. M. Dekkers, "Redesigning a first year physics lab course on the basis of the procedural and conceptual knowledge in science model," *Phys. Rev. Phys. Educ. Res.* **20**, 010117 (2024).
7. C. F. J. Pols, "One setup for many experiments: enabling versatile student-led investigations," *Phys. Educ.* **59**, 015007 (2024).
8. C. F. J. Pols, "The Vitruvian man: An introduction to measurement and data analysis," *Phys. Teach.* **62**, 356–359 (2024).
9. B. R. Wilcox and H. Lewandowski, "Open-ended versus guided laboratory activities: Impact on students' beliefs about experimental physics," *Phys. Rev. Phys. Educ. Res.* **12**, 020132 (2016).
10. B. M. Zwickl et al., "Epistemology and expectations survey about experimental physics: Development and initial results," *Phys. Rev. Spec. Top. Phys. Educ. Res.* **10**, 010120 (2014).
11. D. Hodson, "A critical look at practical work in school science," *School Sci. Rev.* **70**, 33–40 (1990).
12. C. Wieman, "Introductory labs; what they don't, should, and can teach (and why)," in *APS April Meeting Abstracts*, Baltimore, MD, 2016.
13. M. Zion and R. Mendelovici, "Moving from structured to open inquiry: Challenges and limits," *Sci. Educ. Int.* **23**, 383–399 (2012).
14. J. Kozminski et al., "AAPT recommendations for the undergraduate physics laboratory curriculum," (AAPT, 2014).
15. V. K. Otero and D. E. Meltzer, "The past and future of physics education reform," *Phys. Today* **70**, 50–56 (2017).
16. G. Geschwind et al., "Development of a global landscape of undergraduate physics laboratory courses," *Phys. Rev. Phys. Educ. Res.* **20**, 020117 (2024).
17. S. Saxena, L. Panicker, and S. Gautam, "Rheology of Indian honey: Effect of temperature and gamma radiation," *Int. J. Food Sci.* **2014**, 935129 (2014).
18. C. F. J. Pols et al., "Students' report on an open inquiry," *Phys. Educ.* **56**, 063007 (2021).

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