Soil Colour as Physics — Detailed Lesson Plan: Classes 5–8

Earth Pigments from the Soils of Müllrose

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Earth Pigments from the Soils of Müllrose

Erdpuls Müllrose — Living Laboratory & Makerspace Garden

Part of the "Brücken bauen durch Boden — 13 Questions to the Soil" project

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Overview

Target group	Classes 5–8 (ages 10–14)
Number of units	6 × 45 minutes
Total time	270 minutes (~4.5 hours)
Location	Unit 1 outdoors / farm sites; Units 2–6 in Erdpuls Zone B (Boden-Labor) or school lab
4A focus	All four stages; Acknowledgment as the primary new cognitive challenge
Cognitive mode	Observational-experimental: noticing, measuring, comparing, explaining
Core question	*"Why does soil colour change — and what does it tell us?"*
Key methods	Dry and wet grinding, sieve analysis, wet-dry experiment, binder comparison, introduction to colour measurement
Safety	FFP2 masks and goggles required during dry grinding and sieving
Output	Class pigment set from the three farms; wet-dry diagram; binder comparison chart; personal colour journal

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Teacher Notes for This Grade Band

Students at this age are beginning to enjoy the satisfaction of measuring things and finding patterns. They are ready to move from "I noticed that…" to "I can show that…" — and that shift is the heart of this unit.

The key transition for Classes 5–8 is from **direct sensory observation** to **structured experiment**. The wet-dry experiment and the binder comparison are the backbone of the unit — both give students something measurable to hold onto, while remaining grounded in direct physical work with the material.

Physics concepts introduced at this level: - Light scattering (informal, phenomenological) — why wet soil is darker - Particle size effects — why ground pigment covers better - Pigment vs. dye distinction - Binder as colloid — how paint holds together

What you deliberately hold back: - Mie scattering formula (that is for Grades 9–12) - Ligand field theory (Grades 9–12) - CIELAB colour space (Grades 9–12) - Statistical correlation (Grades 9–12)

The concepts introduced here are the scaffolding for what comes later. Plant the terms; do not rush the full explanation.

Cross-curricular connections: Physics (light, scattering), Biology (soil organisms, organic matter), Chemistry (iron compounds — informal), Geography (Brandenburg soil types), Art (colour pigments in art history), Mathematics (graphing, percentages for sieve fractions).

Unit 1 — Fieldwork: Collecting Evidence from Three Farms

Duration: 45 minutes (or 90 minutes if combined with a farm visit — recommended) **Location:** Partner farm sites and/or Erdpuls field collection points **4A-Pathway stage:** Awareness **Materials needed:** Sample bags (200–500 g each, labelled), site description form (one per site), Munsell Soil Color Chart or photographic reference, pH indicator strips, spade, camera or phone, GPS (phone)

Learning Objectives

By the end of this unit, students will be able to: - Collect soil samples systematically using a site description protocol - Compare soil colour using the Munsell system or photographic reference - Record site parameters (vegetation, moisture, depth) - Describe at least two visible differences between the soils of the three farms

Unit Plan

Opening (5 min): At the first farm site, gather the group. Pose the question: *"Do farms with different approaches to growing food have different soils? How would we find out?"*

Let students respond. Establish the day's task: collect samples from at least three sites (the three partner farms, or contrasting sites if farm visits are not possible), describe what they observe, and bring the evidence back to the lab.

Direct Experience (10 min): At the first site, expose a small soil profile using a spade — 30 cm deep is enough. Ask students to observe before touching: - *"What colour is the surface soil?"* - *"Does the colour change with depth?"* - *"Does it smell of anything?"* - *"Is there visible life — roots, worms, fungi?"*

Then invite students to handle a pinch of soil. Ask them to estimate the texture (rub between thumb and forefinger: gritty = sand-dominated, smooth-plastic = clay, silky = silt).

Investigation (20 min): Students work in pairs to complete the site description form for each site: 1. Photograph the profile with a scale bar (a pen or ruler works). 2. Record the colour wet using the Munsell chart (or describe in your own words, recording as carefully as possible). 3. Record the colour dry (take a small amount, spread on the back of the form, and let it dry in the air — takes about 5 minutes in dry weather). 4. Test pH with the indicator strip. 5. Record GPS coordinates. 6. Collect the sample (200–500 g) in a labelled bag: site name, farm, depth (0–5 cm, 10–15 cm, 25–30 cm), date, class.

Repeat at each collection site.

Synthesis (8 min): Back together, compare initial observations across sites: - Which farm had the darkest surface soil? - Which had the most obvious colour contrast between surface and deeper layers? - Did pH differ between farms?

Record predictions: *"I predict that the darkest soil will make the most intense pigment because…"*

Closing (2 min): Pack and label all samples. Preview: *"In the next session we will process these samples in the lab and find out if the colours survive the drying and grinding."*

Unit 2 — Laboratory Processing: Drying, Sorting, and the Wet Route

Duration: 45 minutes **Location:** Erdpuls Zone B or school laboratory **4A-Pathway stage:** Awareness → Acknowledgment **Materials needed:** Collected soil samples (from Unit 1 or pre-prepared by teacher), oven or dehydrator (set to 50°C), shallow trays, sieves (500/250/100/63 µm), balance (1 mg), dishes, FFP2 masks, safety goggles, mortar and pestle; also water and glass plates for the wet route

Learning Objectives

By the end of this unit, students will be able to: - Prepare soil for pigment production using both the dry and wet routes - Explain why the drying temperature must not exceed 50°C - Conduct a basic sieve analysis and record grain size fractions - Follow the dust safety protocol

Unit Plan

Opening (8 min): Demonstrate the two processing routes side by side. Place a sample of pre-dried soil on the table and a sample of clay-rich wet soil in a jar of water.

Ask: *"Why do we have two different routes? What might determine which one to use?"*

Introduce the safety protocol: *"Any time we grind or sieve dry soil, there can be very fine dust in the air. This dust is not immediately dangerous, but with regular exposure it can harm the lungs — that is called silicosis. So: FFP2 mask and goggles on before we grind, windows open, and we work carefully."*

Have all students fit masks and goggles.

Direct Experience + Investigation (28 min):

Group A — Dry route (for sandy or loamy samples): 1. Place pre-dried sample in mortar. Grind 5 minutes, then sieve. 2. Weigh each sieve fraction: record as grams and as percentage of total mass. 3. Plot a simple bar chart: grain size fraction vs. mass. 4. Compare the colour of each fraction — does colour intensity differ by size?

Group B — Wet route (for clay-rich or humus-rich samples): 1. Stir sample into water in a beaker — leave to settle 5 minutes. 2. Sand sinks first; note the clear water forming above the sediment. 3. Pour off the upper cloudy suspension (the fine clay fraction) onto glass plates. 4. Allow to dry (or use a warm surface or low oven). 5. Observe the thin clay film left on the glass — lift it when dry and observe the colour.

Bring both groups together at the halfway point to compare approaches and observations.

Synthesis (7 min): Discuss: **-** *"Which route produced the more intense colour so far?"* **-** *"Why does the wet route separate particle sizes automatically?"* (Gravity settles heavier particles faster — Stokes' Law, introduced informally: "bigger things fall faster through water.") **-** *"Why must we not heat the soil above 50°C?"* (Goethite, the yellow-brown mineral, transforms into haematite above ~250°C and turns redder — but even 100°C can begin to affect moisture-bound minerals; staying at 50°C is safe.)

Closing (2 min): Record sieve fraction data in lab book. Samples that still need drying go into the oven for the next session. Preview: *"Next we will grind more carefully and do our first real experiment — does grinding time change the colour?"*

Unit 3 — Grinding Experiment: Does Particle Size Change Colour?

Duration: 45 minutes **Location:** Erdpuls Zone B or school laboratory **4A-Pathway stage:** Acknowledgment **Materials needed:** Pre-dried and pre-sieved soil samples, mortars and pestles (1 per pair), sieves, balance, watercolour paper, brushes, water in a small dish, timer, FFP2 masks, safety goggles; optional: smartphone with Spectroid or colour analysis app

Learning Objectives

By the end of this unit, students will be able to: - Conduct the grinding-time experiment systematically - Record quantitative observations (sieve fraction, colour description) - Describe the relationship between particle size and colour intensity - Plot the data as a simple graph

Unit Plan

Opening (5 min): Review the previous unit's sieve data. Show the colour difference between the > 500 µm fraction and the < 63 µm fraction if these are available from Unit 2. Pose the question: *"If we grind the same soil for longer, does the colour become more intense? Let us test it."*

Direct Experience (5 min): Masks and goggles on. Give each pair the same soil sample (brown earth or podzol ortstein — a strongly coloured sample works best for this experiment).

Investigation (28 min): Each pair conducts the following experiment in sequence:

Step	Action	Record
0 min (raw)	Apply unground soil paste (add a few drops of water) to paper.	Colour description + photo
After 5 min grinding	Sieve → record fraction passing 100 µm. Apply paste to paper.	Colour description + photo
After 15 min grinding	Sieve → record fraction. Apply paste.	Colour description + photo
After 30 min grinding	Sieve → record fraction. Apply paste.	Colour description + photo

For each sample, note: - Visual colour saturation (1–5 scale, class-agreed rubric) - Covering power: does it cover the paper or look thin? - Texture feel: gritty, smooth, or silky?

If Spectroid or a colour analysis app is available, photograph each swatch and record the RGB value or the dominant reflected wavelength.

Synthesis (5 min): Students plot their data: x-axis = grinding time, y-axis = visual colour saturation score (or measured value). Describe the shape of the curve: - Is it a straight line? - Does it reach a peak and then level off? - At what point does covering power begin to drop even as saturation increases?

Introduce the concept: *"There is an optimal particle size for pigments — typically 5–50 µm. Below that, pigment particles become so small that they behave more like dye and stop covering properly."*

Closing (2 min): Record graph in lab book. Journal: one sentence describing the relationship you found.

Unit 4 — The Wet-Dry Experiment: Why Does Paint Lighten as It Dries?

Duration: 45 minutes **Location:** Classroom or laboratory **4A-Pathway stage:** Acknowledgment → Attitude **Materials needed:** Ground pigment paste from Unit 3, watercolour paper, brushes, water, phone camera for documentation, timer, colour comparison chart or app

Learning Objectives

By the end of this unit, students will be able to: - Measure the colour change of a pigment as it dries over time - Describe the physical mechanism of Mie scattering in simple terms - Connect the wet-dry effect in paint to the wet-dry effect observed outdoors in Unit 1

Unit Plan

Opening (5 min): Ask: *"In Unit 1 we noticed that wet soil looks darker than dry soil. We said water fills the air spaces and stops light bouncing around. Now let's watch the same thing happen in paint as it dries."*

Direct Experience (5 min): Students apply a thick swatch of wet pigment paste to watercolour paper. Take a photograph immediately.

Investigation (25 min): Students monitor the drying patch every 5 minutes, photographing each time and recording the RGB value using a phone app (or describing brightness on a 1–5 scale).

While waiting between observations, students complete the following: 1. Draw a diagram showing wet soil versus dry soil at the particle level (air pores, water in pores). What does light do in each case? 2. Make a rough graph: brightness vs. time. What shape is the curve?

Introduce the term **Mie scattering** formally: *"When light hits a very small particle — like a pigment grain in the air — it scatters in all directions, much more strongly than large particles would. Air has a lower refractive index than any liquid binder. So when the binder evaporates and air takes its place around each pigment grain, the overall scattering increases — and more scattering means more reflected white light, which makes the colour look lighter."*

Grades 7–8 can note this. Grades 5–6 can hold the concept informally — *"more air = more bouncing = lighter."*

Synthesis (7 min): Compare graphs across the class. Key questions: - *"Did all soils lighten by the same amount?"* - *"Which binder produced the darkest dry colour? Why might the refractive index of the binder matter?"* - *"How does this connect to what we saw in the field?"*

Closing (3 min): Journal: the wet-dry diagram. Label the air pores, water, and pigment particles. Add one sentence of explanation.

Unit 5 — Binder Comparison: Five Ways to Hold a Colour

Duration: 45 minutes **Location:** Laboratory or classroom **4A-Pathway stage:** Acknowledgment → Action **Materials needed:** Ground pigment paste (from Units 2–3), five binders in labelled containers: water only, linseed oil, gum arabic solution (10%), egg yolk diluted 1:1 with water, casein (from quark, dissolved); watercolour paper strips, flat brushes (1 per binder), timer, ruler for test strips

Learning Objectives

By the end of this unit, students will be able to: - Apply five binders to the same pigment and describe the physical differences - Measure or estimate drying time, colour shift on drying, and covering power for each binder - Identify which binder would be appropriate for which use case - Describe paint as a colloidal suspension

Unit Plan

Opening (5 min): *"All paint is two things: pigment and binder. We have been making the pigment. Now we compare the binders."* Introduce the five binders briefly — what they are made of (materials students can mostly name: egg, oil, plant gum, milk protein, water). Ask: *"Which one do you think will dry fastest? Which will last longest?"*

Direct Experience (5 min): Students set up their test card: a piece of watercolour paper divided into five labelled columns. Apply a test stripe of each binder+pigment mix to the card.

Investigation (25 min): Students observe and record over the full investigation period:

Binder	Mixing notes	Drying time	Colour shift on drying	Covering power (1–5)	Texture when dry
Water only	Mix paste directly				
Linseed oil	Mix paste into oil				
Gum arabic (10%)	Mix paste into solution				
Egg yolk + water	Mix paste into diluted yolk				
Casein	Mix paste into casein solution				

While waiting for drying, students discuss: - *"Why does linseed oil dry by absorbing oxygen from the air, not by evaporation? How is that different from water-based binders?"* - *"The egg yolk is an emulsion — it contains both water and fat. How might that affect the way it holds the pigment?"*

After 24 hours (noted in the next session or reported back by the teacher): perform the tape peel test (apply tape to the dried test strip, remove firmly, observe adhesion) and the droplet test (one drop of water on each strip — does it bead or absorb?).

Synthesis (8 min): Share results as a class. Compile a comparison table on the board. Ask: - *"Which binder would you choose for outdoor use?"* - *"Which would you choose if you needed the paint to dry in 20 minutes?"* - *"Which binder do you think the Erdpuls exhibition paintings should use?"*

Brief historical context: Tempera (egg yolk) was used in mediaeval panel painting; linseed oil became dominant in Europe from the 15th century (van Eyck); gum arabic is the basis of watercolour and gouache. Earth pigments were used in all three traditions.

Closing (2 min): Lab notebook: complete the binder comparison table. One sentence: your recommendation and reason.

Unit 6 — Pigment Production and the Colour Library

Duration: 45 minutes **Location:** Erdpuls Zone B or classroom **4A-Pathway stage:** Action **Materials needed:** All processed pigments, chosen binder (class decision from Unit 5), glass jars with lids, labels, watercolour paper for final artwork, brushes, large white card for the class colour palette

Learning Objectives

By the end of this unit, students will be able to: - Produce a sufficient quantity of finished pigment for the Erdpuls WP4 collection - Label the pigment jar with complete provenance information - Discuss the connection between the scientific work and the artistic output - Describe what the class's colour library contributes to the "Brücken bauen durch Boden" project

Unit Plan

Opening (7 min): Bring out all the pigments produced over the unit — sorted by farm source. Stand back and look at the range together.

Say: *"We started this unit by asking: does the way a farmer treats the soil affect its colour? What do you think now? Does our pigment collection give us any evidence?"*

Allow a genuine discussion. Do not rush to a conclusion — the question should remain open.

Introduce the task: *"Today each of you will fill a jar with the best pigment from your work, label it with its full story, and make a final painting."*

Investigation / Making (28 min):

Part 1 — Final pigment production (15 min): Students select their strongest pigment (usually the most finely ground batch). Mix with the chosen binder. Fill a labelled glass jar. Label format: *[Site name] / [Farm name] / [Depth] / [Date] / [Class] / [Student name]*

Part 2 — Final colour painting (13 min): Students use the three farm pigments together to create one final painting on watercolour paper. The subject is free, but students are asked to use the colour of each farm's soil intentionally — not mixed together randomly, but placed where that colour "belongs" in their image.

Synthesis (8 min): Lay out all the labelled jars and all the final paintings. Walk around the display together.

Ask: *"If a visitor to the exhibition saw this collection and asked you what you did here — what would you tell them?"*

Invite two or three students to answer in a few sentences. This is the beginning of the ability to communicate scientific findings to a non-specialist audience — a key BNE competency.

Optional: photograph the jar collection and paintings for the Erdpuls project archive. If a farm partner can visit this session, invite them to see the results.

Closing (2 min): Final journal entry: one paragraph describing what you learned, one question you still have, and one thing you would investigate if you could continue.

Assessment for Classes 5–8

Lab Book / Journal

The lab book produced across Units 2–6 is the primary assessment document. It should contain: - Site description form from Unit 1 - Sieve fraction data and bar chart (Unit 2) - Grinding-time experiment table and graph (Unit 3) - Wet-dry diagram with explanation (Unit 4) - Binder comparison table with recommendation (Unit 5) - Final labelled jar photograph and one-paragraph reflection (Unit 6)

Assessment Criteria

Criterion	Indicator
Scientific observation	Records what is observed, not just what is expected; uses specific colour language
Experimental method	Sets up a fair test; keeps one variable constant while changing another

Criterion	Indicator
Data recording	Tables and graphs are complete, labelled, and readable
Explanation	Connects observation to physical concept (scattering, particle size, binder)
Communication	Final paragraph is clear and addresses a non-specialist reader

Exit Question (optional, verbal or written)

"Why does wet soil look darker than dry soil?" A satisfactory answer for Grade 5–6: "Because water fills the air spaces and there is less light bouncing around." A strong answer for Grade 7–8: "Because the air-mineral interfaces that cause Mie scattering are replaced by water, which has a higher refractive index and causes less scattering, so the soil looks darker."

Materials Summary for Classes 5–8

Unit	Key materials
1	Sample bags, site description forms, Munsell chart, pH strips, spade, camera
2	Soil samples, oven (50°C), sieves, balance, dishes, mortars, FFP2 masks, goggles
3	Pre-dried samples, mortars, sieves, balance, watercolour paper, brushes, timer
4	Ground pigment paste, watercolour paper, brushes, timer, phone camera
5	Ground pigment, 5 binders (water / oil / gum arabic / egg yolk / casein), test cards
6	All pigments, binder, glass jars, labels, watercolour paper, brushes

FFP2 masks and safety goggles required in Units 2 and 3 during dry grinding and sieving.

Further Reading (for teachers)

- Toland, A., Noller, J.S. & Wessolek, G. (Eds.) (2019): *Field to Palette — Dialogues on Soil and Art in the Anthropocene.* CRC Press. [Core reference for the science-art pedagogy of this unit; includes fieldwork methodologies and soil-as-knowledge frameworks]
- Feller, C., Landa, E.R., Toland, A. & Wessolek, G. (2015): Case studies of soil in art. *SOIL* 1: 543–559. DOI: 10.5194/soil-1-543-2015 [Open access; good background reading for Units 1 and 6. Free download]

- Schwertmann, U. & Cornell, R.M. (2000): *Iron Oxides in the Laboratory.* Wiley-VCH. [Technical background on iron oxides, particle size, and colour — underpins Units 3 and 4]
- Blume, H.-P. et al. (2018): *Scheffer/Schachtschabel: Lehrbuch der Bodenkunde.* 17th ed. Springer Spektrum. [Soil formation, texture, and classification — background for Unit 1 site description and Munsell colour work]
- Doerner, M. / Hoppe, T. (2011): *Malmaterial und seine Verwendung im Bilde.* 24th ed. Maier, Ravensburg. [Background for Unit 5 binder comparison. In German]

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