A POLARIZING VIEW

SEDIMENTARY METAMORPHIC IGNEOUS

An unconventional use of microscopes for teaching high school geology and physics

RACHEL BERNARD AND COLLEEN HENEGAN

For many students, the first—and sometimes only—chance to look through a microscope is in high school biology class, where they observe plant and animal cells up close. Even in college, few students use a microscope for a subject other than biology. Thus, it can be a surprise to learn that microscopes are a primary tool used to understand the chemical and physical properties of rocks (e.g., Gunter 2004, Reinhardt 2004).

Petrography—the use of microscopes to study optical properties of rocks and minerals—is a cornerstone of a geoscience education. *Polarized-light microscopes* show thin, polished rock slices in a beautiful and informative light. Though such microscopes are expensive, a standard high school microscope can be easily and inexpensively altered so it can identify fascinating features in rocks.

This article describes a lesson plan developed for an AP environmental science (APES) class that can be adapted for any course that addresses the rock cycle. Parts of the lab could also be used in a physics class that addresses light waves.

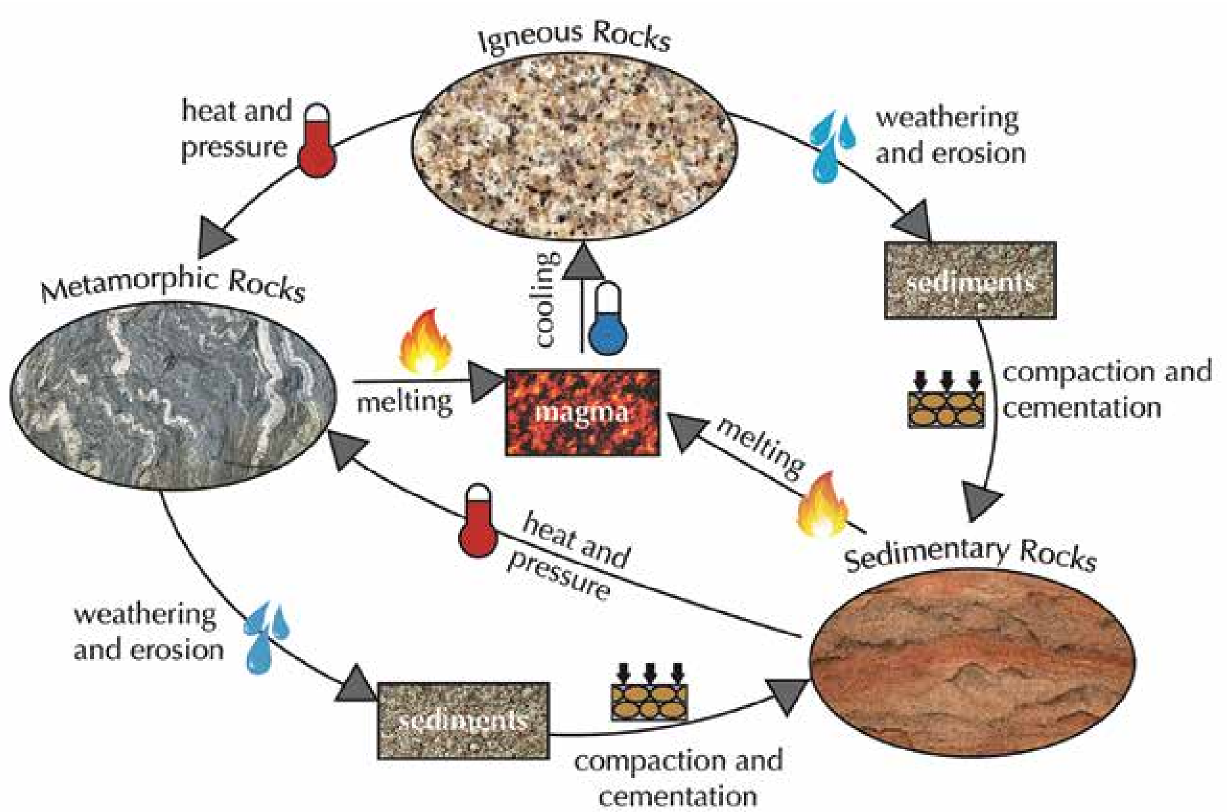
Concepts covered by the lesson

The concept of the rock cycle is that sedimentary, metamorphic, and igneous rocks can be transformed into one another through fundamental Earth-system processes (Figure 1). This is taught at various grade levels (see *Next Generations Science*

FIGURE 1

Illustration of the rock cycle.

The rock cycle illustrates the processes that transform igneous, metamorphic, and sedimentary rocks into each other. Microscopic observations of thin sections of each rock type in the cycle can give students a higher order understanding and appreciation of the processes involved.

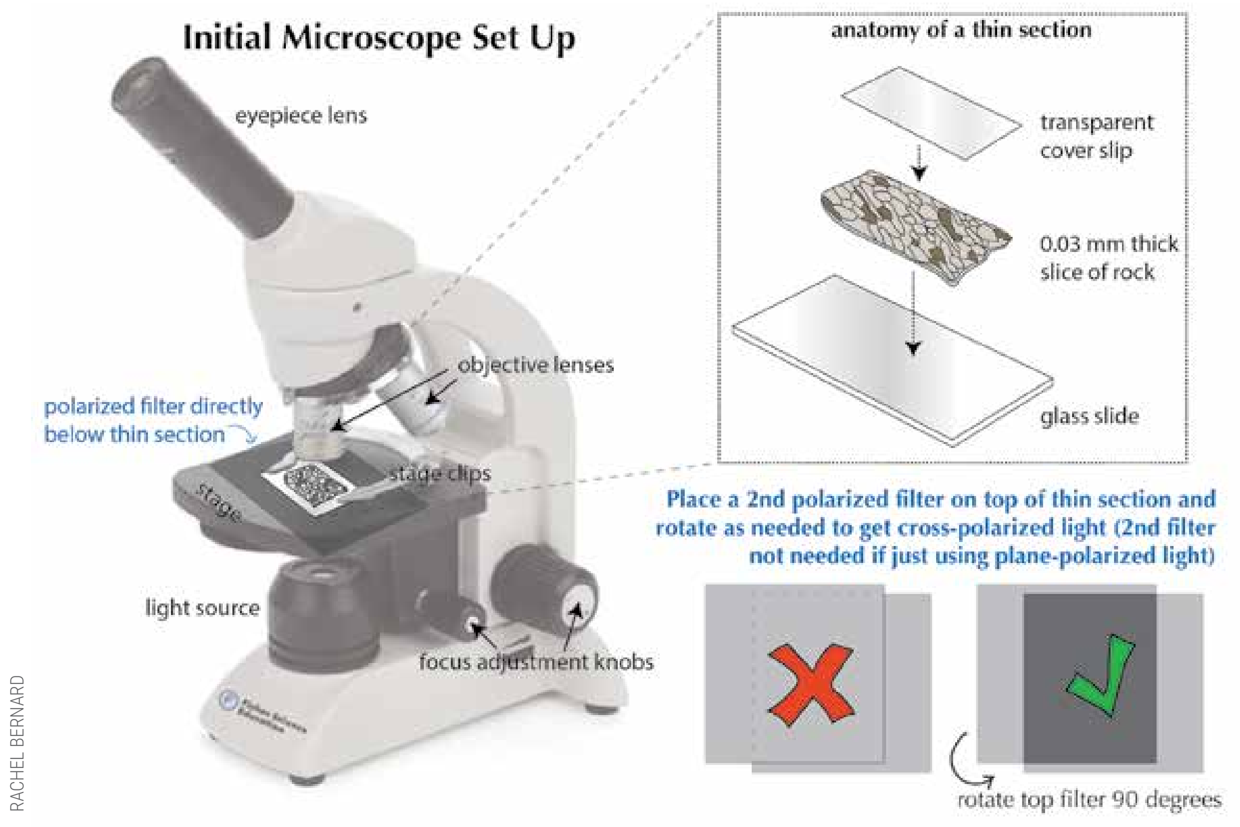


RACHEL BERNARD

FIGURE 2

Microscope setup.

To view a rock in plane polarized light (PPL), all that is needed is a standard classroom compound microscope, and a sheet of polarized filter placed below a thin section (a 30-micron slice of polished rock mounted on a glass slide with adhesive and sometimes covered with a transparent cover slip). Cross polarized light (XPL) can be achieved by placing a second polarized filter on top of the thin section. This filter may need to be rotated to achieve the desired effect.



Standards connections box, p. 36) and is required in APES classes, falling under the category of Earth Systems and Resources (see “On the web”).

Objectives

By the end of the lesson, students should be able to differentiate igneous (intrusive and extrusive), sedimentary, and metamorphic rocks by

1. recording observations of thin sections of rock samples under the microscope,
2. correctly identifying the rock type being observed, and
3. providing evidence to support their conclusions.

Students should also be able to make inferences about how porosity, permeability, and composition relates to natural resource availability.

Rock slices under a polarized microscope

Earth scientists commonly use thin, polished slices of rocks mounted on glass slides called *thin sections*. A *hand sample* is any studied rock that can be held. Thin sections help scientists differentiate among minerals that may look the same in a hand sample or are too small to see with the naked eye. They help quantify porosity and mineral grain size.

Polarizing filters are needed for microscopes to observe some features of minerals that help identify them. Two types of polarizing light that geologists use are *plane polarized light* (PPL) and *cross-polarized light* (XPL). PPL can be achieved by placing a polarizing filter (one that only allows light to pass

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standards

HS-ESS2 Earth's Systems

HS-PS4 Waves and Their Applications in Technologies for Information Transfer

Performance Expectations

The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The activities outlined in this article are just one step toward reaching the performance expectations listed below.

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

HS-ESS2-5. Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Developing and Using Models Use a model to provide mechanistic accounts of phenomena.	Students use the model of the rock cycle to understand changes of earth materials.
Constructing Explanations and Designing Solutions Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Students use observations from hand samples and thin sections to describe physical or chemical processes that formed rock types.
Analyzing and Interpreting Data Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS2-2)	Student observations serve as data that allows them to support scientific claims of rock formation or deformation.
Disciplinary Core Ideas	
ESS2.A: Earth Materials and Systems • Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes (HS-ESS2-2)	Students make observations and look for clues as to how rocks can be transformed by rock cycle processes.
ESS2.C: The Roles of Water in Earth's Surface Processes • The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. (HS-ESS2-5)	Student learn that water can promote metamorphism, and is the primary driver of sedimentary processes such as sediment weathering, transport, and deposition.
Crosscutting Concept	
Energy and Matter Energy drives the cycling of matter within and between systems.	Energy and matter are core concepts in understanding the rock cycle. Students hypothesize the causes for what they observe under thin sections. They also focus on the structure of minerals, as this is an important clue in mineral identification.

through in one direction) between the microscope's light source and the thin section (Figures 2, p. 35, and 3). In this view, often the most useful for viewing rocks, even the most vibrantly colored minerals can appear colorless, because the sections are too thin to significantly absorb or enhance specific wavelengths of light.

XPL, on the other hand, can be achieved by placing one polarized filter directly above and a second one below the thin section and oriented at 90 degrees from the first one. In this view, colors are often brighter and different than the true color of the mineral. These "interference colors" result from the interference of two light rays produced as polarized light passes through a mineral (Figure 3).

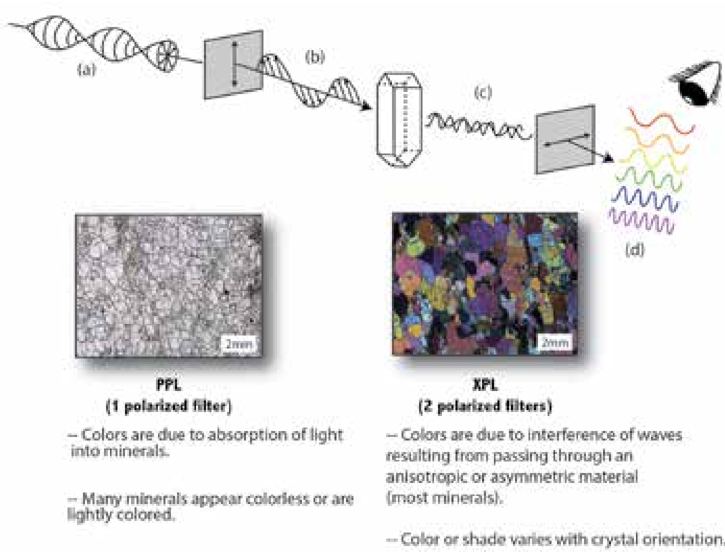
Interference colors depend on the type of mineral and its orientation, so the same mineral may appear as a range of colors throughout the thin section. The orientation of the mineral also affects how much light passes through, so some grains of the same type of mineral will appear darker and some lighter. Nonetheless, different minerals have sufficiently distinct optical properties that identifying and distinguishing them in thin sections is often much easier than in hand samples.

Observing and interpreting subtle distinctions in these optical properties is taught in semester-long classes in geoscience graduate school. However, in this lesson, students can readily observe and interpret the key features among different component rocks of the rock cycle.

FIGURE 3

Schematic representation of how light travels through a petrographic microscope.

Normal light vibrates in all directions as it travels (a). A polarized filter results in light vibrating in only one direction (b). If this light then gets filtered through an anisotropic mineral (asymmetric or longer in one direction, which most minerals are), the wave is split in two (c). Those waves interfere with each other and are finally passed through a final filter before reaching the microscope's optical lens. Without the final filter, most minerals will appear almost colorless in thin section (bottom left). With the final filter, our eyes see minerals in "interference" colors, due to the interference of the waves as they pass through the mineral, making it easy to identify them (d). The two photos are the same olivine-rich rock shown in PPL and XPL.



PHOTOS: CREATIVE COMMONS; IMAGE CREDIT: RACHEL BERNARD

Materials needed

- Two polarized filters for each microscope (see "On the web").
- Any standard classroom microscope capable of 10–1000× magnification (see "On the web").
- One hand sample and thin section each of basalt (or other extrusive igneous rock such as rhyolite or obsidian), granite (or other intrusive igneous rock such as gabbro or diorite), folded marble or gneiss, and fossiliferous limestone.
- Optional: two pairs of polarized sunglasses for demonstration purposes.

Part 1: Engage

The lesson began with a five-minute video about the rock cycle and a discussion of related handout questions (see "On the web"). Instructors then briefly explained how polarized light aids mineral identification under microscopes, pointing out that polarized filters are similar to polarizing sunglass lenses, which absorb sunlight reflected from road surfaces, for example, to make driving easier. Students took turns wearing a pair of polarized sunglasses while rotating a second pair before their eyes. The rotation demonstrated how light is blocked when polarization directions are perpendicular. The students were then given a handout showing what six common minerals—quartz, feldspar, mica, olivine, amphibole, and calcite—look like under XPL (Figure 4, p. 38).

Part 2: Explore

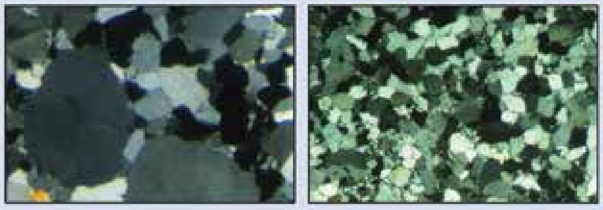
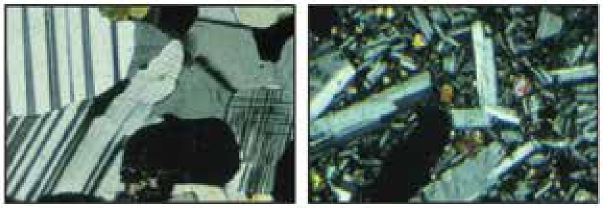
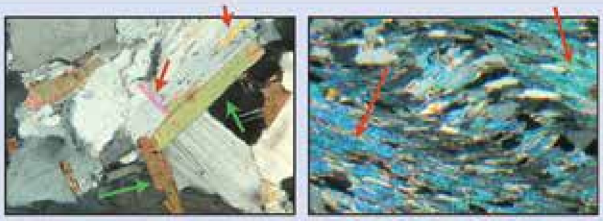
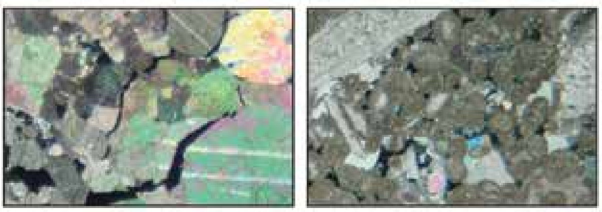
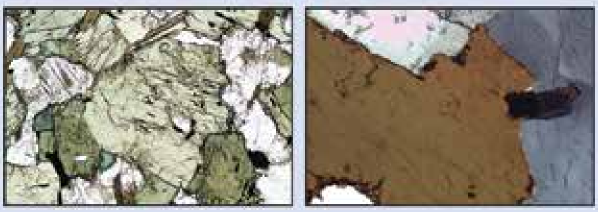
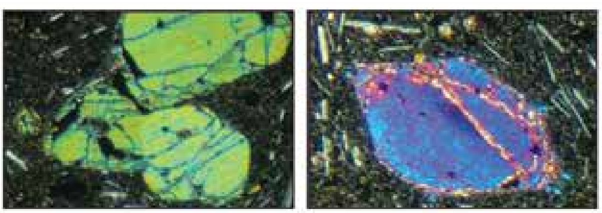
Students spent the rest of the class period using the thin sections and hand samples to answer questions provided in a handout packet. This involved students spending 10–20

FIGURE 4

Mineral identification handout.

Handout provided to students with information on six common minerals present in the lesson thin sections.

Appearance of six common minerals under cross polarized light (XPL)

Quartz		Appears as shades of black, gray and white (varies due to orientation). Grains often appear relatively round.
Feldspar		Also appears as shades of gray, black and white, but with stripes (called "twinning") or plaid patterns (left). Grains often appear rectangular (right).
Mica		Grains are rectangular or needle-shaped. Biotite "black mica" appears as shades of brown, green and light pink (green arrows) while muscovite "white mica" is brighter colored (red arrows). In PPL, biotite is brown and muscovite is colorless.
Calcite		Often appears striped or plaid, and is distinushable from feldspar due to gray and pastel coloring. As calcite often replaces organisms during fossilization, many fossils also have this appearance (right).
Amphibole		Shades of brown or green in both PPL (left) and XPL (right). The "hornblende" variety (shown in both photos) is common in granites and other igneous and metamorphic rocks.
Olivine		Colorful shades of green, blue, purple, pink (varies due to orientation). Commonly blocky or rounded with cracks or fractures. Dark appearance of surrounding material (left and right) is typical of extrusive igneous rocks.

IMPERIAL COLLEGE ROCK LIBRARY; IMAGE CREDIT: RACHEL BERNARD minutes using microscopes at each of three stations set up on tables before class. (Safety note: Remind students to carefully handle the glass slides, which break easily if dropped. Also, to avoid eyestrain, students should keep both eyes open when using a monocular microscope [which has only one eyepiece]).

The three stations

Station 1: This station included a hand sample of a limestone containing abundant fossil shells, as well as a microscope for viewing a thin section of that sample (Figure 5c). Students were asked to describe the hand sample (rock) on the table and to draw a picture of any fossils seen under the microscope. Students were asked whether they think the fossils are made out of the same mineral as the rest of the rock (answer: yes), and instructed to describe their evidence (calcite surrounds—and has also replaced—the fossilized items).

Station 2: This station consisted of a metamorphic hand sample and an accompanying thin section and microscope (Figure 5d). Students were asked again to describe the hand sample, hypothesize on the process that resulted in its layers becoming folded, and use the mineral ID handout (Figure 4) to identify the two minerals that form the dark and light layers.

Station 3: This station had hand samples and thin sections for two rocks: basalt (extrusive igneous, Figure 5a) and granite (intrusive igneous, Figure 5b). Students hypothesized whether intrusive or extrusive rocks cool faster and were asked which type of rock would likely have larger mineral crystals (hint: crystals grow bigger during slow cooling of magma). Students attempted to identify various minerals under the microscope and to connect those observations to the hand samples. ("Use what you see in the thin section to identify the black minerals in the granite." Answer: amphibole or black mica.) Students were asked, based on their hypotheses and observations, to determine which rock was extrusive and which was intrusive and to provide a rationale for their conclusion.

Modifications

Kits of hand samples and thin sections (geared for college courses) can be expensive (see "On the web"). Interested teachers can borrow kits for free from the lead author (see "On the web"). Some university geology departments may also be willing to loan theirs out.

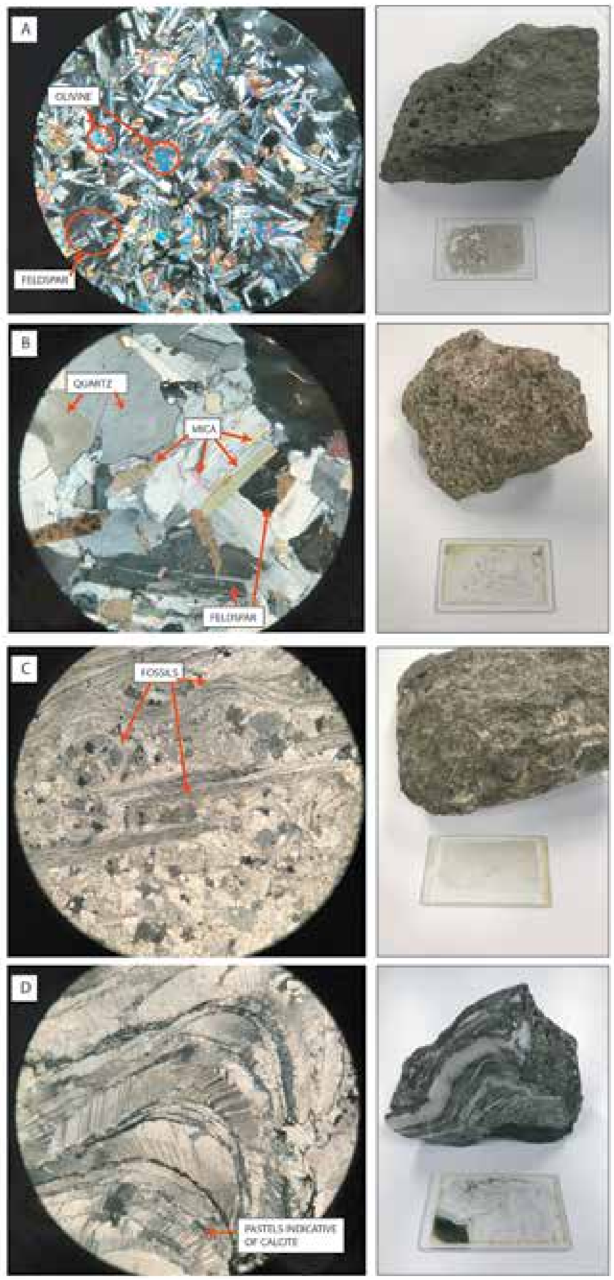
Otherwise, this lesson can be adapted to use virtual microscopes online, increasingly common in undergraduate courses (e.g., Edwards, Bryon, and Sowerbutts 1996, Milliken et al. 2003, Tetley and Daczko 2014). The Open University Virtual Microscope (see "On the web"), for example, has images of the various rock types as hand samples and under both PPL and XPL.

We had some difficulty accommodating 20–30 students (groups of four or five) in a single 100-minute block period. This lab could easily be stretched to more class periods. Breaking Station 3 into two stations of one rock each could also speed up the lab.

FIGURE 5

Thin sections and hand samples of rocks.

From top to bottom: Basalt, granite, limestone, and marble hand samples with full thin sections *(right)* and microscopic view under XPL at 10× magnification, image taken with cell phone camera down eyepiece lens *(left)*. (A) Feldspar and olivine are minerals found in the basalt; (B) quartz, feldspar, and mica are minerals found in the granite; calcite is the major mineral in both the limestone and marble. (C) Wavy and circular features in the limestone thin section photo are fossil shells. (D) The folded nature of the marble (in both thin section and hand sample) is a clue that this rock is metamorphic.



RACHEL BERNARD

FIGURE 6

Student drawings.

Examples of student drawings of, and mineral identifications in, thin sections.

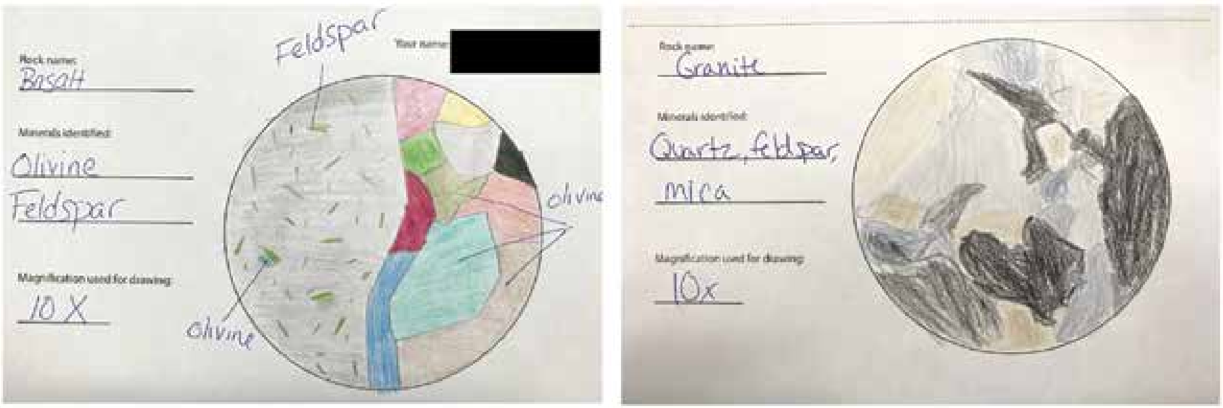


FIGURE 7

Student test scores before and after the lesson.

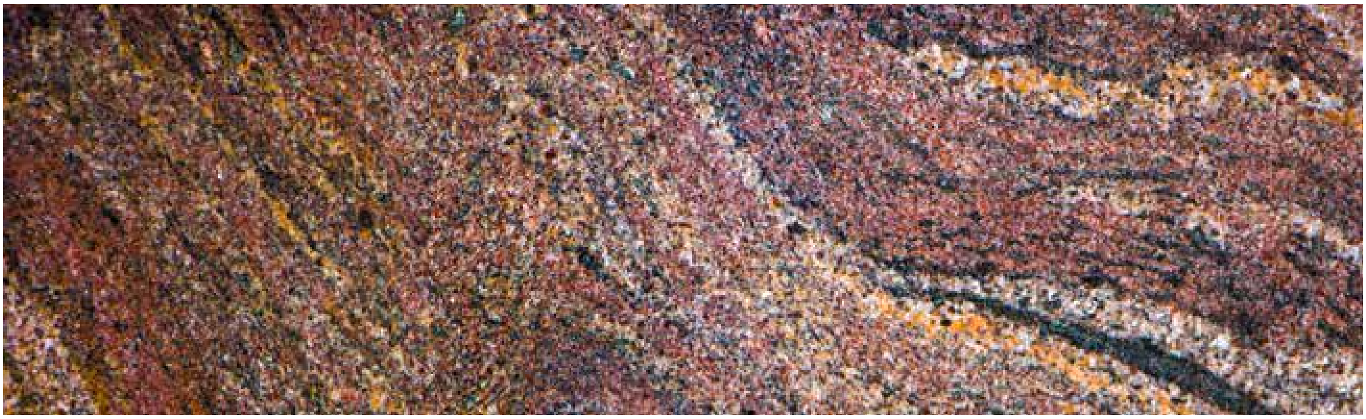
	CLASS 1	CLASS 2	CLASS 3	COMBINED
Number of students	29	20	25	74
Mean Pre-lesson Exam Score	53.1	55.5	73.4	60.6
Standard Deviation	27.4	31.5	11.2	26
Mean Post-lesson Exam Score	74.7	83.5	88	81.6
Standard Deviation	22.5	21.8	9.2	19.5
Mean Improvement	21.6	28	14.6	20.9
P-value (for test of null hypothesis of no improvement)	1.73E-06	2.77E-04	1.51E-06	7.37E-04

For larger classes, we added a station with no microscope but only hand samples of sandstone. Students were asked to describe sandstone and explain how they might design an experiment to quantify its porosity. We also asked how porosity might relate to natural resource exploration. (Hint: More porosity means more potential hydrocarbon or water storage space.) Thus, for larger classes, we had five total stations.

Part 3: Explain and Elaborate

Many of the questions in the lab handout were qualitative to encourage students to describe what they saw creatively. Open-ended questions challenged students to go beyond memorized answers (e.g., "What could explain the different hole sizes throughout the basalt?" "What could have caused the folds visible in the metamorphic rock?" "How could you increase permeability in a sedimentary rock, and why would you want to?"). Students were encouraged to draw specimens (both hand samples and thin sections; Figure 6). Some students, without prompting, photographed rocks through the microscope and posted these images on social media.

Learning outcomes for this lesson for an Earth science course included the ability to describe the rock cycle, identify a rock type from observations, and understand a tool used by professional geologists. For a physics course, learning outcomes might instead include explaining how polarized filters



manipulate light waves, how the angle between two polarization directions affects the intensity of light, and what happens to a polarized light wave as it travels through a mineral that is anisotropic (asymmetric and splits incoming polarized waves) vs. isotropic (symmetric and does not split incoming polarized waves). Physics students could also use the microscope to determine whether particular minerals are anisotropic or isotropic (hint: because isotropic minerals do not split the incoming polarized wave, no interference colors are produced, and they will always appear black in XPL, like the sunglasses in the demo).

Our goal was not to make students experts in mineral identification but to get them excited about rocks. Many were especially pleased to hear that this exercise was typically reserved for college geology majors.

Part 4: Evaluate

In a recent year, three of the second author's APES classes did this microscope lab. To evaluate the effectiveness of the lesson, all 74 students were given identical pre- and postlesson quizzes (see "On the web") in addition to the lab handout assignment. The questions on this quiz are similar to ones from past official APES exams.

Overall, students scored an average of 61 out of 100 on the pretest, and 82 out of 100 on the posttest (Figure 7). In the three classes, average test scores were as follows: 53% before and 75% after for Class 1 (29 students), 56% before and 84% after for Class 2 (20 students), and 73% before and 88% after for Class 3 (25 students). The higher posttest scores were statistically significant with $p<0.00001$, demonstrating the effectiveness of this lesson in teaching important concepts related to the rock cycle.

Conclusion

While a commonly used tool by geoscientists and some physicists, microscopes are not widely used in high school Earth science or physics lessons. This lesson plan provides a blueprint for pursuing the resources to make such a lab possible in high school. This lab is a great option for physics teachers interested in updating an optics lesson, or Earth science teachers wanting to get students excited about rocks and minerals. ■

ACKNOWLEDGMENTS

We would like to thank the University of Texas at Austin Environmental Science Institute Scientist-in-Residence program for making this partnership possible, the Department of Geological Sciences in the UT Austin Jackson School of Geosciences for allowing us to borrow samples from their teaching collection, and especially the students for making for an amazing semester.

ON THE WEB

AP environmental science course details: *http://bit.ly/APESdetails*
Assessment quiz, lesson plan: *www.nsta.org/highschool/connections.aspx*
Commercially available thin section and hand sample kit: *http://bit.ly/wardsKit*
Intro Rock Cycle video: *http://bit.ly/rockCycleVideo*
Loaner kit requests on author's personal website: *http://bit.ly/RocKits*
Open University Virtual Microscope: *www.virtualmicroscope.org*
Source for an affordable microscope: *http://bit.ly/studentMicroscope*
Source for polarized film: *http://bit.ly/polarizedFilm*

REFERENCES

Edwards, D.J., D. Bryon, and B. Sowerbutts. 1996. Recent advances in the development and use of courseware within Earth science teaching. *Journal of Geoscience Education 44* (3): 309–314.

Gunter, M.E. 2004. The polarized light microscope: Should we teach the use of a 19th-century instrument in the 21st century? *Journal of Geoscience Education* 52 (1): 34–44.

Milliken, K.L., J.P. Barufaldi, E.F. McBride, and S.-J. Choh. 2003. Design and assessment of an interactive digital tutorial for undergraduate-level sandstone petrology. *Journal of Geoscience Education* 51 (4): 381–386.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press.

Reinhardt, J. 2004. Optical mineralogy in a modern Earth sciences curriculum. *Journal of Geoscience Education* 52 (1): 60–67.

Tetley, M.G., and N.R. Daczko. 2014. Virtual petrographic microscope: A multi-platform education and research software tool to analyse rock-thin sections. *Australian Journal of Earth Sciences* 61 (4): 631–637.

Rachel Bernard *(bernard.rachel.e@gmail.com)* is a PhD candidate in the Jackson School of Geosciences at the University of Texas at Austin, and **Colleen Henegan** is an AP Environmental Science teacher at KIPP Austin Collegiate high school in Austin, Texas.