INQUIRY & INVESTIGATION

Students Dig Deep in the Mystery Soil Lab: A Playful, Inquiry-Based Soil Laboratory Project

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Abstract

The Mystery Soil Lab, a playful, inquiry-based laboratory project, is designed to develop students' skills of inquiry, soil analysis, and synthesis of foundational concepts in soil science and soil ecology. Student groups are given the charge to explore and identify a "Mystery Soil" collected from a unique landscape within a 10-mile radius of our university by determining its soil formation and development history, associated plant community, and official taxonomic designation. Student groups have 4 consecutive weeks to conduct the lab assignment using observation and laboratory techniques. After 4 weeks, students present their findings by describing their process of inquiry, soil analysis results, and the conceptual reasoning behind their hypotheses using key course concepts. This project enhances students' abilities to conduct iterative science using the scientific method, improves foundational knowledge of soil properties and processes, and builds students' skills and confidence for a subsequent, independent soil ecology research project later in the semester.

Key Words: *Inquiry-based activity; soil ecology; soil processes; soil physical properties; soil science.*

Teachers may be challenged to effectively teach soil science and soil ecology because soil is inherently opaque and difficult to study; the majority of soil organisms are microscopic and concealed, and observing them requires specialized instrumentation and skills that many schools and instructors lack. Further, the laboratory setting, procedures, and instrumentation used to evaluate many soil properties can intimidate some students. Because science courses at many levels still emphasize aboveground ecology, even students who are interested in earth science and ecology may not be aware that soil contains fascinating living creatures that are critically important in ecosystem functioning. Nevertheless, an understanding of soil physical, chemical, and ecological properties is increasingly important as environmental scientists better understand how soil properties and soil organisms affect plant communities, ecosystem functioning, and global change (Wardle et al., 2004; Bardgett & Wardle, 2010).

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With creative lessons and minimal technical instrumentation, teachers can make soil interesting and exciting, and, in turn, give students an entirely new way of looking at the world. In addition to their critical roles in global ecosystem functioning (Wardle et al., 2004; Bardgett & Wardle, 2010), soils also affect our lives in practical ways that can be emphasized to inspire students' interest and develop their skills. For example, community planning decisions are based, in part, on whether an area has the appropriate soil texture and structure to support development, and soil texture, structure, permeability, and nutrient cycling influence whether local waterways will be pristine or polluted (Addiscott et al., 1991; Kay et al., 2009). The activity of soil organisms such as plant-parasitic nematodes, earthworms, and mycorrhizal fungi affect the productivity of forests (Bohlen et al., 2004) and important commercial crops (Sherwood & Uphoff, 2000; Stocking, 2003; Haney et al., 2010), and hot spots of nutrients in ant and termite nests can enhance plant growth (Folgarait, 1998; Lenoir et al., 2001). Encouraging students to make these connections motivates learning and builds foundational knowledge for exploring more complex concepts such as the effects of soil properties and processes on plant communities, carbon sequestration, nitrogen deposition, and global environmental change.

The learning objectives of this soil laboratory activity are for students to

(1) apply foundational concepts in soil physics, chemistry, and ecology to assess, describe, and explain a given "Mystery Soil";
(2) accurately describe and explain the unique soil properties that characterize the geographic region in which they live;
(3) determine and employ the appropriate techniques for analyzing specific soil properties;
(4) apply the scientific method to the process of scientific inquiry;
(5) analyze and interpret quantitative and qualitative scientific data; and

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(6) exemplify increased interest in and motivation to learn about soils.

○ Mystery Soil Lab Activity

The Mystery Soil Lab is a 4-week laboratory project developed for a graduate-level soil ecology course, but the project can be readily adapted for high school and undergraduate students. Before the semester begins, I collect bulk soils from various landscape positions near campus, including agricultural land, undisturbed forest, disturbed forest, and wetland. On the first day of class, students are divided into groups of four and each group is given a bucket of bulk "Mystery Soil" with this challenge: Using careful observation and analysis, determine the development history, plant community, landscape position, and taxonomic designation of your Mystery Soil (Appendix 1). I set a playful tone by dividing groups according to "mystery soil images," photos of mycorrhizal fungi, a predatory loop fungus, nodules of *Rhizobia* bacteria, and a nitrogen atom; students pick "mystery soil images" from a hat and group with other students who picked the same image. After establishing groups, each Mystery Soil Lab group occupies a laboratory station where I have set up the group's Mystery Soil and various scientific equipment (Appendix 2), instructions for using the instrumentation, and a list of possible soil properties they may explore (Appendix 3). I also provide students with a 30-cm-deep soil core collected from the site of their Mystery Soil so that they can observe its horizonation and development history. Students are given more than 1 hour during the first class period to explore and experiment with their soils using a set of guiding questions (Table 1). Students have 4 weeks to study their soils using whatever approaches, techniques, and instrumentation they wish, including the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) Cheshire County Soil Survey (1989). While introducing the project, I stress the iterative nature of the scientific method and create a tone of playfulness by emphasizing suspense and open-ended inquiry.

After the introductory class period, students are given 1 to 1.5 hours of class time each week to work on their projects with my guidance; all other work is done outside of class (Figures 1 and 2).

Table 1. Research questions to guide students in their Mystery Soil Lab inquiry.

Questions	Possible Approaches to Experimentation	Learning Areas
Which soil properties are most relevant for classifying your soil and locating it on the surrounding landscape?	Review table 15 (Physical and Chemical Properties of the Soils) in the appropriate County Soil Survey Review literature and class notes for information about important distinguishing soil properties	Soil physical, chemical, and biological properties that define and distinguish soil taxa Differences in various soil properties among agricultural, forested, and wetland soils, and among soils under different land uses
What initial observations of your soil can help you narrow down your soil series or the landscape position of your soil right off the bat?	Observe soil horizonation in the soil core provided (i.e., O, A, [E], B, C horizons) Observe soil color, smell, and evidence of specific vegetation types (e.g., conifer needles, hay, undecomposed plant material)	Soil development and classification as indicated by horizonation and development Soil formation processes and movement of soil around the landscape Differences in soil properties among agricultural, forested, and wetland soils, and among soils under different land uses
What are some soil physical and chemical properties that may help you identify your soil and its position on the landscape?	Measure soil pH, organic C, conductivity, texture, porosity, moisture, bulk density, and structure	Soil physical and chemical properties and their relevance Differences in soil physical and chemical properties among agricultural, forested, and wetland soils, and among soils under different land uses
What organisms (or evidence of organisms) do you observe in your soil, and what do they tell you about the identity and landscape position of your Mystery Soil?	Observe soil organisms (e.g., microbes such as fungi and actinomycetes, insects, worms, protozoans) Observe evidence of organisms (e.g., nests, middens, exoskeletons, fungal decay)	Soil organisms and soil food-web constituents Differences in soil organismal constituents and soil food webs among agricultural, forested, and wetland soils, and among soils under different land uses

Figure 1. Graduate students in the Environmental Studies Department at Antioch University New England working on their Mystery Soil Lab assignment. This student group fashioned its own Tullgren funnels for microarthropod and nematode extraction. (Students from front to back: Britta Dempsey, Barbara Beers, and Valerie Snowdon.)

During each class period in which students have time to work on their projects, I help them frame the most relevant questions to ask about their soils, how to decide which soil properties to emphasize on the basis of information provided in the County Soil Surveys, and how to operate instrumentation with which they are unfamiliar. Initially, students tend to underutilize the County Soil Survey and need to be directed to do so; table 15 (Physical and Chemical Properties of the Soils) of the survey is particularly helpful because it summarizes specific soil properties that the USDA uses to classify soils.

During the 4 weeks that students are working on their projects, I devote nonlab class time to delivering foundational soil science concepts such as soil formation and development, soil taxonomy, global soil distribution, and soil as a habitat for organisms. Specific content includes soil formation, the (cl, o, r, p, t) and bioturbation models of soil development (Johnson et al., 2005), texture, structure, porosity, bulk density, the gaseous environment, nutrient and organic-matter cycling, and soil food webs. Each week that students are presented with more conceptual content, they gain a deeper understanding of soil that guides their ongoing exploration of their Mystery Soils. Common soil properties that students measure in their Mystery Soils include texture, aggregation (structure), horizonation, pH, bulk density, porosity, total organic carbon, color, moisture, and invertebrate community structure (e.g., insects and worms).

After 4 weeks of exploring their Mystery Soil, each group gives a 25-minute presentation in which they describe their process of discovery, guess the taxonomic grouping (soil series) from the County Soil Survey, and defend their hypotheses. Students cannot use computers for their final presentations; instead, they must express their scientific process and conclusions in some other manner, and they must incorporate a sample of their Mystery Soil into the presentation somehow (Appendix 1).

Students' self-confidence increases perceptibly over the 4 weeks of this project, and the tone of the final presentations is fun, anticipatory, and suspenseful. Students are excited to finally describe their deduction process and check their hypotheses about their Mystery Soil. Students frequently identify the correct soil series their Mystery Soil represents and successfully guess what plant communities and land uses their soils support; other groups come very close. Discussion after each presentation is an opportunity to engage all students in a generative, safe evaluation of each group's work.

Figure 2. Graduate students in the Environmental Studies Department at Antioch University New England working on their Mystery Soil Lab assignment. Here, a student group hunts for soil insects while setting up CO_2 chambers for soil respiration measurements. (Students from front to back: Magdalena Vinson, Meghan Powell, and Megan Boyle.)

Together we identify the strengths and weaknesses of the groups' experimental approaches and scientific reasoning. In those rich discussions, I correct misperceptions and reiterate foundational course concepts, and students themselves often help one another make important conceptual connections.

My evaluation of student work is based on the level of sophistication of connections that students make among foundational soil properties and processes. The group that effectively explains an iterative scientific reasoning process using data and connections among key course concepts is considered a high-achieving group. For example, one student group, observing no visible horizonation in their soil core, hypothesized that their Mystery Soil was collected from an agricultural setting where tillage was used. To test this hypothesis, the group measured soil pH and found that it was much higher than is typical for forest soils in this region of New Hampshire, which gave them confidence that their soil was indeed from a farm that was regularly limed. The group then used the County Soil Survey to identify agricultural soil parcels within a 10-mile radius of our university. They used table 15 in the survey to learn that bulk density and total organic carbon were characteristics that varied among the parcels, so they conducted bulk density and carbon analyses, compared their results with data in table 15, and correctly deduced that their Mystery Soil originated from a specific local organic farm.

In addition to providing students with an opportunity to delve deeply into an unknown soil using inquiry-based techniques, another benefit of this lab assignment is that students gain skills and confidence for conducting a subsequent, independent research project later in the semester. The independent research project intimidates many students, but they regularly express that the Mystery Soil Lab primes them for that project by requiring them to engage in the scientific method, become familiar with practical soil analysis and data analysis skills, and make connections among complex soil science and soil ecology concepts.

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Appendix 1. Mystery Soil Lab assignment given to students on the first day of class in the graduate-level soil ecology course at Antioch University New England. The assignment can be readily modified for high school and undergraduate students.

The Charge

Using careful observation and analysis, determine the development history, plant community, landscape position, and taxonomic designation of your Mystery Soil.

To meet your charge, your group should characterize physical, chemical, and/or biological features of your Mystery Soil that you think will best help you to solve the mystery!

Suggestions for how to proceed:

To address your charge, you and your lab group will have 3 in-class lab periods (1-1.5 hours each). Use time and any instrumentation provided in class (or anything you can invent) over these 3 weeks, as well as any time needed outside class, to address and synthesize the following questions:

1. What are some important **physical, chemical, and biological** properties of your soil? See the Guiding Research Questions for ideas. Choose any properties you think will help you identify and locate your soil, and measure them however you want – it's up to you! Be creative! Use any resources at your disposal to develop techniques.
2. Given what you discovered in question 1, where might your soil be found on the NH **landscape**? Is it a forest soil, an agricultural soil, a wetland soil? Did it come from a slope, or a depressional area? What plants and animals (both aboveground and belowground) might fare well in your soil? What type of land use is your soil under? Answer these questions to hypothesize and defend which USDA **soil series** your soil represents, and where, specifically, your soil was collected within 10 miles of Keene.
3. Given your evaluation of questions 1 and 2, how do you think your soil **formed** (i.e., how did it get there and what changes has it undergone?), and how might it develop on or get moved around the landscape over time?

In your final presentation, detail your process of discovery, including your iterative process of hypothesis generation and testing, and defend your final hypothesis about the soil series that your Mystery Soil represents. *Presentations may not be in the form of PowerPoint; instead, they must be three-dimensional and interactive in some way (e.g., diorama, collage, poster, group activity, other ideas?), and a sample of your soil must be incorporated somehow*.

Appendix 2. List of materials to include at each Mystery Soil laboratory station on the first day of the activity. The instructor should provide additional materials and instrumentation upon student request for additional soil assays over the 4-week activity.

- Bucket of bulk Mystery Soil (different soil at each station)
- 20-cm coil core collected at site of Mystery Soil
- One dissecting microscope
- One compound microscope
- Petri dishes
- Soil sieves (4 mm, 2 mm)
- Microscope slides and cover slips
- Squirt bottle with distilled water
- Immersion oil
- Kimwipes
- Four dissecting probes
- Four tweezers
- One soil pH kit
- One soil texture kit
- Munsell soil color chart
- USDA/SCS County Soil Survey
- List of soil properties students may explore
- Instructions for all soil assays

Appendix 3. List of soil properties that students may explore to determine the taxonomic designation and landscape position of their Mystery Soils.

Below are lists of the soil parameters that you can measure using resources that we currently have, followed in parentheses by the equipment we have to support the work.

Physical & Biogeochemical Features

Total soil C (muffle furnace)

pH (pH meter)

Temperature (thermometer)

Texture (soil texture analysis – hydrometer method or soil texture kit)

Aggregation/structure (soil sieves and drying oven)

Bulk density (soup cans and drying oven)

Soil type and development using characterization of horizonation (soil core)

Moisture and field moisture capacity (drying oven)

Ecological Features

CO_2 respiration, a proxy for soil organismal respiration, primarily microbial respiration (LabPro infrared gas analyzer)

Protozoans (we'll need to find a good extraction method for this assay, but it might be possible!)

Macroarthropods (naked eye)

Microarthropods (Tullgren apparatus using Berlese funnels)

Nematodes (Tullgren apparatus using Berlese funnels)

Earthworm and/or redworm density, casting, and distribution (naked eye)

Other ideas?