

From laboratory methods to empirical research methodology: Evolving a bachelor's course for broader relevance

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Introduction

I often wonder how many of the students I teach in the BSc course “*Laboratory Methods in the Geosciences*” will eventually pursue careers involving practical lab work or roles where a solid understanding of laboratory practices is essential. Likely only a small fraction. As an elective course, it seems many students are drawn to it more for the opportunity to engage in hands-on activities – a welcome break from theory-heavy coursework – than as a step toward a specific career path. This raises an important question: how can I make the course relevant to a broader range of students and offer them more than just a temporary escape from textbooks – even for those who enroll for exactly that reason? My answer is to shift the course’s focus from simply teaching laboratory methods to teaching empirical research methodology – an approach that holds value across all scientific disciplines.

A student-designed soil sampling campaign

The term 'methods' refers to the specific procedures, techniques, or tools employed in research, while 'methodology' encompasses the overall strategy and justification for those methods. Empirical research methodology involves all steps, from posing a research question, formulating hypotheses, and designing a study, to collecting and analyzing samples, interpreting data, discussing initial hypotheses, and drawing conclusions.

A central element of transforming this course is allowing students to design the initial soil sampling campaign themselves, rather than assigning them sample locations based on a predefined experimental design. The rationale for this shift is to move from a *research-oriented* teaching model – where the teacher formulates research problems and suggests relevant methods – to a *research-based* teaching model, in which students formulate their own research questions and apply scientific methods to address them (Healey, 2005). This inquiry-driven, or problem-based teaching approach has been shown to promote deeper learning among students (Dolmans et al., 2016) and ensures that practical work does not become 'hands-on, minds-off' (Rienecker et al., 2015).

Here, I will explain how I implemented this exercise, analyze its outcomes, and propose future perspectives. The specific objectives of this intervention were: i) to equip students with the skills to make informed decisions about study design, ii) to provide practice in formulating research hypotheses, and iii) to foster ownership, independence, and curiosity among the students."

Course background

The course *Laboratory Methods in the Geosciences* (NIGB21024U) is a 7.5 ECTS BSc course that enrolls up to 24 students from the geography and geology programs. It introduces basic laboratory techniques used to determine the physical and chemical properties of soils in geoscience. In the first week, students participate in a field trip to collect soil samples, which they then analyze throughout the course.

At the core of the course is hands-on laboratory teaching. Students work in small groups of two to three on predefined, step-by-step ('cookbook') exercises. Each week, they attend two lab sessions lasting 3 hours and 1.5 hours, respectively. A weekly 2-hour lecture provides the scientific background for the analyses, while a 1.5-hour 'ReportLab' session offers an interactive space for discussing data, performing calculations, and receiving guidance on report writing. The final exam consists of a group report in IMRaD format, covering all laboratory exercises and simulating a scientific investigation, rather than being a portfolio of single-exercise lab reports.

The lab exercises are facilitated by three experienced and dedicated laboratory technicians. I am course responsible and teach all other sessions.

Implementation

Before the full-day field trip where soil sampling is conducted, students participate in two class-based teaching sessions. These sessions provide a brief introduction to the physical and chemical properties of soil, along with a crash course in soil sampling techniques and experimental design. This foundation prepares students to plan and design their own sampling campaign."

When planning the sampling campaign exercise, I had to balance the students' creative freedom with the practical constraints of the course –such as site access, sampling permissions, and transport time. I chose to designate a single area for sampling: an agricultural sloping field and its adjacent uncultivated surroundings, including a fallow field, a shrubbery, and an herbaceous field boundary. This site offered the opportunity to explore the effects of both land use and elevation.

While selecting the sampling site in advance does reduce the students' degrees of freedom, it helps them concentrate on the core of the exercise: defining a clear objective and designing a sampling strategy that aligns with it. In this sense, the limitation follows the principle of 'simplify to magnify' – narrowing the scope in order to deepen the learning experience.

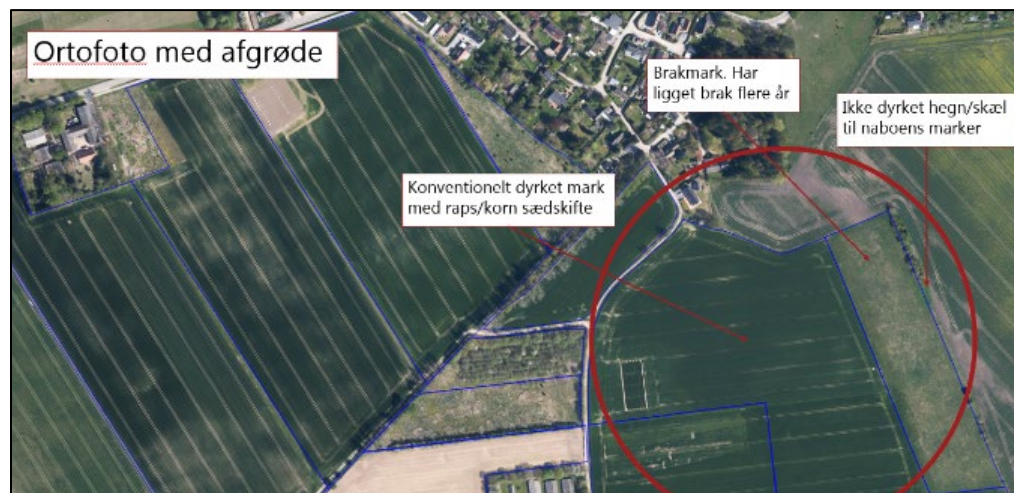




Fig. 1. Examples of information about the sampling area provided to students to support the design of their sampling campaign. Top: Orthophoto indicating land use categories. Bottom: Visual documentation of soil conditions at selected locations within the area.

Each laboratory group in the course has the capacity to analyze three soil samples. With eight groups, this allows for a total of 24 samples. To enable a meaningful investigation – one that could cover multiple soil depths and include replicates – I asked the students to collaboratively develop a single, shared experimental plan.

To support the planning process, I provided students with orthophotos of the area, a topographic map, and a set of photographs I had taken from various locations within the site – including images of soil I had dug up at those points (Fig. 1). Initially, students were asked to discuss potential soil investigations and sampling campaign designs within their laboratory groups. These group discussions then served as the basis for a plenary session, where the students collectively agreed on a single, shared sampling campaign.

A major challenge in this exercise is that students are expected to design a field campaign and formulate hypotheses with only a limited understanding of soil properties and the laboratory analyses they will later perform. To address this, I asked them to begin by focusing on the overarching aim of the study – for example, “What is the effect of land use on soil properties?” – and to propose a few initial hypotheses based on parameters they were already somewhat familiar with, such as “We hypothesize that the cultivated soil contains less carbon than the

uncultivated.” Students were then encouraged to refine and expand their hypotheses progressively, revisiting them before each laboratory exercise as their understanding deepened.

Outcome

The students actively engaged in the exercise, and all groups developed relevant study designs. They applied their newly acquired knowledge about different study designs and their applicability to various research questions. From both the group discussions and the questions posed to me, it was evident that they were curious about what could be achieved – even within the scope of a relatively small-scale study. However, the chosen sampling area was more relevant to the geography students than to the geology students. This was reflected in the course evaluations, with comments such as: *“There is a lack of geological content in the course”* and *“I do not feel that the course has enough content related to geology to be a geology elective.”*

Several students expressed frustration with the constraint imposed by the limited total number of samples. However, from my perspective, this sparked valuable discussions about the trade-offs between including replicates and expanding the number of treatments – highlighting a key challenge in experimental design. Importantly, it helped students realize that such considerations are not unique to a lab course, but central to research planning in general.

In their final reports, all student groups formulated hypotheses for each laboratory exercise and referred to them in their discussions. However, many of these hypotheses were either not clearly aligned with the overall research aim or lacked relevance, suggesting a need for further support in integrating hypothesis formulation with broader study objectives.

Own reflections and future perspectives

It was with great pleasure that I reviewed this year’s course reports. Overall, the quality has improved significantly compared to last year. This progress is not solely attributable to the sampling campaign design exercise but can also be credited to the newly introduced ReportLab

sessions and the updated instructions for the report. However, I believe the exercise itself plays a key role in framing the reports.

Most reports were centered around the overall aim of the study, as seen in formulations like this example from an introduction: “*Can variations in the analyzed soil samples be explained by differences in land use or topography?*” Additionally, some students independently chose to emphasize specific aspects of the study. For instance, one group submitted a report titled: “*Soil properties and carbon sequestration in Danish arable land under cultivation or left fallow.*”

Despite my emphasis on including replicates in the study, I still find that many students struggle with understanding the sources of variation. This includes factors such as soil heterogeneity and the precision of laboratory measurements, which can be influenced by both instrumental limitations and human factors."

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