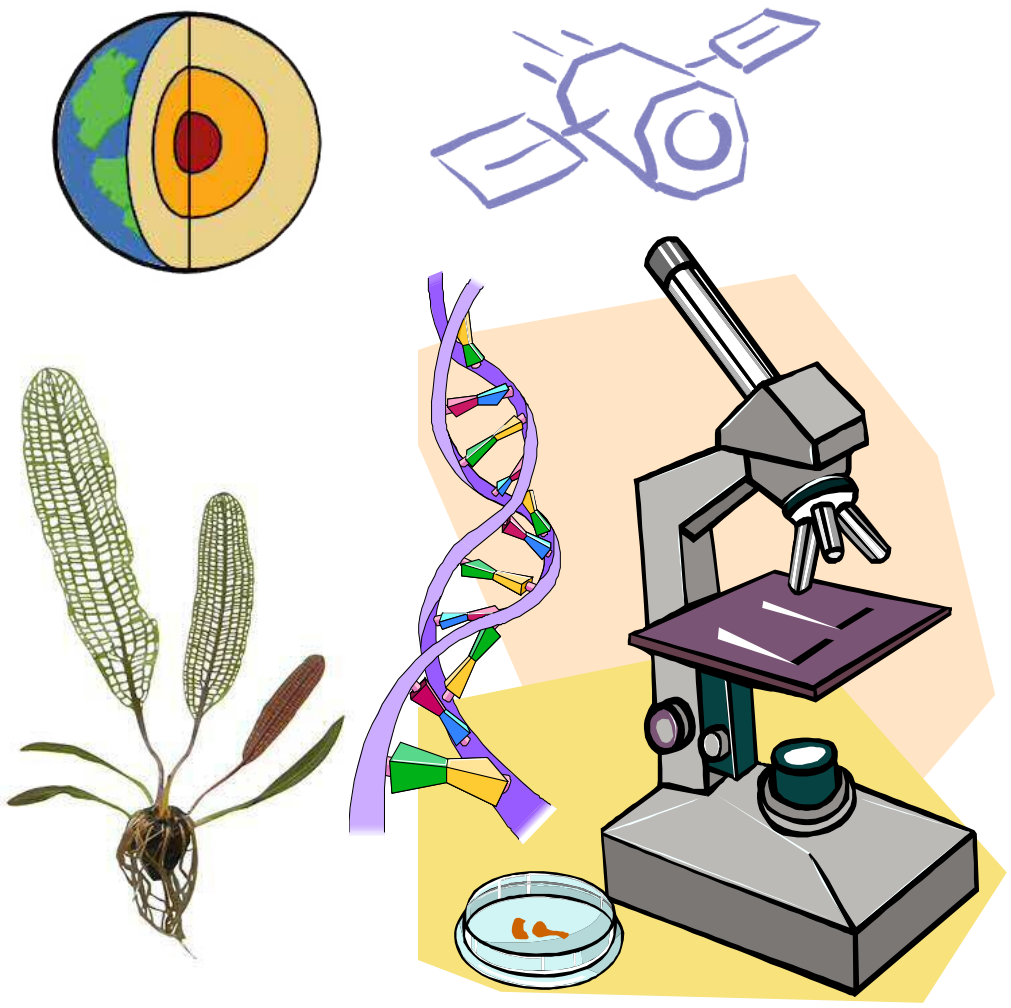

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ASLA'S CONFERENCE FOR SCIENCE TEACHERS

26 AUGUST 2022

Program and Lab Manual

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SCIENTISTS and INNOVATORS in the SCHOOLS

Acknowledgements

ASLA would like to thank our sponsors:

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We would also like to thank all the volunteers and participants for helping to make this project a success.

SCIENTISTS and INNOVATORS in the SCHOOLS

ASLA's Science Teachers Conference Schedule
26th August 2022

Time	Event		Location
8:30 am – 9:00 am	Registration		5th Floor Biology Lounge LSC
9:00 am – 9:10 am	Opening words from ASLA's President Welcome speech from Dean of the Faculty of Science		5th Floor Biology Lounge
9:15 am - 10:25 am	Group A	Science from Space	Lab 2087
	Group B	Exploring Structure and Function in Biology	Lab 2100
10:30 am -10:55 am Tea & Coffee Break in 5th Floor Biology Lounge			
11:00 am – 12:10 pm	Group B	Science from Space	Lab 2087
	Group A	Exploring Structure and Function in Biology	Lab 2100
12:15 pm – 12:55 pm Lunch in 5th Floor Biology Lounge			
1:00 pm – 1:25 pm	Greenhouse Visit		8th Floor LSC
1:30 pm – 2:40 pm	Group A	Minerals and Crystal Structures	Lab 2055
	Group B	Creating E-Books to Engage with Cell Biology	Lab 2100
2:45 pm – 3:10 pm Tea & Coffee Break in 5th Floor Biology Lounge			
3:15 pm – 4:25 pm	Group B	Minerals and Crystal Structures	Lab 2055
	Group A	Creating E-Books to Engage with Cell Biology	Lab 2100
4:30 pm – 5:00 pm	Group Photo		5th Floor Biology Lounge
	Closing remarks from the Chair of Biology and the Chair of Earth and Environmental Science Vote of Thanks from ASLA's Executive Director		

TABLE OF CONTENTS

Lab 1: Plant and Animal Tissues

Exploring Structure and Function in Biology

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Introduction

The relationship between structure and function is a central – and fascinating! – idea in biology. Many of us have an intuitive grasp of this concept, whether or not we have studied much biology, but it can still be challenging to articulate and illustrate the connections between structure and function in the science classroom. Today, we'll explore some ways to talk and work with students to help them develop their understanding of structure and function in biology through general discussion, lab activities, simple models, and concrete examples.

In this workshop, we'll begin with a discussion to help us define some terms and describe some of these relationships. Then, we'll set to work at the lab benches, practicing several different approaches to help students develop a structure-function interpretation of plant leaves and animal digestive organs. By focusing on biological systems that are likely to be familiar to students, we can encourage them to share their prior knowledge and to apply what they already know to new areas of biology.

In the first case, we'll work with easy-to-find plant materials to study some structure-function relationships in leaves, observing structures at the cell, tissue, and organ levels and considering how structure and function are related at and across multiple levels of organization. Animal material can be less accessible for classroom use, so in our second case we'll work with a combination of materials to help students understand structure-function relationships in the small intestine, pairing simple physical models with microscope images to understand structural features and make connections to the small intestine's function in nutrient absorption during digestion.

Part 1: Talking About Structure and Function in Biology

At all levels of biology learning, we work and think with the concept of Structure and Function. The influential *Vision and Change* report on biology education identified Structure and Function as one of five biology core concepts,[1] and in the years since the report biology education scholars have worked to explain and articulate these core concepts (AAAS 2011, Brownell et al. 2014, Cary and Branchaw 2017).

[1] The other four Vision and Change core concepts are Evolution; Information Flow, Exchange, and Storage; Pathways and Transformations of Energy and Matter; and Systems (AAAS 2011).

In Nova Scotia, "Structure and Function" is included in the list of Nature of Science fundamental concepts in the renewed Science 7 and Science 8 curriculum documents. Science 8 includes the most sustained engagement with biological structure and function, under the outcome "Learners will analyse how the characteristics of cells relate to the needs of organisms" (NSDEEC 2020 (Grade 8), p. 10). On your bench, you will find a copy of page 10 from the Science 8 document. Take a few minutes to read through that page and to think about how you engage with biological structure and function in your science teaching. Then, we'll use that reference sheet and your reflections to have a short discussion about the following three questions.

- What is "structure"?
- What is "function"?
- How could we describe the concept of "Structure and Function" in biology?

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Part 2: Structure and Function in Plant Leaves

Reviewing levels of organization in plants and animals

Let's first consider levels of organization in plants and compare them to something more familiar: a human. We recognize one human as an organism made of up of skin, muscles, bones, internal organs etc. The same can be said for the entirety of a plant, for example, a pea plant (combination of roots, leaves, fruiting bodies, flowers, etc). If we go down a level of organization from the whole organism we would then consider an organ system, say the digestive system in humans, or the shoot system in plants (consisting of everything above ground: leaves, stems, flowers, and fruit.)

Going down another level of organization from the organ system, we consider an organ. In a human digestive system there are many organs to choose from; let's focus on the liver. In a plant, we could consider a leaf, which is a subsection of the shoot organ system with a specific function different from other subsections (like the stem for example). Moving down yet another level, we reach tissues; a tissue is a group of many specialized cells working together to carry out a particular function. In the liver we may consider the parenchyma tissue; in a leaf, we could consider the dermal tissue (which can be likened to the upper layer of our skin).

We then reach the level of the cell. In the parenchyma tissue of the liver, hepatocytes are a specialized cell making up most of this tissue. In the dermal tissue of a plant, we see epidermal and guard cells. Finally, we reach the level of the organelle. Organelles are small structures within the cell specialized for particular functions. In both examples we may consider the

nucleus, Golgi apparatus, endoplasmic reticulum (ER), and the mitochondria; and in plants we also see the chloroplast in some types of cells.

Table 1 Summary of levels of organization between plants and animals.

Level of organization	**Animal example**	**Plant example**
Organism	Human	Pea Plant
Organ System	Digestive system	Shoot system
Organ	Liver	Leaf
Tissue	Parenchyma tissue	Dermal tissue
Cell	Hepatocyte	Epidermal cells, guard cells
Organelle	Nucleus, Golgi, ER etc.	Nucleus, Golgi, ER, chloroplast etc.

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Considering structure and function in land vs. aquatic plants

The comparison of closely related organisms adapted to vastly different environments can demonstrate how structure relates to function. In this section, we'll compare an aquatic plant to a land plant and focus one a key structural difference.

The lace plant (*Aponogeton madagascariensis)* (right) is an aquatic plant native to Madagascar. It has the unique and distinctive feature of forming holes throughout its leaves via a process called programmed cell death (PCD). On the right, we can see an entire organism, a few organ systems, and many organs. To see tissues, cells, and organelles, we'll have to take a closer look with the help of microscopes.

For our land plants, most commonly available species will do the trick for our purposes! We'll be considering rhododendron and oak leaves for comparison at the microscopic level.

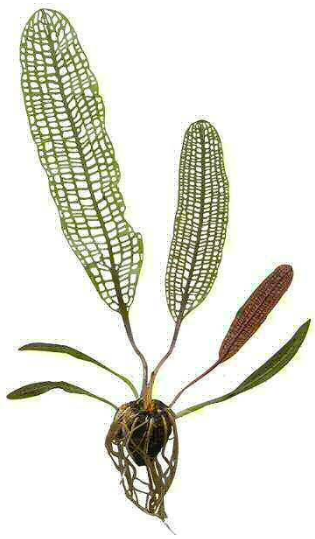

Figure 1 Lace plant (*Aponogeton madagascariensis*)

Looking up close: microscopy with aquatic and land plant epidermal tissue

To consider the differences between aquatic and land plant leaves, we'll be making observations between our aquatic and land plant. For observations at the lower levels of organization we'll be using a microscope. Our aim is to view the dermal tissues of lace plant and land plant samples. Lace plant cells are easily viewed under the microscope (Figure 2) because their leaves are **semi-transparent** (why might this be?). It is difficult however, to see details of

cells in our land plant leaves (see Figure 3) as they are not transparent (again, why not?). To view the epidermal layer of our land plant, we'll remove it with the technique outlined below. We're hoping to observe a key structural difference between land plants and aquatic plants, take careful note of the differences you observe and consider what function this structure serves.

Materials at your bench

- A selection of land plant leaves
- Clear nail polish
- Tape
- Microscope slides
- Prepared lace plant slides
- Microscope

Methods

1. Paint a small section of the **lower** side of the leaf (abaxial surface) with clear nail polish and let dry ~10 mins
   → Why are we more interested in the lower epidermal layer?
2. While the nail polish is drying, view the prepared lace plant slide under the microscope and note your observations in table 2.
3. When the nail polish is dry, place a piece of tape over the painted section and press firmly down. Carefully peal the tape off the leaf, the nail polish and epidermal layer of the leaf should come with it. Place the piece of tape sticky side down on a slide and view under the microscope. Note your observations in table 2.

→ Why do we remove the lower epidermal layer? Why not view the land plant entirely as we do the lace plant?

Table 2 Record your observations under the microscope here (notes or sketches)!

Observations in aquatic plant	**Observations in land plant**	**What are some similarities/differences?**

Aquatic (Lace) plant microscopy

Below is an example of what we might see in a lace plant under a microscope. What stands out? What organelles can we see or not see?

Figure 2 Microscopy of mature lace plant leaf under 20x (left) and 60x (right). Micrographs show chloroplasts in epidermal layer.

Land plant microscopy

Below we can see the difference in observing our land plant leaf in its entirety vs. the epidermal layer alone. What structure are we seeing in this epidermal layer? What is its function? Why is it well suited to land plants?

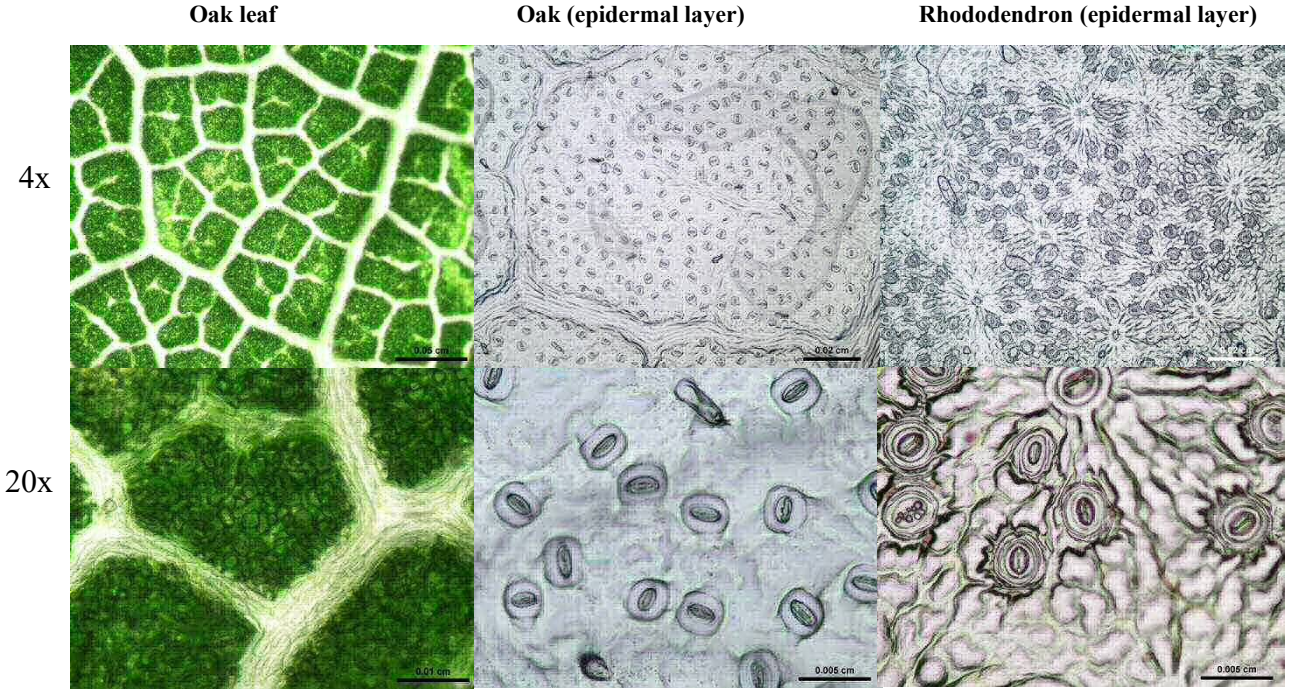

Figure 3 View of lower side of oak leaf, no modification (left). Oak and rhododendron leaf lower epidermal layers showcasing characteristic structure of land plants (middle and right). Top row: 4x magnification, bottom row: 20x magnification.

Notes:

Relating structure and function: Questions

1. Under the microscope, what could you see at the tissue and cell level in your samples? Did you notice anything at the organelle level?

2. What is the structure that can be seen in the land plant epidermal layer which we don't see in the lace plant?

3. At what level of organization is this structure? (Organism, organ, tissue etc.)

4. What function do these structures serve and why are they well suited to land plants?

And a tough one….

5. Why do you think the lace plant forms holes across its leaves?

Structure and function takeaways and talking points

By now you've likely deduced the structures we can see on the epidermal layer of our land plant are **stomata.** Small openings on the surface tissues of leaves that allow for gas exchange. Specifically, they grant the ability to draw in carbon dioxide (CO_2) and release oxygen (O_2) through the process of photosynthesis. Stomata make a lot of sense for plants who live in a gaseous medium – air, an effective vehicle for CO_2 and O_2. It would not make as much sense for fully submerged aquatic plants to have these pores for gas exchange as they live in a liquid medium – water, a more complex vehicle for CO_2 and O_2. Instead, CO_2 most often diffuses into the leaves of aquatic plants.

→ The main idea here is that stomata are present in land plants because they provide an easy way for intake/release of necessary gases, and they wouldn't be as effective in aquatic plants as gases behave differently in air than in water. Hence the structure of stomata are pores because they serve the function of gas exchange in a gaseous environment. We can see this demonstrated by looking at its presence in plants that live in air, and its absence in plants that live fully submerged in water.

Finally, an interesting example of structure and function are the holes we see in the lace plant's leaves. We know a quite a bit about **how** the holes are formed, but lace plant is a good example of a structure/function relationship that remains a mystery! A few functions have been hypothesized for the formation of these holes but as of yet, none have been convincingly supported by experiments. It's a good reminder that we don't have all the answers and that there are a plethora of questions science is trying to answer, and many that haven't even been asked yet.

Notes:

Part 3: Structure and Function in the Small Intestine

Accessing students' prior knowledge of digestion

Food and digestion are common topics of conversation in everyday life, and your students probably already have some understanding of digestion to build on in this next activity. To bring students' prior knowledge into the classroom, it can be useful to begin with a short discussion about this process and the structures involved, using the language of function.

Some possible prompts for discussion:

- Why is digestion important to an animal?
- What happens during digestion?
- What are some organs that are part of the digestive system?
- What roles do these organs play in digestion?

(A couple of resources for brushing up on digestion: if you want to remind yourself quickly about the different organs and functions of the digestive system, you might find this short video from the University of Michigan Health System helpful, from the beginning until 3:27, with the section about the small intestine beginning at the one-minute mark: https://youtu.be/lm3oIX6jjn4, and if you'd like to read a bit more detail with clear explanations about the small and large intestine, try this page from the Children's Hospital of Pittsburgh: https://tinyurl.com/2p9fzb5n.)

Among the organs that make up the digestive system, students might have the most knowledge about the stomach, and in this section of the lab we're going to focus on the next structure along the way, the small intestine. Some prompts:

- Where does partially-digested food go after it leaves the stomach?
- What are some things you know about the small intestine?

Similarly, students might have the most knowledge about the breaking-food-down function of the digestive system, and in this section of the lab we're going to focus on the next function along the way: absorption of nutrients from digested food. Some prompts:

- What happens next, after food leaves the stomach and goes on to the small intestine?
- What happens after the food has been broken down?
- How does your body get access to the nutrients in food, in order to get the energy and materials it needs to stay alive?

Notes:

The amazing small intestine

In gathering up students' existing knowledge about the small intestine, someone might mention that it is surprisingly long (estimates vary from 3-6 metres!) or that it has an incredibly large surface area for its size. Many sources mention that the surface area inside the small intestine is as large as a tennis court. The small intestine is a complex and dynamic structure and its inside surface area is difficult to estimate, but a more recent estimate (Helander and Fändriks 2014) puts the internal surface area at about 30-40 m^2, with most of that surface area in the jejunum and ileum, the two lower sections of the small intestine most involved in nutrient absorption. That's not as big as a tennis court, but it's still impressive, and we might reasonably wonder whether there's some connection between the structural feature of large surface area and the function of nutrient absorption.

Some questions to consider, now that we're wondering:

- A question about function: why might it make sense to see a very large interior surface area in the small intestine, where nutrients are being absorbed through the cells lining the intestine?
- A couple of questions about structure: there's a good functional reason to have a large surface area in the small intestine, but how can this be accomplished in a relatively small amount of space within an animal's body? That is, what kinds of structures can make this function possible?

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Using physical models and micrographs to understand structure and function in the small intestine

To understand how it's possible to have such a large surface for nutrient absorption within the body, we'll use physical models and microscope images to learn about some specialized structures in the interior surface of the small intestine: **microvilli**, **villi**, and **circular folds.** If the human small intestine were just a simple 3-metre-long tube with a smooth interior surface, in order to have an internal surface area of 30 square metres it would have to be really, really wide – over 3 metres in diameter. (That's not a very small intestine: its internal volume would be almost 24 cubic metres!) Together, the microvilli, villi, and circular folds allow for an enormous surface area in an organ that is only about 2.5-5 cm in diameter (Helander and Fändriks 2014, Dworkin et al. 2022).

In this activity, we'll look at ways to help students visualize these three important structural features, and to think about the role of surface area in the function of nutrient absorption, using some inexpensive and easily available objects. We'll begin with the smallest of these structures, the microvilli, then work upwards to the villi and finally the circular folds.

As students work through the three structures and their models, it can be helpful for them to collect their observations in a summary table like this one:

Table 4. Record of observations of physical models for small intestine structures.

Structure	Comparison	Make a sketch of the comparison.	What differences in *structure* (not in colour or material, just in shape) do you notice?	Which one has the most surface area?
microvilli	silicone basting brush (microvilli) *vs* foam paintbrush (no microvilli)			
villi	noodle bath mat (villi) *vs* flat bath mat (no villi)			
circular folds	folded paper tube (circular folds) vs smooth paper tube (no circular folds)			

Some suggested instructions for students

First, let's look at microvilli. Most of the lining of the inside of the small intestine is made of a specialized cells called enterocytes. Enterocytes have a distinctive structure: the end facing into the small intestine has many long projections called microvilli, and all of the microvilli from one enterocyte are known together as the "brush border". Microvilli are very small and can only be seen using a microscope. In Figure 4 below, you can see the brush border as the fuzzy pink area around the

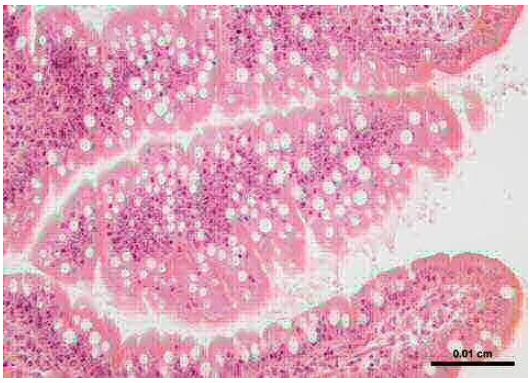

Figure 4 Microvilli in a human small intestine. 20x magnification.

edges; if you wish to explore some more microscope images to see the microvilli, the Online Histology Guide is a good resource: https://tinyurl.com/3na8znwb.

Nutrients from digested food are absorbed into the enterocytes through the microvilli, then pass out of the enterocytes on the other end of the cell and continue on into the body. Compared to a smooth surface, researchers have estimated that microvilli increase the surface area inside the small intestine by a factor of about 9-14 times (Helander and Fändriks 2014).

In order to think about these structures in three dimensions, it's helpful to have a physical model to observe and manipulate. A silicone basting brush, with its smooth rounded bristles, is a good physical model for enterocytes.[2]

1. Take a look at a silicone basting brush, holding the handle close to the head of the brush. The head and bristles together are a nice model for one enterocyte, with its microvilli extending from one end. Now group a few basting brushes (enterocytes) by holding them closely together in one hand and imagine that the whole inside of the small intestine is lined with enterocytes, each with their brush border facing into the interior of the small intestine.
2. Compare the basting brush with a foam paintbrush. The foam paintbrush head is a similar size but has no projections. Make a quick sketch of the two brushes side by side in your observation table, and write down anything that you notice about the structural differences between the two brushes. Which of the two brushes has the greater surface area? How might microvilli increase the surface area of the inside of the small intestine?

Next, let's look at villi. The interior surface of the small intestine, lined with enterocytes, is not a flat surface: it's arranged into leaf- or finger-shaped projections called villi that extend into the lumen (the space in the centre) of the small intestine. Each of these villi is covered with enterocytes (and recall that each of these enterocytes has its own microvilli that also extend inward towards the lumen). Compared to a smooth surface, researchers have estimated that villi increase the surface area inside the small intestine by a factor of about 6-8 times (Helander and Fändriks 2014). Using a microscope, we can see these villi projecting out from the wall of the small intestine (Figure 5).

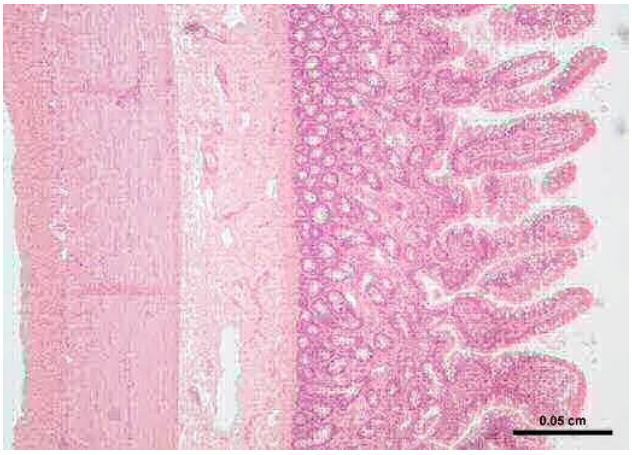

Figure 5 Villi in a human small intestine. 4x magnification.

[2] Supply note: silicone basting brushes are sold at many grocery stores as well as Canadian Tire, Ikea, and other large stores. Recently a set of two was purchased for $6.99 at Sobeys.

A good physical model for understanding the villi is the kind of bathmat often called a “noodle rug”.[3]

1. Take a look at a noodle rug and think of it as a model for the interior surface of the small intestine, with its villi extending into the central space (try rolling up the noodle rug into a tube to see this).
2. Compare the noodle rug with a flat bathmat or towel of a similar size, and try rolling each into a tube to compare. Make a quick sketch of the two rolled mats side by side in your table and write down anything that you notice about the structural differences between the two. Which of the two tubes has the greater interior surface area? How might villi increase the surface area of the inside of the small intestine?

Finally, let’s look at circular folds. Not only is the interior surface of the small intestine covered with villi, but the whole villi-covered surface is arranged in a series of folds running along the circumference, so that it looks a bit like a series of rings or ridges. These structures have various names, the simplest of which is “circular folds”. Compared to a smooth surface, scientists estimate that circular folds increase the surface area inside the small intestine by a factor of about 1.5-3 times (Helander and Fändriks 2014). Figure 6 is an illustration (from 1670! it's such a useful image by an early observer of intestinal structure that Helander and Fändriks used it in their 2014 paper as well) showing this structural feature of the organ.

Figure 6 Diagram showing the circular folds in the small intestine, from Kerckring (1670).

You can use a piece of copier paper to make a simple physical model of the circular folds.

1. Take a piece of paper and fold it fan-style, such that the folds run along the shortest dimension of the paper. You can use a few pieces of tape on the outside to secure some of these folds. Then, roll the paper into a cylinder such that the folds run in rings along the inside of the tube.
2. Measure the length of your tube, and then cut another piece of paper to the same length and roll it into a smooth tube. Make a quick sketch of the two rolled paper tubes side by side in your table, and write down anything that you notice about the structural differences between the two. Which of the two tubes has the greater interior surface area?

[3] These are available in the towel section of stores like Walmart ($5.97 for a 16” x 24” mat).

Which tube occupies more space? How might circular folds increase the surface area of the inside of the small intestine?

Now that you have explored some aspects of the structure of the small intestine, let's finish by returning to its function. The presence of microvilli, villi, and circular folds all make it possible for the small intestine of mammals to have a very large internal surface area. We know that an important function of the small intestine is the absorption of nutrients from digested food. Why is a large surface area important for absorption? How would this function be affected if the small intestine had a smaller internal surface area?

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Conclusion, and thank you!

Biologists very often think and talk about structure and function: it's one of the core ideas in our subject. But understanding and describing the world in this way takes practice, and in helping students to develop these habits of thought and explanation it can be useful to combine some different approaches to the topic. We hope that these investigations into the relationship between structure and function in plants and animals have offered you some fun and practical ideas for working with your students. Thank you for joining our workshop!

Acknowledgements

We are grateful to Shanukie Embuldeniya for her friendly and helpful coordination of the workshop and lab book projects, and to Amber Peck for her generous advice about lab supplies and for permission to use a slide and microscopes from the BIOL 1010/1011 lab rooms. We thank our Gunawardena lab helpers for their assistance during the workshop: Shanukie Embuldeniya, Nathan Rowarth, MacLean Rivers, Kestrel Adams Unger, and Sohiba Khayol Muhammad.

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Lab 2: Viewing Earth from Space

Using satellite imagery to view changes to Earth's surface over time

Developed by: Amy Mui, PhD
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Dalhousie University, Amy.Mui@Dal.Ca

Image Credits: NASA / USGS / rawpixel

Background

There are almost 5,000 active satellites orbiting Earth as of the year 2022. Satellites are used for a variety of purposes such as communications, global positioning systems, and weather monitoring. A subset of these satellites are designed for Earth Observation, or what we call EO Satellites. They are built to send us information about Earth's surface, including land, water, and air. The payload of these complex satellites takes the form of digital imagery that allows us to see vast areas over time. Advanced sensors produce imagery that captures wavelengths both within and outside of the range of human vision. EO imagery has helped us to monitor important changes such as global deforestation, the spread of forest fires, rapid urban growth, natural disaster impacts and can play a powerful role in helping to fight climate change.

Objectives

A. View and query Earth imagery to identify dominant features
B. Compare a time series of images and identify changes over time
C. Quantify some simple changes and make inferences as to what has caused them
D. Learn how and where to download free satellite imagery from anywhere on Earth

Satellites & Sensors

There are many different types of EO satellites developed by governments and private companies worldwide. A few of the most popular and widely-used image data for education and research purposes comes from NASA's Landsat series of satellites (1-9). Landsat is an example of a medium resolution satellite with a pixel size of 30 meters, that senses reflected light energy across 11 different regions of the EM spectrum. It will revisit the same spot on Earth every 16 days. Landsat 8 and 9 collectively acquire 1500 images over Earth daily.

METHODS

Required Materials:

1. Internet-enabled computer with web browser
2. ArcGIS Free Online account (www.arcgis.com)
3. Satellite Imagery (Free to Download – files provided for this workshop)
4. Some basic computer know-how and a willingness to click buttons !

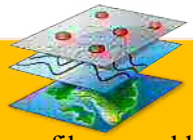
INSTRUCTIONS:

Display the Imagery in ArcGIS Online

- ✓ *Sign into your ArcGIS Online Account*
  - Once signed in click on the following:
  - **Content** in the top menu > **New Item** in the top left corner > **Your Device** and navigate to the folder in the USB drive provided
  - Select a few images from the TRUE COLOUR folder and click **Open** (add each file one at a time)
- ✓ Click on **Map** in the upper menu and select **Open in Map Viewer Classic**
- ✓ Select **Add** > **Search for Layers** from the top left menu pane. Select your layers one at a time, clicking **Add to map** or the plus symbol ⊕.
  - Zoom out and find the country or region of the world your image resides in. *Record your findings.*
  - Click on the three dots beneath each layer in the left Contents pane, and select **Zoom to** to locate each image.

ArcGIS

ArcGIS is a popular geospatial software created by ESRI. ArcGIS Online is a simplified web-based version of the full software that allows viewers to view spatial data and make simple queries at no cost.



Once image files are added to the map, they are refered to as **layers**. Layers can be stacked such that two files occupying the same location (e.g., Bahamas_TCC, Bahamas_FCC) can be toggled on and off to view them both.

Identify Dominant Land Surface Features

- ✓ Zoom in and scroll around the image. Try to identify as many features as you can (e.g., lake, mountain, urban area, forest)
- ✓ Add a few more images from the FALSE COLOUR folder. *What do you notice?*
  - False colour composites (FCC's) apply colour to light detected from regions of the EM spectrum outside of the human visible range (e.g., ultraviolet, nearinfrared, thermal infrared). For this reason, they look different from what we are used to seeing with our eyes.

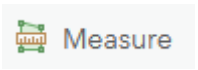
File Name	Location	Dominant Features	Colour

View Time Series Images

- ✓ Add a new layer again and this time choose all imagery from the TIME SERIES folder
    - Each group of files will overlay on top of each other as they occupy the same geographical location but at different points in time
- ✓ Toggle each image on and off sequentially. *What changes? And what is the likely cause?*

Quantify Change Over Time

- ✓ Select one dominant feature that exhibits clear change over time
- ✓ Use the **Measure** tool to measure either area or distance of this one feature over time. *Record your results. Is the rate of change fast? How many years would it take to double the change?*



File Name	Year	Feature Length or Area	Change (+/-)
		Total Change	
		Average Rate of Change per Year	

Download Imagery from anywhere in the world

EO satellite databases are a great example of open data (data that is free and accessible to the public). Many government and multinational space agencies provide free access to EO satellite imagery. Some examples are the CSA (Canadian Space Agency), NASA (National Aeronautics and Space Administration) and ESA (European Space Agency). Government portals typically require the user to create a free account before accessing the data. Below are steps for downloading imagery from the USGS Earth Explorer portal (US-based):

- ✓ Go to: https://earthexplorer.usgs.gov
- ✓ Sign up for a free account (keep track of your login details)

- ✓ Zoom around the world and select a location of interest – there is a simple base map to show you surface landforms

✓ **Set the Search Criteria**

Geocoder:

- Method: Address/Place (type in a location such as 'Paris' and click 'Show')

Polygon:

- Zoom into the extent desired (make it slightly larger than your area of interest) and click *Use Map.* The selected area will turn red. Zoom out and you will see your area highlighted in red. Click on the blue corner handles to adjust (drag and drop) if needed.

Date Range:

- Leave as blank unless you are looking for a specific time (e.g., of a natural disaster)

Cloud Cover:

- Set as 20% (adjust higher if no imagery is found)
- Next click on Data Sets. Here the options can be overwhelming! For this lab select Landsat Collection 2 (Level 2 and Level 1) and check the boxes for Landsat 8 or 9 OLI/TIRS

NOTE:. Ensure your area of interest is cloud-free, at least over key features. Rule of thumb is less than 20% cloud cover.

Understanding Earth Explorer Landsat Products

- **Landsat Collection 1** : Basic processing completed. This level will be retired after Dec 21, 2021.
- **Landsat Collection 2**: Improvement in georeferencing (location accuracy) and radiometric calibration. Level 2 data is available 15-17 days after the imagery is acquired.
- **LANDSAT C2 Analysis Ready Data (ARD):** Created using level 2 data and available for the conterminous United States only. Data is processed (corrected) and available ~ on month AFTER imagery was acquired. Therefore, real-time ARD data is not available, there is always a lag.

Which one do I need? Generally Collection 2 will suit your purposes (Level 1 or 2). If you are conducting work that requires a high level of accuracy (e.g., classifying individual trees in a forest), you will need ARD or higher level products.

- **Click on RESULTS**
  - For a true colour image, download bands 2-4 (individually or as a bundle depending on your computer's download speed)
  - For a false colour image, download bands 2-5
  - The files will be saved in the .tif format and typically range in size from 100-500 MB depending on the total size of the tile.

Critical Thinking Questions

- Why is it important to look at Earth's surface through satellite photography? What can be learned?
- What is the length of an individual pixel in any of the images provided? (the answer should be 30m, as all imagery is from Landsat). If you wanted to see more spatial detail in your image, should the pixel size increase or decrease?

- Humans perceive the world in shades of blue, green, and red. But there many more forms of light that we cannot see. What is the benefit of collecting data outside of the human visible range?
- Why is it important to monitor changes to Earth's surface over time? What applications can be used with this information?
- Managing Earth's resources sustainably is the most important challenge of our time. How can Earth-Observing satellites help us to do this?
-

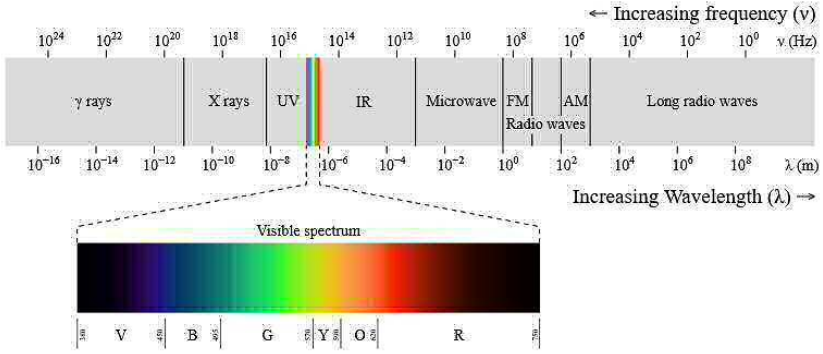


Figure 1. Light energy radiating from the sun is composed of many wavelengths from the high frequency gamma waves to the low frequency radio waves. Human vision is only able to perceive light in the visible spectrum (~400-900nm). Satellites can capture sections of the EM spectrum outside of this range, making them a powerful tool. Image Credit: Wikimedia Common

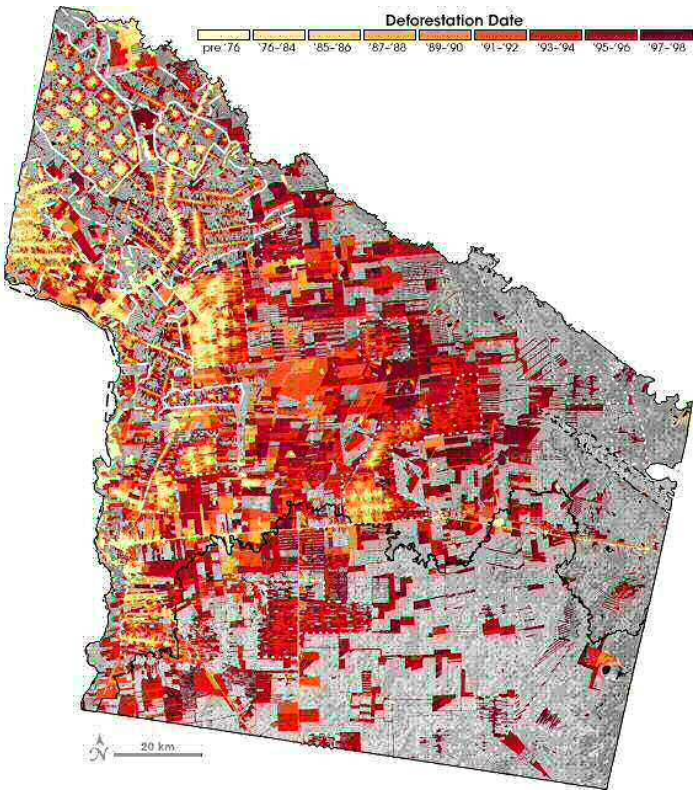


Figure 2. Using imagery the Landsat constellation, the longest running EO satelites (1972 to present day), NASA compiled this detailed map of deforestation over time. Data such as this is used to enforce environmental policies to halt illegal logging practices across the world's tropical rainforests. Image Credit: NASA

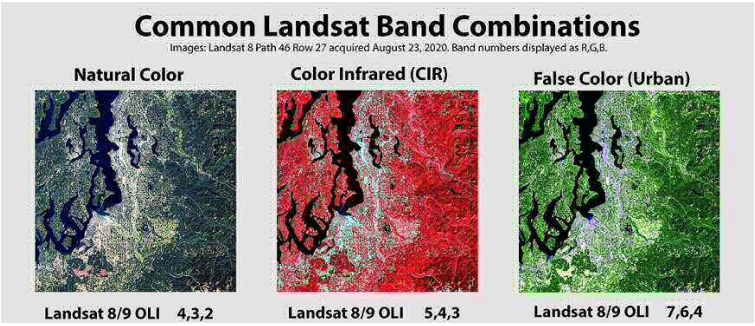


Figure 3. Using different combinations of spectral bands (layers that make up a colour image), certain features can be emphasized by applying 'false' colours. In a standard false colour composite (CIR), live green vegetation appears bright red/pink. This works because the nearinfrared wavelength reflects most strongly in live vegetation. Image Credit: NASA/USGS

Conclusions & Take-Home Message

When we look at Earth from our ground-level perspective it can be easy to think our impact is not as profound or far-reaching as it really is. But looking from space gives us an invaluable perspective on how much we already have and continue to alter our planet's natural ecosystems, thereby changing the natural cycles of this pale blue dot that we call home. Learning to live sustainably and combat climate change is a challenge to humanity that will require skilled people from all sectors and disciplines to solve, and the use of satellite imagery is one powerful tool that we have at our disposal.

Remote sensing and geographic information sciences (GIS) is an advancing field of study that involves digital image manipulation and geospatial (location) analysis. As our satellite technology improves, so too does our ability to extract critical information about Earth's resources from it and apply it to improve the state of our world. Environmental scientists with knowledge of these technical skills are highly in demand and sought after for a wide range of roles such as environmental consulting, natural resource conservation, environmental engineering, geosciences, mapping and mining, and the energy sector.

Additional learning and interest resources can be found here:

Google Earth Timelapse
https://world.time.com/timelapse/

Remote Sensing for Beginners
https://storymaps.arcgis.com/stories/cb1577b0f5bc485c974b4ea19d52282d

Natural Resources Canada Remote Sensing Tutorial
https://www.nrcan.gc.ca/maps-tools-and-publications/satellite-imagery-and-air-photos/tutorial-fundamentals-remote-sensing/9309

Current earth observation research conducted by NASA/USGS
https://www.usgs.gov/centers/eros

Lab 3: Making eBooks to Engage with Cell Biology
Capturing student-narrated explanations of mitosis and meiosis

Gabrielle J. Tompkins, Dalhousie Integrated Science Program

(Gabrielle.Tompkins@Dal.Ca)

Introduction

Cells are the basic units of structure and function of organisms, and all cells come from preexisting cells. **Cell division** is the process by which new cells form from existing cells.

Cell division functions in **reproduction, growth and development**, and **tissue maintenance**. Cell division increases the number of cells during development. Organisms that have stopped cell division for growth will still have ongoing cell division for maintenance – to renew and repair tissues. Cell division can also lead to the formation of **gametes** (eggs or sperm).

In this lab, we will focus on **cell division in eukaryotes** (organisms in which the chromosomes are contained within a membrane-bound nucleus). Eukaryotic cell division requires the following:

1) **Duplication of chromosomes** (structures which DNA is packaged into) – that is **replication of DNA** contained withing the chromosomes
2) **Division of the cell contents** to form two separate cells from a single starting cell.

In short, cells replicate their DNA, segregate the DNA copies to the two opposite poles of the dividing cell, and then split the cell in half to form two cells.

Cell division is part of the overall **cell cycle**; the life cycle of a cell from the time a cell arises from a **parent cell** until it divides to form two new **daughter cells**. For most of the cell cycle (~90% of the time), the cell is in a phase called **interphase**. During interphase the cell grows, new organelles are made, and chromosome DNA is replicated. Interphase is followed by **mitosis** or **meiosis**, depending on the tissue a cell is located in. Mitosis and meiosis are processes within the cell cycle that lead to **division of genetic material (DNA)**. **Cytokinesis** is the process that divides the **cytoplasm**.

- **Mitosis** produces **two genetically identical daughter cells from each parent cell**, allowing growth or cell replacement.
- **Meiosis** produces gametes in animals or spores in plants. Meiosis produces **four genetically non-identical daughter cells**. Each daughter cell has **half the chromosomes of the parent cell**.

Mitosis and meiosis in secondary school (details from https://curriculum.novascotia.ca/)
Nova Scotia secondary students are introduced to mitosis and meiosis in **Science 9** and further explore details in **Biology 11 and 12**. In **Science 9** students are expected to **illustrate and**

describe the basic processes of and appreciate the **purpose of mitosis and meiosis**. Students share explanations using simple **models to represent stages**; and **compare** the two processes without necessarily memorizing stage names.
Biology 11 students learn **how DNA within chromosomes is replicated** and consider the role of chromosomes in transmitting hereditary information to new cells. **Biology 12** students are expected to **describe mitosis and meiosis in detail**. Students are encouraged to present their understanding with **simulations** such as moving images (i.e., flip book/animation) or by arranging simple materials (i.e., pipe cleaners) to represent pairs of homologous chromosomes (a maternal and a paternal chromosome) through the steps in both mitosis and meiosis. Students should be able to apply their understanding to **sketch and describe stages**. For meiosis, students should know **crossing-over creates genetically distinct gametes**, and **reduction in chromosome number** is necessary in gamete formation.

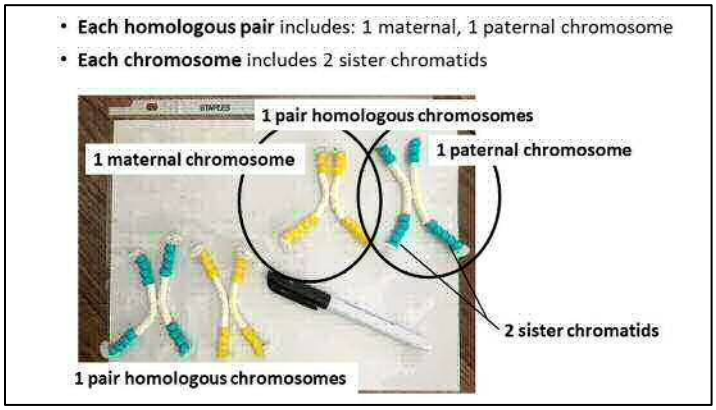
Lab objective: Embed student descriptions of mitosis and meiosis in eBooks

This lab facilitates **student-led learning of mitosis and meiosis** and incorporates elements and objectives already included in the Nova Scotia secondary school curriculum **(bolded in previous section)**. Students are given **simple materials/models** (mitosis and meiosis figures from their text, white boards, pipe cleaner chromosomes, dry erase markers/eraser) and an iPad with the Book Creator app to capture and **publish their explanations** in eBook form – creating a study aid for future use.

Instructions (complete in a group of 3-4)

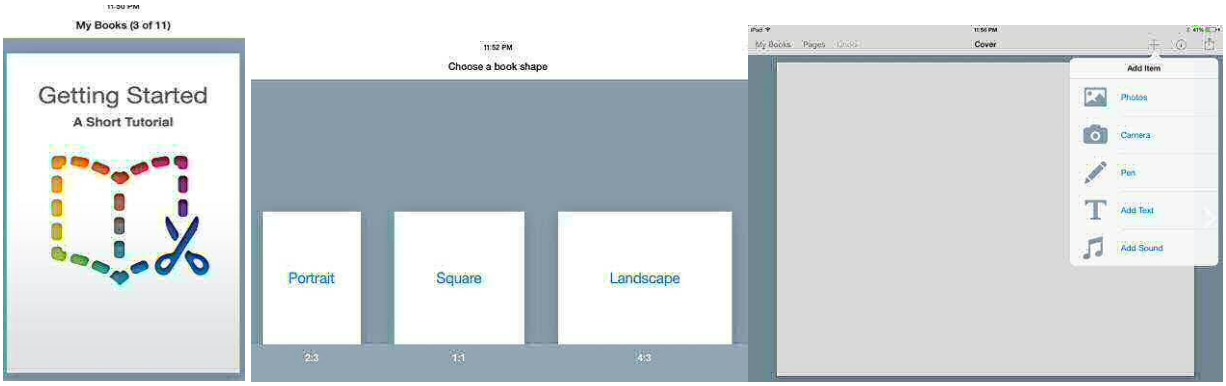
1) Gather materials for eBook preparation:

- A white board that will represent a cell
- Dry erase markers for drawing in microtubules
- White board eraser to erase microtubules
- iPad with the Book Creator app
- iPad stylus (optional)
- Photocopied textbook sections with background on mitosis and meiosis (see end of handout)
- Two pairs of homologous chromosomes (below)



2) Work through the Book Creator in-app tutorial to learn how to make an eBook

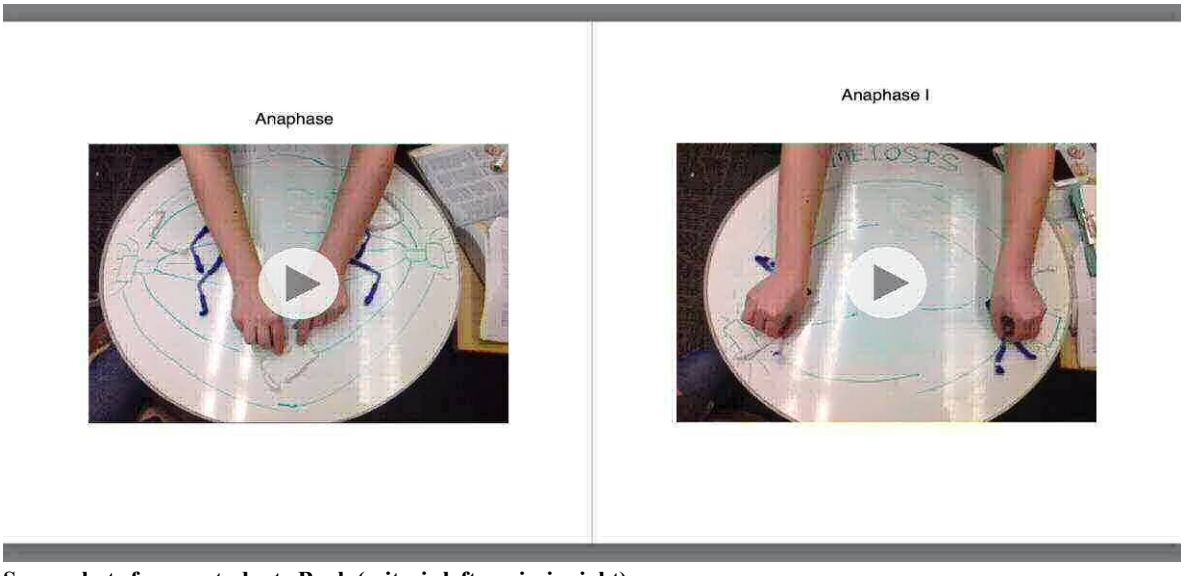
Open Book Creator and find the eBook "Getting Started – A Short Tutorial." Book Creator allows you to insert video or images (from your camera or photo library) with associated text (typed or written) into pages of a digital book. You can also insert audio clips.



Screen shots from Book Creator "Getting Started. A Short Tutorial"

3) Prepare and capture your descriptions of the major events in mitosis and meiosis

Use the flexibility of the eBook app to capture and annotate your descriptions of the mitosis and meiosis stages below**. Use the provided materials** (homologous chromosome pairs, white board, and markers) to illustrate the stages.



Screenshots from a student eBook (mitosis left, meiosis right)

Partition tasks within your team. For example, work together on content but assign members to 1) narrate, 2) move chromosomes within the cell (whiteboard), 3) draw in or erase microtubules,

4) record video. Video is useful for showing processes that involve movement or change over time. If you prefer still photos, annotate and/or add audio clips to describe the images.

Position equivalent stages of mitosis and meiosis on adjacent pages in your eBook. This will allow you to make highlight key differences. To facilitate stage-by-stage comparisons, you will not be asked to include prometaphase (in mitosis only). Interphase will be the same in mitosis and meiosis

Mitosis	**Meiosis I**
Interphase	Interphase I
Prophase	Prophase I
Metaphase	Metaphase I
Anaphase	Anaphase I
Telophase and Cytokinesis	Telophase I and Cytokinesis
	Meiosis II
	Prophase II
	Metaphase II
	Anaphase II
	Telophase II and Cytokinesis

Use the mitosis and meiosis **summary figures from your textbook to assist you** in developing your script or text for your eBook. **Include the following terms in your eBook** (instructor may adjust this list):

homologous chromosomes • sister chromatids • centromeres • crossing over • tetrad • synapsis • kinetochores • kinetochore and non-kinetochore microtubules • spindle • DNA • diploid/haploid

Tips and clarifications for mitosis and meiosis descriptions:

A duplicated chromosome with two chromatids is still considered a single chromosome because the two copies remain connected together. We go from one duplicated chromosome to two chromosomes only after the sister chromatids of the duplicated chromosome separate. In mitosis anaphase and in meiosis anaphase II, sister chromatids separate and are pulled to opposite ends of the dividing cell.

Synapsis is the key event distinguishing meiosis from mitosis and occurs during meiosis prophase I. In synapsis the maternal and paternal chromosomes in a homologous pair attach. This allows maternal and paternal chromosomes to exchange DNA at points of contact, shuffling genetic information. Synapsis impacts next steps in meiosis because the homologous chromosomes stay attached as a tetrad when lining up at the midline of the cell (in metaphase I). This dictates how chromosomes eventually separate.

Steps in meiosis II are identical to those in mitosis. It may be possible to refer to previous eBook pages.

4) Publish your eBook

To finalize your book, tap on My Books and select the action button (square with arrow inside) at the bottom of the page. Select Export as ePub (for reading in iBooks and editing) and choose "Books" (formerly iBooks) to open in Apple Books. Publishing as a PDF as well is recommended as a backup. In Books you can rename your project using "edit" then the square action button. You can then further share your book. The options for sharing will depend on installed apps. Students can, for example, sign in to and upload their book to Google Drive.

Mitosis and Meiosis Simulation Student Checklist (can be used by instructor to develop a rubric)

- ✓ Chromosomes duplicated in interphase
- ✓ Chromosomes have correct number of chromatids in all steps
- ✓ Spindle formation in prophase
- ✓ Crossing over of homologous chromosomes shown in meiosis prophase I
- ✓ Recombinant chromosomes shown after meiosis prophase I
- ✓ Microtubules (kinetochore and non-kinetochore) drawn
- ✓ Chromosomes line up in correct orientation during metaphase (individually in mitosis and meiosis II; in pairs in meiosis I)
- ✓ Chromatids pulled apart in mitosis anaphase; chromosomes pulled apart in meiosis anaphase I
- ✓ Haploid cells labelled n; diploid cells labelled 2n
- ✓ Consistent chromosome number
- ✓ Use terms in correct context
    - Homologous chromosomes
    - Sister chromatids
    - Centromeres
    - Crossing over
    - Tetrad
    - Synapsis
    - Kinetochores
    - Spindle
    - Kinetochore microtubules and non-kinetochore microtubules
    - Diploid/haploid
- ✓ Clarity: Is the eBook easy to follow with logical flow of information and stages in the correct order?
- ✓ Materials: Student names included on title page. External sources credited.

Additional tips and information for getting started with iPad learning activities

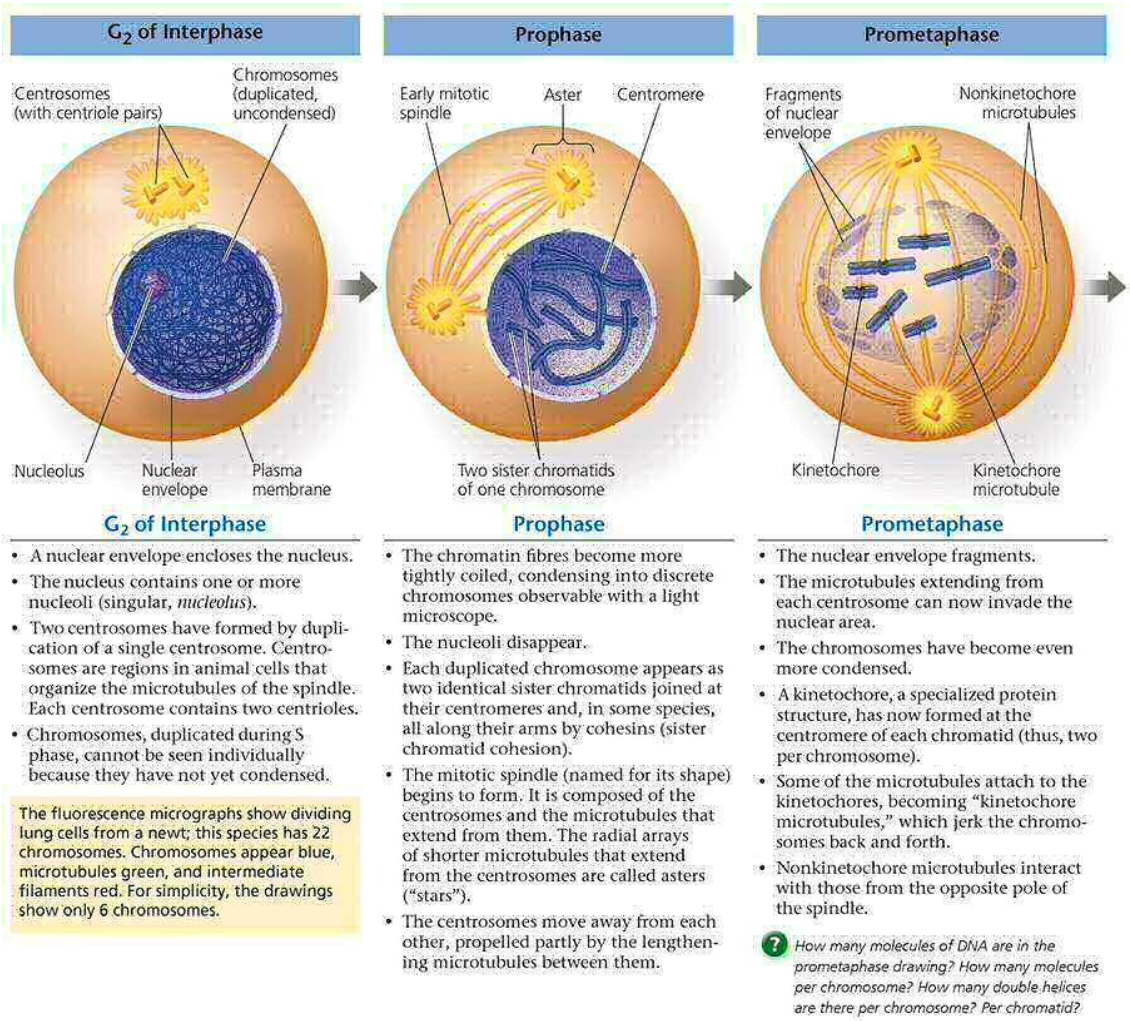
You will need an iTunes account and password to purchase apps. If you are managing 10 iPads or less, you may wish to have a single iTunes account shared across devices because a single app purchase can be synced on up to 10 iPads with the same iTunes ID. iTunes gift cards can be used to load funds. Alternately, apps can be purchased in bulk through Apple's Volume Purchase Program.

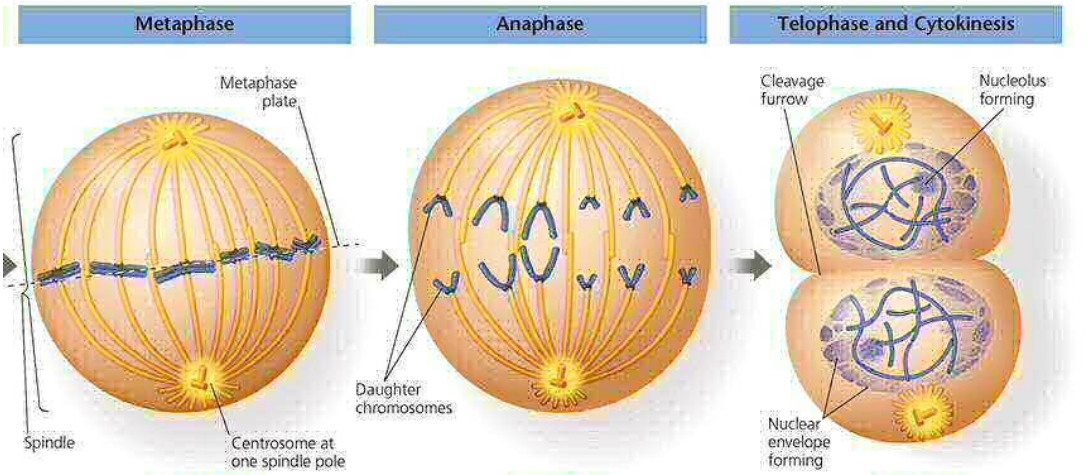
Other app/device combinations can be easily used to capture student explanations if Book Creator for iPad is not an option. Explain Everything, Canva and Microsoft PowerPoint, for example, can be used on mobile devices or computers.

Supporting Mitosis and Meiosis textbook figures

From: Campbell Biology / Jane B. Reece [and nine others]. 2021. Third Canadian Edition: Pearson.

Figure 12.7. Exploring Mitosis in an Animal Cell





Metaphase

- The centrosomes are now at opposite poles of the cell.
- The chromosomes have all arrived at the *metaphase plate*, a plane that is equidistant between the spindle's two poles. The chromosomes' centromeres lie at the metaphase plate.
- For each chromosome, the kinetochores of the sister chromatids are attached to kinetochore microtubules coming from opposite poles.

Anaphase

- Anaphase is the shortest stage of mitosis, often lasting only a few minutes.
- Anaphase begins when the cohesin proteins are cleaved. This allows the two sister chromatids of each pair to separate. Each chromatid thus becomes a distinct chromosome.
- The two liberated daughter chromosomes begin moving toward opposite ends of the cell as their kinetochore microtubules shorten. Because these microtubules are attached at the centromere region, the chromosomes move centromere first (at about 1 μm/min).
- The cell elongates as the nonkinetochore microtubules lengthen.
- By the end of anaphase, the two ends of the cell have equivalent—and complete—collections of chromosomes.

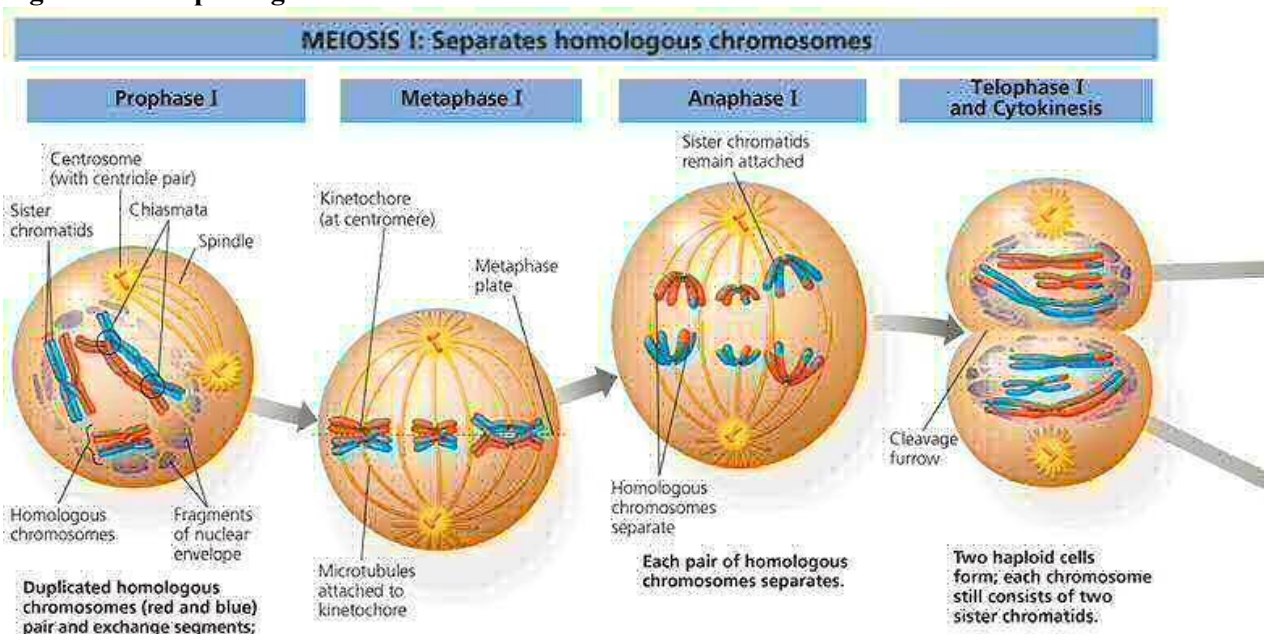
Telophase

- Two daughter nuclei form in the cell. Nuclear envelopes arise from the fragments of the parent cell's nuclear envelope and other portions of the endomembrane system.
- Nucleoli reappear.
- The chromosomes become less condensed.
- Any remaining spindle microtubules are depolymerized.
- Mitosis, the division of one nucleus into two genetically identical nuclei, is now complete.

Cytokinesis

- The division of the cytoplasm is usually well under way by late telophase, so the two daughter cells appear shortly after the end of mitosis.
- In animal cells, cytokinesis involves the formation of a cleavage furrow, which pinches the cell in two; in plant cells a cell plate forms.

Figure 13.8. Exploring Meiosis in an Animal Cell



Prophase I

- Centrosome movement, spindle formation, and nuclear envelope breakdown occur as in mitosis. Chromosomes condense progressively throughout prophase I.
- During early prophase I, before the stage shown above, each chromosome pairs with its homologue, aligned gene by gene, and **crossing over** occurs: The DNA molecules of nonsister chromatids are broken (by proteins) and are rejoined to each other.
- At the stage shown above, each homologous pair has one or more X-shaped regions called **chiasmata** (singular, *chiasma*), where crossovers have occurred.
- Later in prophase I, after the stage shown above, microtubules from one pole or the other will attach to the two kinetochores, one at the centromere of each homologue. (The two kinetochores of a homologue, not yet visible above, act as a single kinetochore.) The homologous pairs will then move toward the metaphase plate.

Metaphase I

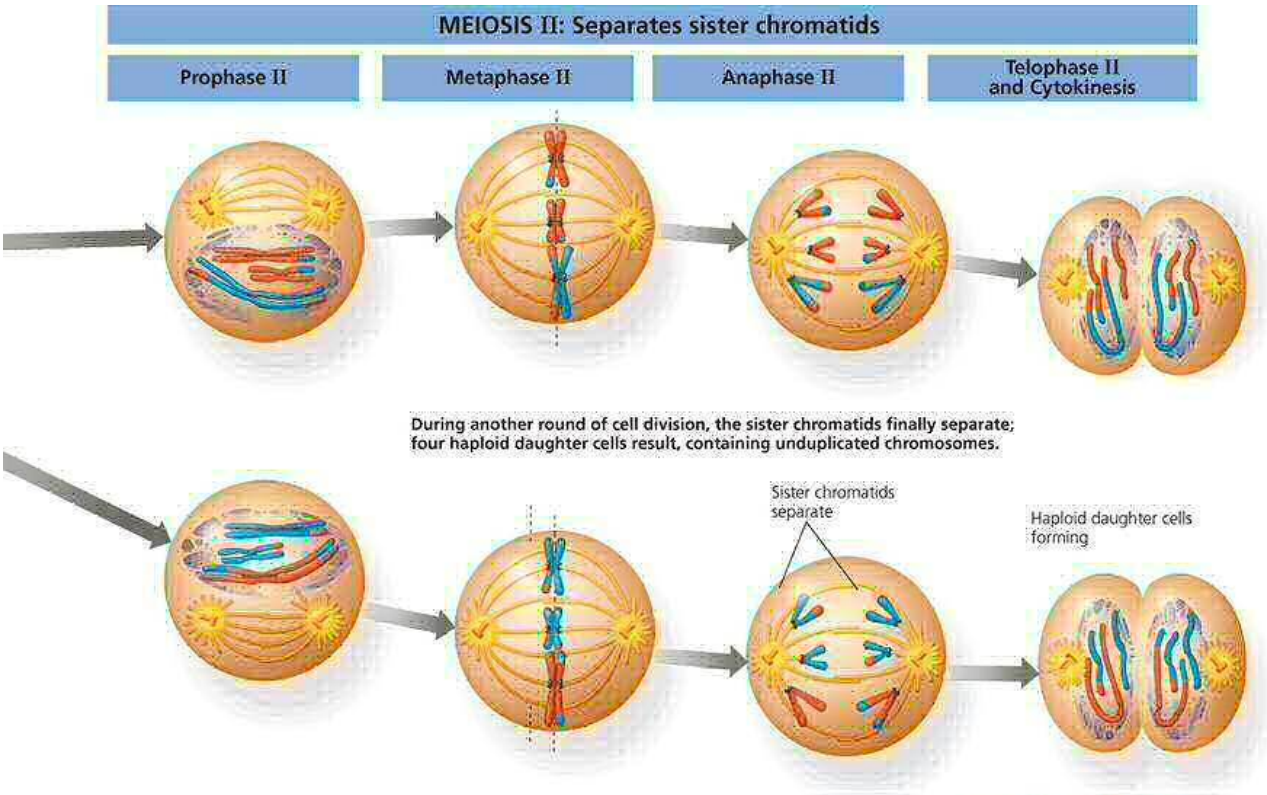
- Pairs of homologous chromosomes are now arranged at the metaphase plate, with one chromosome in each pair facing each pole.
- Both chromatids of one homologue are attached to kinetochore microtubules from one pole; those of the other homologue are attached to microtubules from the opposite pole.

Anaphase I

- Breakdown of proteins that are responsible for sister chromatid cohesion along chromatid arms allows homologues to separate.
- The homologues move toward opposite poles, guided by the spindle apparatus.
- Sister chromatid cohesion persists at the centromere, causing chromatids to move as a unit toward the same pole.

Telophase I and Cytokinesis

- When telophase I begins, each half of the cell has a complete haploid set of duplicated chromosomes. Each chromosome is composed of two sister chromatids; one or both chromatids include regions of nonsister chromatid DNA.
- Cytokinesis (division of the cytoplasm) usually occurs simultaneously with telophase I, forming two haploid daughter cells.
- In animal cells like these, a cleavage furrow forms. (In plant cells, a cell plate forms.)
- In some species, chromosomes decondense and nuclear envelopes form.
- No chromosome duplication occurs between meiosis I and meiosis II.



Prophase II

- A spindle apparatus forms.
- In late prophase II (not shown here), chromosomes, each still composed of two chromatids associated at the centromere, move toward the metaphase II plate.

Metaphase II

- The chromosomes are positioned at the metaphase plate as in mitosis.
- Because of crossing over in meiosis I, the two sister chromatids of each chromosome are *not* genetically identical.
- The kinetochores of sister chromatids are attached to microtubules extending from opposite poles.

Anaphase II

- Breakdown of proteins holding the sister chromatids together at the centromere allows the chromatids to separate. The chromatids move toward opposite poles as individual chromosomes.

Telophase II and Cytokinesis

- Nuclei form, the chromosomes begin decondensing, and cytokinesis occurs.
- The meiotic division of one parent cell produces four daughter cells, each with a haploid set of (unduplicated) chromosomes.
- The four daughter cells are genetically distinct from one another and from the parent cell.

Lab 4: Earth Sciences
Minerals and Crystal Structures

Developed by: Dr. Richard Cox, Senior Instructor, Department of Earth and Environmental Sciences, Dalhousie University (Email: Richard.Cox@Dal.Ca)

Presented by: Prof. James Brenan, Department of Earth and Environmental Sciences, Dalhousie University (Email: JBrenan@Dal.Ca)

Introduction

Minerals are the building blocks of our planet. The rocks, sediments and soils that make up the surface and interior of the Earth are all composed of minerals and by studying them we can construct a record of the very long history of our planet. The natural resources which are used to make products we have become dependent on in our society, things we use on a daily basis, are all ultimately composed of, or are derived from, different minerals. The physical properties of minerals are controlled by their crystal structures, their chemical compositions, and these are in turn related to the wide range of different conditions under which minerals crystalize and grow. This module follows the format of a number of lectures given to our second year students in Mineralogy.

Definition of a Mineral: A naturally occurring inorganic element or compound having orderly internal structure and characteristic chemical composition, crystal form, and physical properties.

Objectives:

The goal of this module is to help students to understand what minerals are and that their physical properties such as hardness, their shapes, their colours, densities, etc., are all properties they have because of their crystal structures ***and*** chemical composition. This general concept in mineralogy is called ***crystal chemistry*** and is the way most modern mineralogy courses are taught. Following these exercises students can be encouraged to participate in follow-up exercises where they can begin to understand the continuing importance of minerals as natural resources for our modern world.

Materials:

Some of the materials for the exercises will be provided so that we can demonstrate the learning concepts. This will include:

Some minerals specimens for illustrating different properties;

A hardness testing kit;

Some HCl for reactivity tests;

There are a number of additional items that may be obtained to help create more in-depth lessons for your students. These are:

Glass beakers or similar, and string for growing crystals;

A hand lens or pocket microscope;

Some graduated measuring beakers (preferably plastic and with a scale in mL);

An inexpensive digital balance available from most hardware/home furnishing stores.

A small bottle of dilute (~10%) hydrochloric acid (HCl) will be provided but it is advised that this only be used to demonstrate the reactions to the students (Ex.6). HCl can be purchased at the hardware store as muriatic acid. The solution should be no more concentrated than 10% HCl for use in reactivity tests, so you may have to dilute this using appropriate plastic bottles and safety precautions. A Materials Safety Data Sheet (MSDS) sheet with important safety information has also been provided.

Access to a Bunsen burner or a propane torch will be required for any simple flame emission tests. The latter can also be purchased at hardware stores.

It is recommended that a simple mineral guidebook be purchased and there are many available. One that is commonly recommended to students as an introductory guide is the National Audubon Society Guide to Rocks and Minerals. However, every mineral guide will be arranged in the same way, using the mineral's chemical grouping (the Dana Classification), and every guide will have the physical properties of each mineral listed. Two excellent on-line databases are: https://www.mindat.org/ and, http://webmineral.com/. Both these online resources are used extensively by our students. They also contain crystal models for many minerals, which we will use in these exercises, and are routinely updated by the geoscience community to provide the most comprehensive information.

PART 1 - Crystal structures: Minerals have properties that are closely related to their crystal structure such as form, hardness and cleavage. In the first part of this module we will examine the properties which are largely controlled by the structure of a suite of minerals.

Ex. 1 Growing crystals of Halite (NaCl) and Sylvite (KCl)) and basic flame spectroscopy

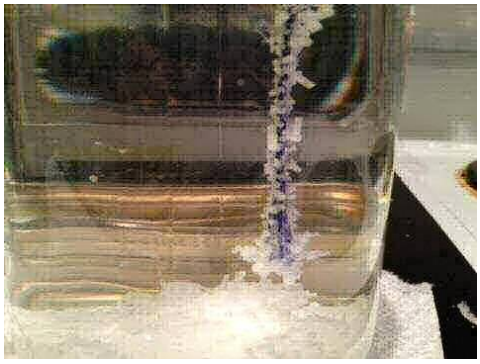
The so-called "form" of a crystal are the shapes that occur when crystals grow, reflecting the underlying symmetry of the atoms as they are arranged in the crystal structure. In order to demonstrate forms and crystal growth to your students you can produce halite and sylvite crystals using available table salts. The standard table salt is comprised of mostly NaCl (along

with some anti-caking agents), but there is also a product called NoSalt which is 99% KCl. You will need a small beaker or glass (about the size of a small juice glass is fine).

1) Fill the glass about half way with warm water, add salt and stir until it dissolves.

2) Continue until it appears that the salt is no longer dissolving.

You have now made a saturated salt solution. If you leave the beaker in a bright widow undisturbed, crystals will begin to form on the walls of the beaker and continue to grow as evaporation occurs. NOTE: The warmer the water the more salt you can dissolve and the larger and faster the crystals will grow. You can also place a pencil with some string or thread tied around it over the glass and let the string sit in the solution. It is interesting to compare the size and the rate of growth of crystals on the threads versus those that grow on the sides and bottom of the glass. If you are lucky, they will look like the crystals in Fig 1 (a) below.



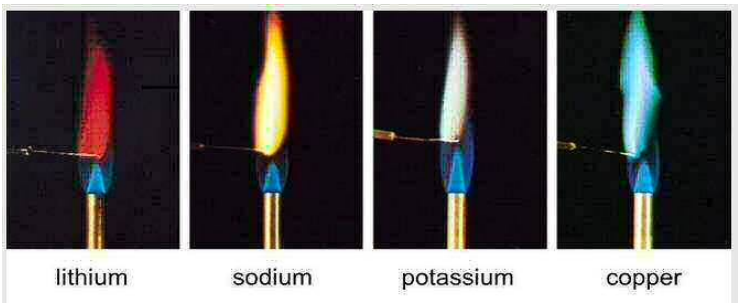


Figure 1:

(a) Halite crystals in a saturated solution *(b) flame emission colours for various elements*

Once grown, you can get the students to look at the forms of the halite crystals and compare them with the crystal models on MinDat. These will generally be small cubes stacked together. The crystals will have the same morphology (cubic crystals) as for both halite and sylvite. So, how do we tell them apart?

For this test you will need a Bunsen burner or propane torch, wooden splinters or other combustible but absorbent material (P-C compostable wooden knives work well), fire-retardant safety glove and safety goggles.

1) Grind up some of the crystals.
2) Wet the splinters or other absorbent material, then touch the splinter to the salt powder, causing some of the powder to adhere to the splinter.
3) Hold the splinter over the flame. The one with adhering NaCl powder will flare a bright yellow (in Fig 1 (b) above).
4) The splinter with KCl powder will flare a lilac/white (in Fig 1 (b) above).

5) It is also possible to purchase other salts that contain different elements with other emission colours. For example, LiCl (which also forms cubic crystals) will flare in a reddish colour.

Ex. 2 (a and b) Hardness, cleavage and crystal structures

(a) Hardness: Following on from the discussion of structures, we can use the hardness kit provided to create a Mohs Hardness Scale. We can then look at the example of diamond and graphite using the crystal models to determine why minerals have different harnesses and how this relates to crystal structure.

1) Use the common objects shown on the scale below (Fig 2) to initially group the nine minerals e.g., harder than copper coin but softer than steel blade. The rules for relative hardness are that harder always scratches softer, but materials with the same hardness will both scratch each other. Note that sometimes a softer material appears to leave dust when "scratching" a harder material, but in fact it is the harder mineral that is abrading the softer one!

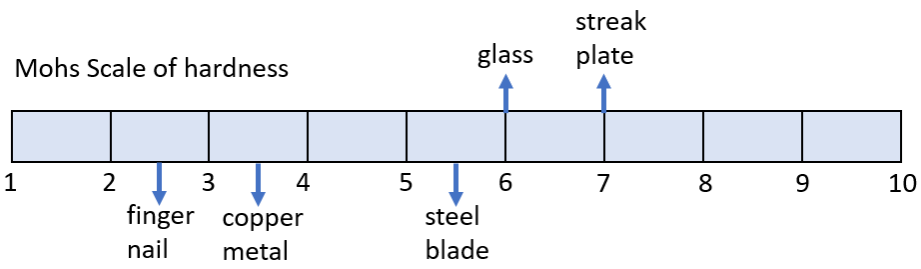


Figure 2: A Mohs hardness scale with the hardness of common objects shown

2) Students can then test the mineral hardness against each other i.e., 1 is softer than 2 and so on. Importantly, they can use the hardness of the common objects (copper metal, steel blade, etc) to place any mineral on this relative scale.

3) Note that the numbers on the mineral specimens do in fact correspond to their hardness but you can leave your students to figure this out themselves.

So, what controls hardness in minerals? Examine graphite and diamond using two crystal models (Figure 3) and on MinDat. Both are made of carbon, with the mineral formula of "C". However, the differences lie in the internal arrangement of the carbon atoms. Graphite is composed of single hexagonal (graphene) sheets which are only loosely bonded together essentially by electrostatic forces. Diamond is cubic and each carbon atom is bonded to four other carbon

atoms to form small tetrahedral shapes. This means there are no clear weaknesses in the structure.

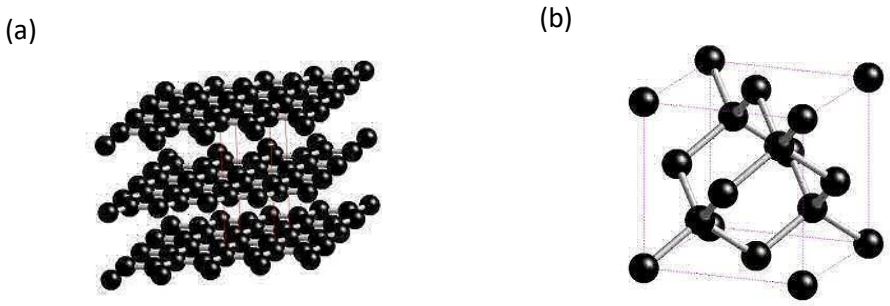


Figure 3: (a) Hexagonal graphite showing weak planes between the individual graphene sheets, (b) cubic diamond structure with no obvious planes of weakness.

(b) Crystal cleavage: Cleavage is visible as a break which can produce what appears to be flat crystal faces. Cleavage occurs in minerals that have specific planes of weakness and these are inherent in the structure of the mineral down to the atomic scale. Look at samples of gypsum (selenite, ($CaSO_4.2(H_2O)$), halite (NaCl) and calcite ($CaCO_3$) which are of a similar hardness, but break to form different shapes along cleavage planes.

1) Look at gypsum, halite and calcite using the crystal models below (Figure 4) and also on MinDat and find the smallest reproducing unit (shape) in the model.

2) Halite (a) is essentially a series of simple cubes. Gypsum (b) forms thin, rhombic shapes which is why the crystals have angular cleavage planes you can see in the real sample. Calcite (c) is similar to gypsum in that it forms rhombic shapes but has 60/120^o cleavage angles, so forms more regular rhombic fragments which look like 3D parallelograms.

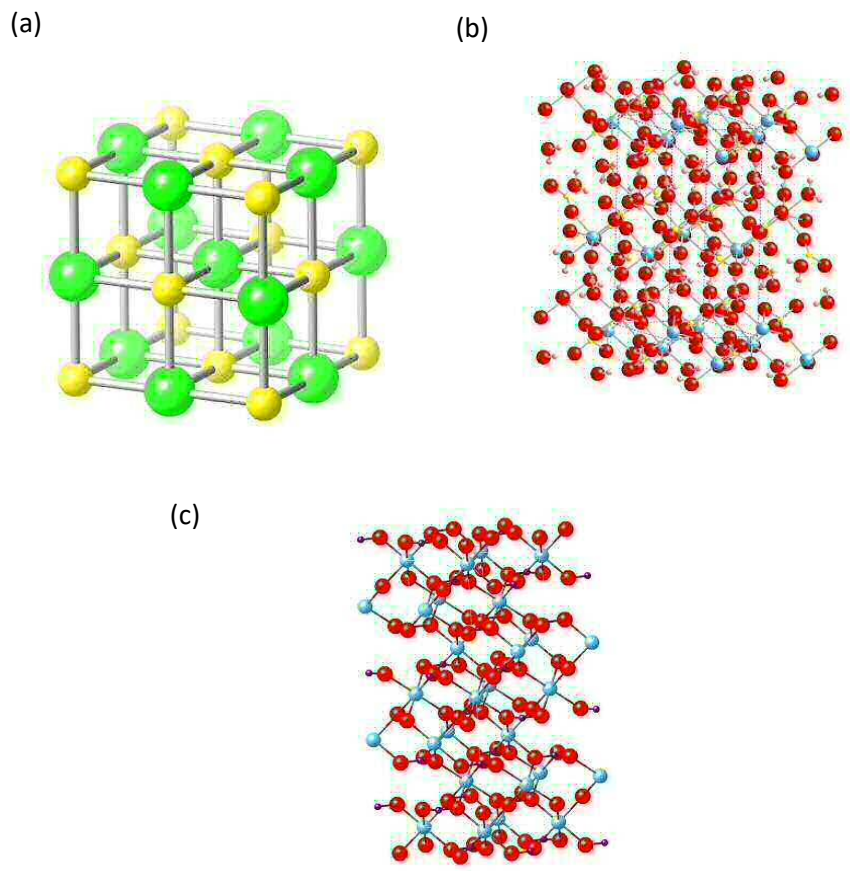


Figure 4: (a) Cubic halite structure showing why it breaks into cubes and (b) the more complex gypsum structure which forms angular cleavage planes which can be seen in the mineral sample. The calcite structure (c) has cleavage planes at 60/120º angles and forms more regular rhombic blocks when broken.

Part 1 Conclusions

Hardness, and the way a mineral breaks (cleavage), are controlled by the internal structure of the crystal, i.e. the way the atoms are bonded together. This can be demonstrated on a hand specimen scale using the models and samples provided. This is one of the best and easiest ways to make the link between a physical property and a 3D crystal structure. It also serves to illustrate that, although minerals have relatively simple formulas, they are not always simple molecular structures. And now that we have shown this concept, we can begin to link the crystal structures and chemical compositions of minerals together.

PART 2 - Crystal chemistry: The properties of minerals which are in part related to their chemical compositions can now be examined. It should be noted that these properties are still controlled by the crystal structure of a mineral as well (hence the term crystal chemistry).

Colour can be a misleading property for mineral identification, as it only takes a small amount of a chromophore (colour-causing element) such as Fe, to cause significant changes to mineral colour, and therefore minerals can have the same colour but very different structures. However, there are also cases in which two minerals may have similar structures, but only one of them incorporates colour-causing elements in significant quantities, making colour differences a good diagnostic tool.

Transparency and ***luster*** are also related to chemical composition. Minerals which have a metallic luster tend to have high levels of transition metals (Fe, Mn, Ti, etc) in their structure and some can be opaque (i.e. you can't see through them) when illuminated in visible light, although may become transparent in other wavelengths. Minerals like quartz are transparent as they contain little or no impurity transition metals.

Ex. 3 Colour in minerals with the same structure

Look at the two different samples of mica in Figure 5. In these images, (a) is muscovite and (b) is biotite. You can also use MinDat to show the atomic-scale structures as well.

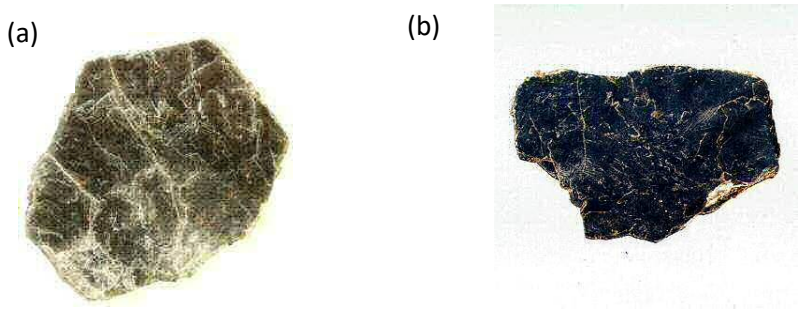


Figure 5: Basal sections of (a) muscovite and (b) biotite.

What obvious physical property suggests that these minerals have a similar structure? The answer is that they have a very clear basal cleavage which causes them to break into flat sheets. These minerals are in fact called *sheet silicates*. What obvious physical property suggests that these minerals have different formulas, i.e. elements present in their crystal structures? The answer is of course that biotite is dark brown and muscovite is clear.

Look at the formulas for these minerals. Which is likely to represent muscovite and which is biotite?

1) $KAl_2(AlSi_3O_{10})(F,OH)_2$ 2) $K(Mg,Fe)_3(AlSi_3O_{10})(F,OH)_2$

Mineral (2) is biotite as shown by Fe in the formula. The lack of any transitional metals (including Fe) is why muscovite is generally colourless. Both minerals are transparent to translucent (you can see through them) and have a dull luster. This can be demonstrated by peeling off a thin sheet from each sample.

Specific gravity (SG) is a measure of the density of a mineral relative to a reference material. Mineralogists usually refer to the SG in terms of the density of the mineral divided by the density of water; SG is a unitless quantity. The density of water is very close to 1 gm/cm^3 at temperatures up to ~25^{o}C and atmospheric pressure, so the SG of a mineral determined under those conditions is essentially equal to the mineral density. The SG of a mineral can reflect both the internal arrangement of its atoms (i.e., how densely arrayed they are) as well as the identity of those atoms (i.e., is it comprised of "heavy" or "light" atomic mass elements). Therefore, simply picking up similar volumes of two otherwise identical minerals (i.e., colour, cleavage, etc) can be used as an identification tool if the SG's show a measurable contrast.

Ex. 4 Measuring specific gravity (SG)

To measure SG in minerals you will need a graduated measuring vessel of some kind and a simple digital balance. Two sulphate samples, barite ($BaSO_4$, *SG = 4.8*) and anhydrite ($CaSO_4$, *SG=2.97*) have been provided for the test. The SG can be calculated as:

SG_{sample} = (Mass $_{Sample}$ / Vol $_{sample}$) / (Mass $_{water}$ / Vol $_{water}$)

As mentioned, the mass of water / volume of water should be ~1, i.e., if you measured out 100 mL (assuming 1 mL = 1 cm^3) of water it would weigh 100 gm. Measuring the mass of the sample is also easy, you can just weigh it on a balance.

So how do we measure the volume of an irregularly shaped sample?

(1) Put some water (say 200mL = Vol_{water}) in a graduated beaker.

(2) Place the beaker on the balance and TARE (zero) the balance.

(3) Place the mineral specimen into the beaker and measure the new volume (Vol_2).

The volume of the mineral sample is: **$Vol_{sample} = Vol_2 - Vol_{water}$** ***(let's say the sample = 135 mL = 135 cm^3)***

(4) Record the sample mass. (***say 400 g***)

(5) Use the formula above to calculate the SG.

Note, if you want to increase the accuracy of your SG calculation, you should also measure the temperature as well, and use an on-line calculator for the density of water (https://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html)

So now it is simply mass (400 g) / volume (135 cm^3)/ 1 g/cm^3 H_2O = 2.96. The sample would be anhydrite. You can repeat the experiment for the barite sample.

So why do gypsum and barite have such different specific gravities?

Solubility and Reactivity: Minerals can be described in general terms such as soluble, normally in reference to water, or reactive in reference to another reagent (such as dilute HCl).

Ex. 5 Reactivity: The acid test

Limestone **(a)** is a rock composed essentially of ***Calcite***. A strong and instantaneous reaction occurs when cold HCl is placed on calcite:

$2HCl + CaCO_3 \rightarrow CO_2 + H_2O + CaCl_2$ which is apparent in Figure 6 (a and b).

Both are sulphate minerals: Anhydrite is: **$CaSO_4$**. Barite is: **$BaSO_4$**. Both have identical structures (look at this on MinDat) and formulas and therefore have the same number of atoms in a given volume. Specific gravity should therefore scale directly with molecular weight. Oxygen has an atomic mass of ~16 and S has a atomic mass of ~32. However, Ba has an atomic mass of ~137 and Ca has an atomic mass of ~40 (see Periodic Table to the left). So the molecular weight of anhydrite is 40 + 32 + (16 x4) = ~120 and for barite is 137 + 32 + (16 x 4) = ~217. Therefore, barite has ~1.8 times greater molecular weight than anhydrite, which is only slightly larger than the ratio of SGs which is ~1.6.

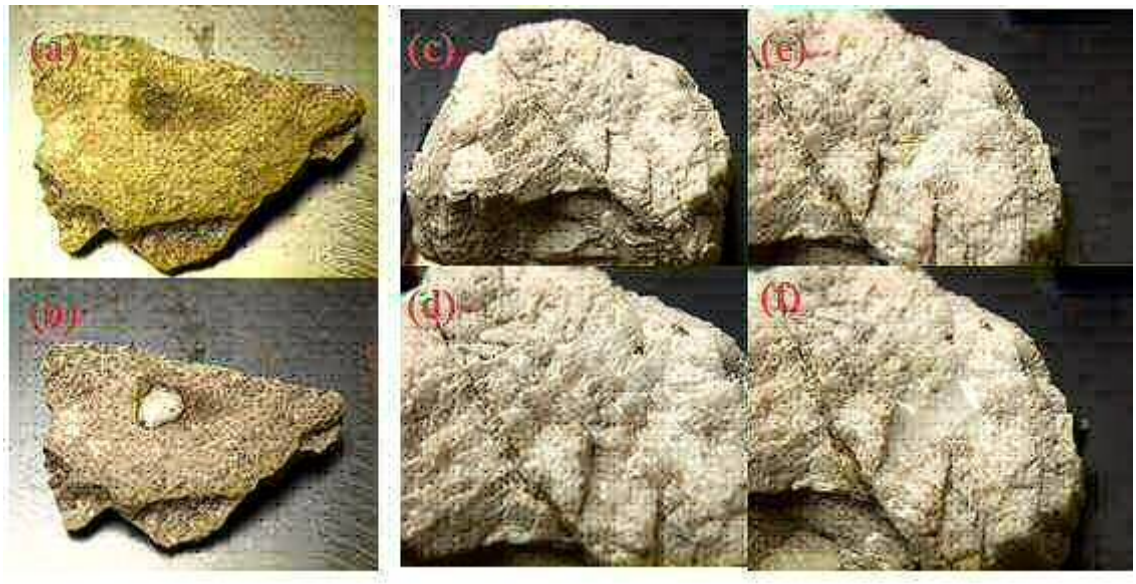


Figure 6: Reactivity with cold HCl shown for calcite (a and b) and dolomite (c to f).

In contrast, the mineral ***Dolomite*** (c) and the carbonate rock dolostone, are composed of $MgCa(CO_3)_2$. As shown in (c and d) there is little or no initial reaction with cold HCl. However, if a small portion of the sample is powdered (e) the reaction with HCl is stronger (f), although not quite as vigorous as with calcite. The reaction is:

$$4HCl + MgCa(CO_3)_2 \rightarrow 2CO_2 + 2H_2O + CaCl_2 + MgCl_2$$

There are a number of other carbonate minerals that can be identified due to their reaction with cold HCl. However, calcite shows the strongest reaction of all, and the rates of reaction vary considerably, as by the comparison between calcite and dolomite, which is a reflection of the underlying chemistry of the individual minerals.

Part 2 Conclusions

Like all other chemical compounds, minerals contain atoms that are arranged into 3D crystal structures and the combination of atoms can be written in terms of a fixed chemical formula. As such, minerals have both physical and chemical properties that indicate their internal atomic arrangement and the identity of the constituent atoms. As seen in these exercises, the chemical compositions can be reflected by, for example, differences in colour, or values of SG or their reaction with acids. Also, differences in the internal arrangement of atoms can be reflected by hardness or in the way that a mineral breaks along certain preferred orientations (cleavage). All of these properties illustrate the important links between the structure, composition and external physical properties of minerals, providing the essential foundation for the various methods of mineral identification.

PART 3 - Mineral Identification: Now that we have established a basic understanding of crystal chemistry and the tests that can be used to show the link between crystal structures and physical properties, you can construct simple diagnostic testing exercises for your students. In the kits you have been supplied, there is a set of sulphide minerals. These are common ore minerals, which are mined for so-called base metals, such as Fe, Cu and Ni. Their physical properties are listed in the table below. We will demonstrate how to identify each mineral in this set using these properties, and this exercise can then be used to build similar exercises for other mineral groups.

Ex. 6 Identification of common ore minerals (sulphide minerals)

Examine Table 1 below and use the physical properties listed to correctly identify each of the sulphide minerals in the kit. One of the best ways to complete an exercise such as this is to make a "from – by" table or flow chart. For example, pyrite, pyrrhotite and chalcopyrite are all types of Fe-bearing sulphide minerals and are also yellow to brown coloured and metallic. So, at first glance they may appear to be very similar. However, it is quite clear that pyrite is much harder than either pyrrhotite or chalcopyrite.

So;

*Pyrite can be distinguished **from** pyrrhotite and chalcopyrite **by** hardness.*

From the table it is also apparent that pyrite tends to form cubes and has a brighter yellow colour and luster as well. These properties will confirm that you have indeed identified pyrite. How do we tell pyrrhotite from chalcopyrite? Again, from the Table 1 below, pyrrhotite is commonly magnetic whereas chalcopyrite is not.

So;

*Pyrrhotite can be distinguished **from** chalcopyrite **by** magnetism.*

Chalcopyrite also shows a brassy colour and brighter luster due to the high Cu content. So again, we have several properties that can be used to confirm the correct mineral identification. If you follow this "from-by" methodology you will quickly be able to identify all the minerals in the Table, and of course this approach can be applied to any group of minerals. The principle therefore is to establish a general idea of the mineral groups (a sulphide, a carbonate, a silicate, etc.) and then limit the possibilities to the most likely. Minerals can also be identified by their association with other minerals in specific rock groups, such as in a granitic rock, in sedimentary layers with fossils, and so on. This also greatly limit the types of minerals likely to be present and helps with the initial identification.

Table 1: A summary of different physical properties for different sulphide minerals.

	Mineral and mineral Formula				
	Galena	*Pyrite*	*Pyrrhotite*	*Chalcopyrite*	*Sphalerite*
	PbS	FeS_2	$Fe_{x-1}S$	$CuFeS_2$	ZnS
Colour / Luster / Transparency	Silver to grey, bright metallic luster. Opaque.	Yellow to golden yellow or white, bright metallic luster. Opaque.	Bronze to brown, with a dull metallic luster, Opaque.	Brass yellow, with a metallic luster. Oxidizes to iridescent luster. Opaque.	Brown to red, dull luster. Sometimes transparent.
Crystal Habit / Form	Forms cubes with striations on surfaces. Commonly twinned.	Forms cubes with striations on surfaces. Commonly twinned.	Mainly massive and granular habit.	Massive, but can show prims with twinned crystals.	Octahedral (cubic) crystals with twinning.
Hardness / Streak	~2.5 with a lead grey streak.	~6-6.5. Dark green to dark brown streak.	~3.5-4.5. Grey to black streak.	~3.5-4.5. Dark green to black streak.	~3.5-4. Yellow to brown streak.
Cleavage / Fracture	Perfect cubic cleavage.	Poor cubic cleavage, uneven fracture.	Uneven fracture with a basal parting.	Uneven fracture and highly brittle.	Conchoidal fracture.
Specific Gravity (SG)	Very high density (>7)	High density (~4.9-5.2)	High density (~4.7)	Medium to high density (~4.2)	Medium to high density (~4)
Other properties			Commonly, (weakly) magnetic.		Sulphurous odour when crushed.

Further exercises

An all too common public perception is that natural resources are no longer required by modern society in the amounts that fueled the industrial revolution. This leads many to the conclusion that mining and mineral processing are industries of the past. Nothing could be further from the truth.

To illustrate this, a simple follow up exercises is to ask your students to look up the uses of the minerals in these exercises on the internet. The reality is that all of them have significant industrial uses and/or are processed to extract important elements.

Another follow-up exercise is to look up the elements used in the production of a cell phone (Figure 7) and their sources. All require extraction from minerals. Students may be impressed by not only the large number of elements required, but the extreme rarity of some.

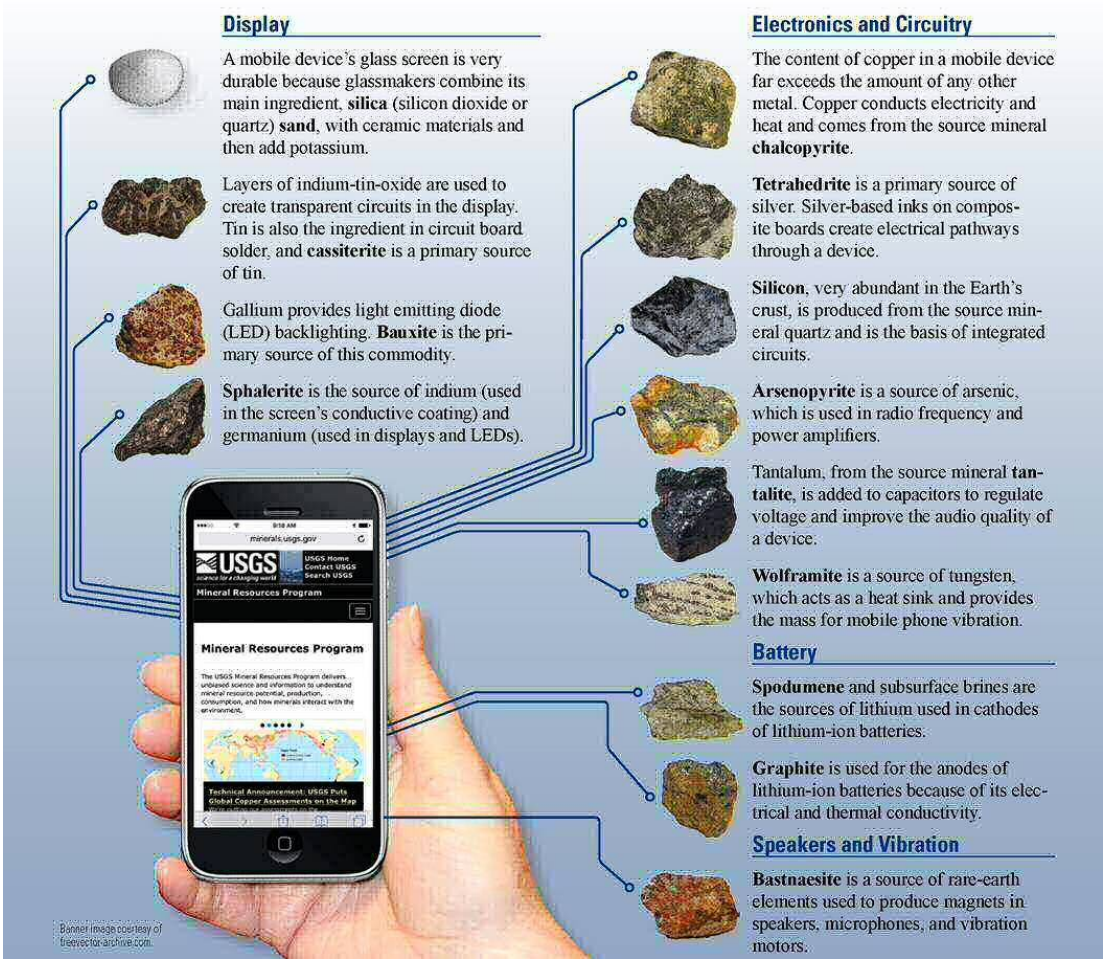


Figure 7: An example of the mineral resources required to produce a cell phone. (USGS website: https://pubs.er.usgs.gov/publication/gip167).

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