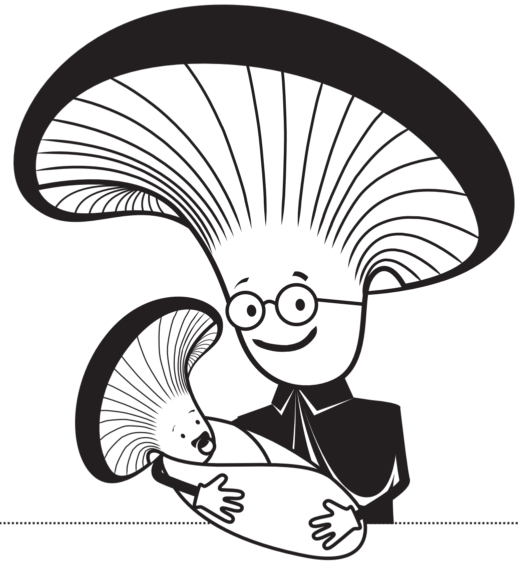


Reproduction and Development

SPORES AND SO MUCH MORE!

At any given time, the air we breathe is filled with the spores of many different types of fungi. They form a large proportion of the "flecks" that are seen when direct sunlight shines into a room. They are also remarkably small; 1800 spores could fit lined up on a piece of thread 1 cm long. Fungi typically release extremely high numbers of spores at a time as most of them will not germinate due to landing on unfavourable habitats, being eaten by invertebrates, or simply crowded out by intense competition. A mid-sized gilled mushroom will release up to 20 billion spores over 4-6 days at a rate of 100 million spores per hour. One specimen of the common bracket fungus (*Ganoderma applanatum*) can produce 350 000 spores per second which means 30 billion spores a day and 4500 billion in one season. Giant puffballs can release a number of spores that number into the trillions. Spores are dispersed via wind, rain, water currents, insects, birds and animals and by people on clothing. Spores contain little or no food so it is essential they land on a viable food source. They can also remain dormant for up to 20 years waiting for an opportune moment to germinate.

WHAT ABOUT LIGHT?

Though fungi do not need light for food production, fruiting bodies generally grow toward a source of light. Light levels can affect the release of spores; some fungi release spores in the absence of light whereas others (such as the spore throwing *Pilobolus*) release during the presence of light.

SEXUAL VS. ASEXUAL REPRODUCTION

Fungi reproduce both sexually and asexually. Sexual reproduction occurs when two compatible mating strains join and recombine their genetic information, whereas asexual reproduction involves only a single parent. There are a variety of ways a fungus could reproduce asexually:

1. There could be a fragmentation of the hyphae in which the pieces go on to grow into their own mycelium.
2. Some fungi, such as yeasts, utilize budding where a small "bud" forms and breaks away from the parent cell.

3. Most commonly, fungi reproduce asexually by forming spores. When conditions are right the spore starts to grow. A hypha grows from the spore, and begins to branch and weave to form the mycelium. If growing conditions continue to be favourable, the mycelium develops fruiting bodies, which produce new spores.

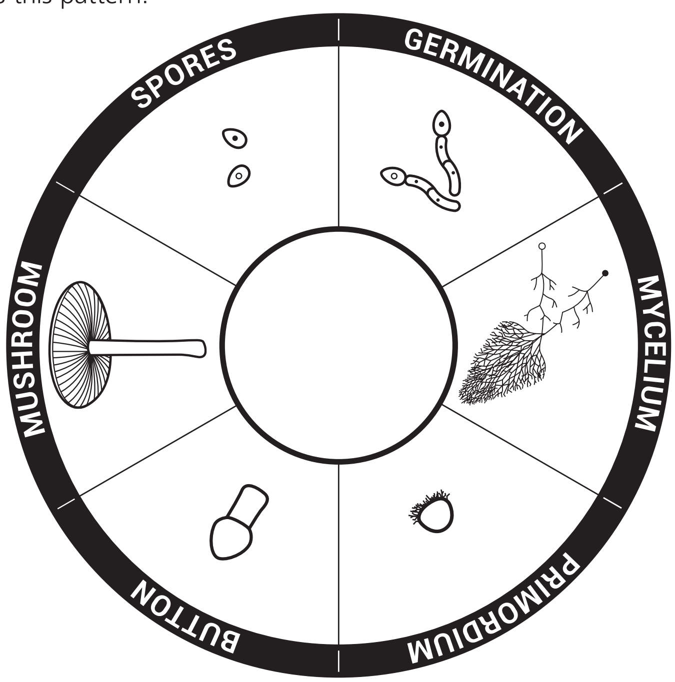
The preferred route for fungi that can reproduce either sexually or asexually is asexual because of its efficiency at producing a massive amount of spores/clones in a short period of time. It appears that sexual reproduction is sometimes undertaken only when conditions become adverse.

SO UH…WHAT GENDER ARE YOU AGAIN?

An interesting point to note about sexually reproducing fungi is that there are often an extremely large number of fungal genders that all look alike; only the fungi themselves are able to tell the difference! This means that almost any two members of the species should be able to undergo sexual reproduction if they meet.

TYPICAL LIFECYCLE OF AGARICS (BASIDIOMYCOTA)

Members of the Phylum Basidiomycota typically reproduce sexually. The basic lifecycle of a basidiomycete—which includes the gilled mushrooms, coral fungi, bracket fungi, puffballs and stinkhorns—follows this pattern:



1. **Spores** are carried away from the fruiting body, and if one lands on an adequate food source, it begins to **germinate** with the formation of a germ tube.
2. The germ tube grows into a hypha which branches into hyphae to form the **mycelium**.
3. If the mycelium encounters another mycelium which is a compatible gender for mating, the strands will join and the fungi will prepare for sexual reproduction. It appears that both moisture and deprivation of food are signals to the fungi to begin the fruiting stage.
4. When the hyphae have absorbed enough food, the mycelium begins to swell at certain points into little bumps called **primordia** (**primordium** sing.).

5. These primordia continue to grow into **buttons** that push upward to the surface.
6. If the conditions remain humid and the button is not subjected to insect attack, a full-sized **mushroom** will develop within a fortnight (two weeks). The mushroom, or fruiting body, is now ready to produce spores that contain a new mix of genetic information that hopefully will be advantageous to the survival of the next generation.

TYPICAL LIFE CYCLE OF BREAD MOULD *RHIZOPUS* (ZYGOMYCOTA)

Black bread mould can either reproduce sexually or asexually. The spores of this fungus are generally quite abundant in living spaces, and this is quite evident when moist bread is left unprotected on a countertop. This is the ideal food source on which the bread mould spore can begin its life cycle.

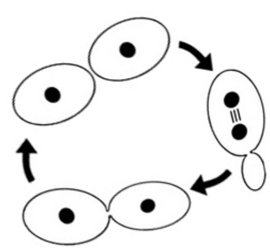
1. Once the spore or spores germinate, their hyphae will penetrate the bread and grow into mycelia.
2. If two compatible mating types meet, they will produce reproductive structures which will unite to form a thick-walled compartment called a **zygosporangium** (zygosporangia plur.).
3. From the zygosporangium, hyphae will grow upward and terminate with a round spore-containing structure called a **sporangium** or **spore case**.
4. When the spores are ripe, the walls of the sporangium split to release the spores.

If the fungus is reproducing asexually (often the preferred method of reproduction), the hyphae themselves will grow erect and form sporangia that contain spores with the same genetic information as the parent mycelium.

TYPICAL LIFE CYCLE OF YEASTS (ASCOMYCOTA)

Like the bread mould, yeasts can potentially reproduce both sexually and asexually. Yeasts are typically categorized by their preferred method of asexual reproduction--which is either by budding or by fission (splitting). Budding occurs when a small bud forms at the poles of the cell on the parent cell and is then released as a clone of its parent. More than one bud can form at any given time so this is a extremely rapid method of reproduction and colonization.

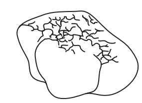
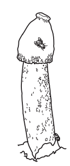
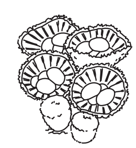
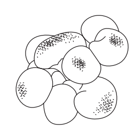
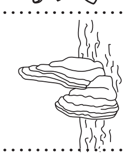
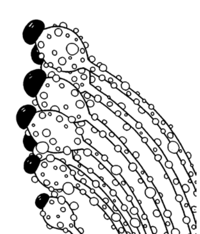
Budding



Yeast can also reproduce sexually, and usually do so under starvation conditions. If they are reproducing sexually, two compatible yeast cells will join to form one cell called an **ascus**. As this cell grows larger, 4-8 spores will form within it. When the spores mature, the cell breaks open and the spores develop into new yeast cells. Alternatively, within the ascus itself, these spores could combine with each other to produce new genetic “offspring” before being released into the environment.

SPORE DISPERSAL

Fungi utilize some incredibly complex methods of getting their spores into the environment. Some of the more interesting methods are explained below:

FUNGI	TECHNIQUE	ILLUSTRATION
Shaggy mane, Inky caps	Most spores are shot away from basidia at the very edge of the gill. The cap then dissolves via autodigestion; enzymes that destroy fungus melting everything, including remaining spores down to the ground.	
Truffles	Truffles produce an odor that attracts mice, squirrels and bears; the spores move undigested through animal's bodies. Truffle hunters in France use dogs and female pigs to sniff out truffles.	
Stinkhorns	Stinkhorns rely on insects; they produce a slimy odorous substance that smells like rotting flesh or excreta. Carrion flies are attracted to the smell and as they walk on the fungus, the spores stick to their feet and are carried off.	
Bird's nest fungi	A drop of water hits an "egg" and it pops out of the nest scattering the spores.	
Puffballs	Some of these fungi have a blowhole, and when it rains, drops fall and hit the sides and cause the spores to jump out. Others are like tumbleweed and blow around spilling their spores as they go.	
Earthstars	The rays of these fungi are closed up and protective when it is sunny. When it rains, the rays open up, and the rain drops splash the spores around.	
Bracket fungi	These fungi reorient if tree falls; in some species, beetles gnaw holes through the fruiting body and the spores fall through the hole into the air.	
Pilobolus	*Pilobolus* is phototropic which means it reacts to light. This fungus grows on horse dung; the clear bulbs at the terminal end explode and shoot spores onto vegetation at speeds up to 50km/hr and as far as 2m! There the spores are eaten by a herbivore whose digestive system dissolves the outer casing, readying it for germination in droppings.	

Wheel of Life

OBJECTIVE
- To familiarize students with the stages of a typical agaric lifecycle.

BACKGROUND INFORMATION
Refer to background information on page 32

TEACHER INSTRUCTIONS
1. Copy the handout Wheel of Life on page 54 for each student.
2. Have the students cut out the six puzzle pieces and arrange them in the order that reflects the agaric lifecycle. When completed correctly, the pieces fit into a circle in order from spores through germination to mycelium to mushroom, and back to spores. See page 37 for solution.
3. You may decide to have students colour the puzzle pieces and glue them onto construction paper.
4. Students may label each stage of the agaric's life cycle. You could call out various characteristics present at a certain stage of the life cycle and have students name the stage it represents or have them tell you the story of the lifecycle as they assemble their puzzle.
5. A great book that shows the mushrooms lifecycle is Barrie Watts' Mushroom 1986. See Sources and Resources page 90.

Activity 2.1

GRADES
K-4

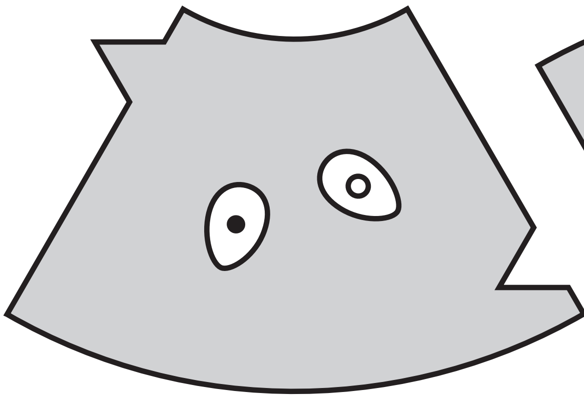
TYPE OF ACTIVITY
Simple Puzzle

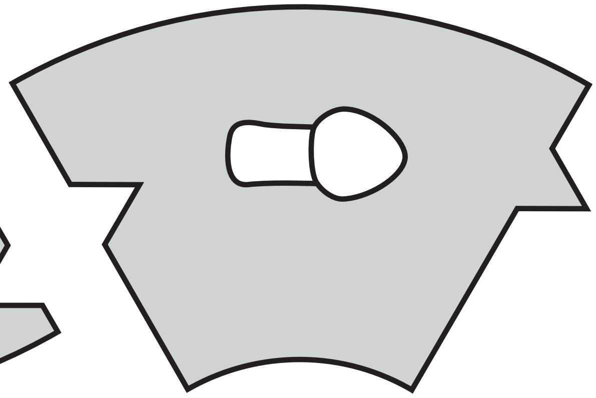
MATERIALS
- copies of page 36
- pencil crayons, crayons, or markers
- glue
- scissors
- construction paper (optional)

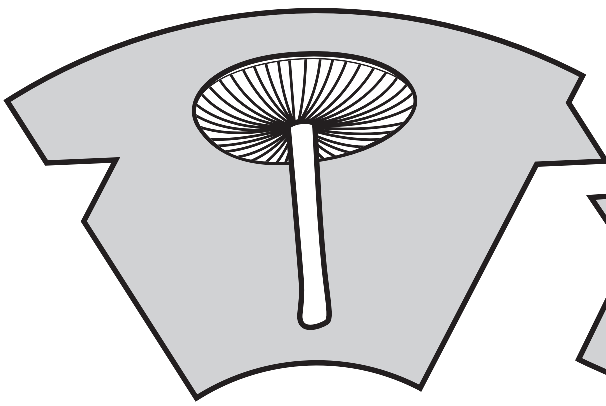
VOCABULARY
agaric
button
germination
mycelium
mushroom
primordium
spores

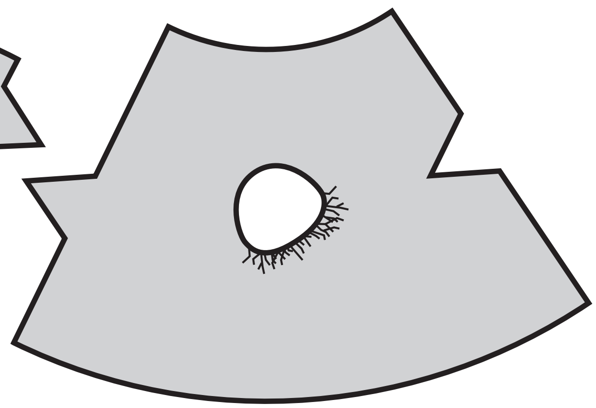
Directions

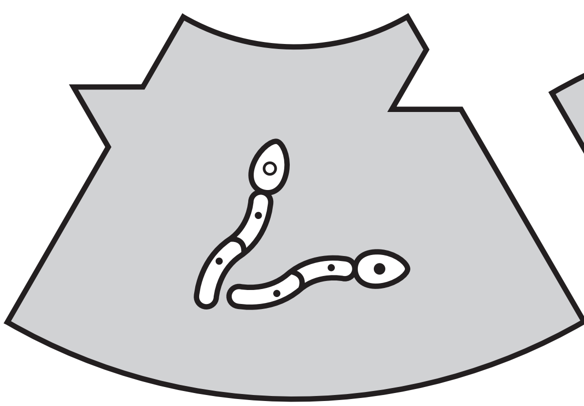
Cut out the six puzzle pieces and place them in the order that shows a gilled mushroom's lifecycle.

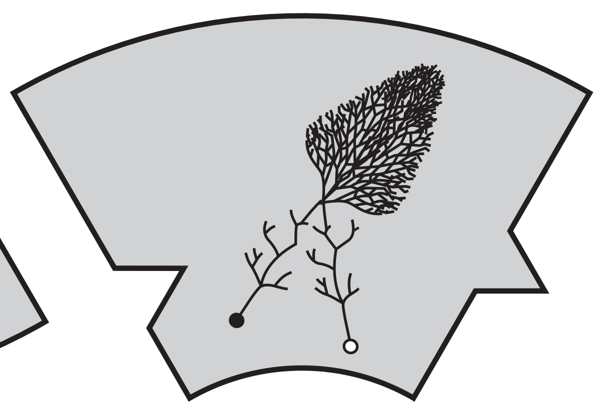




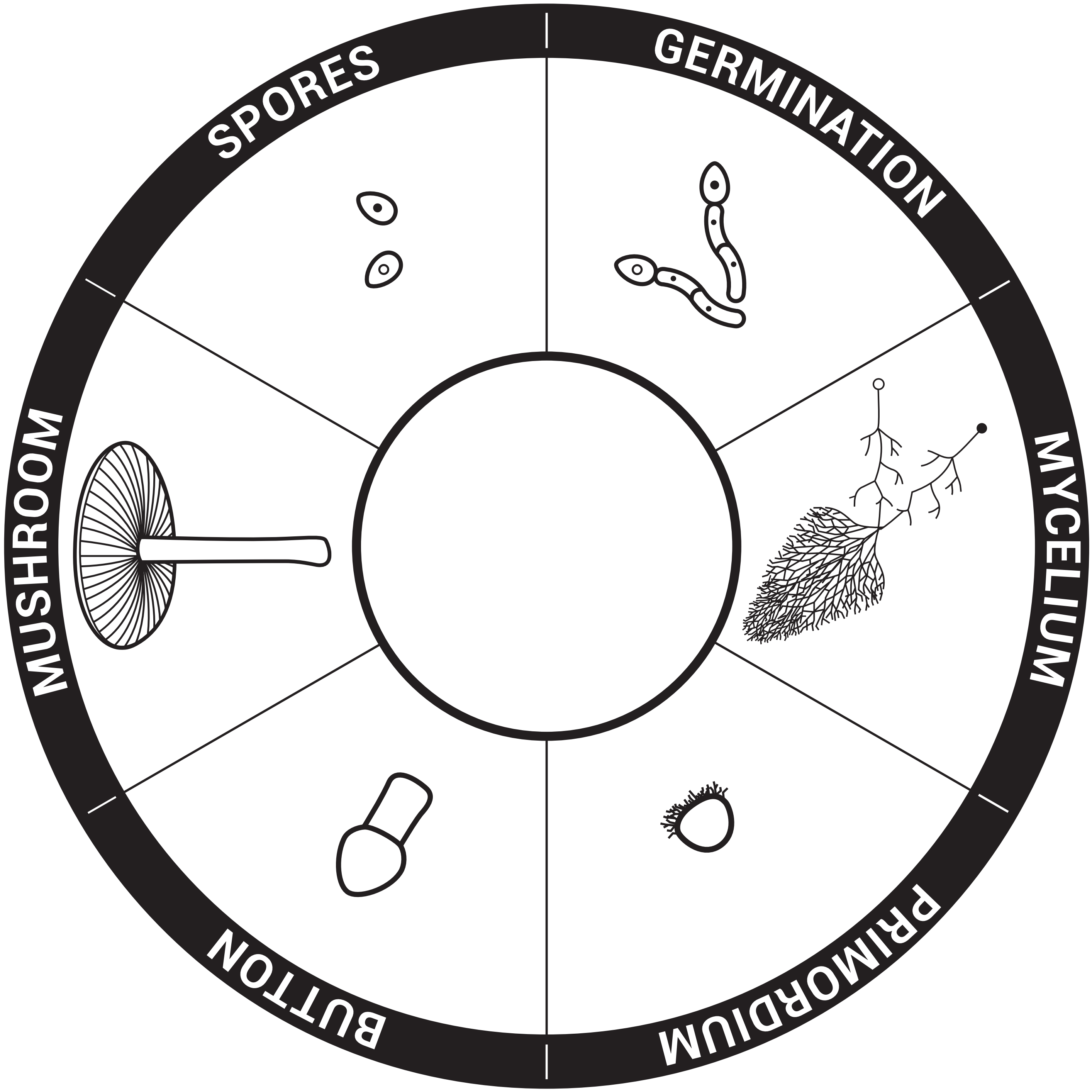








Wheel of Life



Adventures in Moulds and Yeasts

Activity 2.2

GRADES
2-6; **Worksheet** 4-6

TYPE OF ACTIVITY
Experiments; worksheet

MATERIALS
See text body

VOCABULARY
chitin
fission
spores

WARNING!
Before beginning any of the following experiments, make sure due caution is given to prevent direct exposure to molds:

1. Take care in handling all specimens.
2. Make sure to always view moulds through glass or plastic.
3. Make sure nothing is eaten from the experiment.
4. Make sure hands are washed after handling the materials.
5. If you have any students with severe allergies, they may be advised to leave the class during the experiments.

OBJECTIVE
- To expand student knowledge of fungi beyond mushrooms and illustrate some of the properties of moulds and yeasts

BACKGROUND INFORMATION
Most everyone is familiar with moulds; it is what turns our bread black, makes our oranges mushy, and appears like magic on last week's yogurt. Yeast is also readily recognizable to anyone who has been in the kitchen when bread, donuts, or pizza dough are being made--and surely we all know what mushrooms are! What will come as a surprise to students though is that mushrooms, moulds, and yeasts are all members of the Kingdom Fungi. The characteristics that unite these organisms are: their food must come from an external source (unlike plants which can make their own food); they reproduce using **spores**; and they have cell walls that contain **chitin**.

Although moulds are generally inconspicuous and perceived as a nuisance, they have literally changed history for the better. In 1928 a Scottish scientist named Alexander Fleming made medical history when he discovered that the mould *Penicillium* released a chemical that prevented bacteria from growing near it. From this lemon-loving mould, the antibiotic drug Penicillin was developed. Over the last century Penicillin has saved the lives of millions of people world-wide, as well as protecting crops and farm animals from various infections. That is a lot of heroic work for a little mould!

Yeasts are no slackers either! For being nothing more than a single-celled organism, they have leavened breads and given rise to alcoholic beverages for thousands of years. They have also been celebrated for their nutritional qualities as natural sources of folic acid, niacin, riboflavin, pantothenic acid, and other B vitamins. Yeasts have the capability to go dormant in the absence of food and water, but when moisture, food, heat and oxygen are right, yeasts flourish and will grow rapidly.

In the following activities, students will become more familiar with the lifestyles of these microorganisms.

ACTIVITY 1: MUSHROOMS AND MORE

Materials:

- the best possible variety of mushroom samples. Consider: field mushrooms, shitakes, wood ears, Chinese white fungus (*Tremella*), enoki, oyster mushrooms, chanterelles, morels, blue cheese. Most of these are easily found in supermarkets or Asian markets.
- mouldy bread and/or mouldy citrus in ziploc bags (see Activity 2 for instructions)
- sampling of yeast products. Consider: bread, donuts, root beer, Brewer's yeast, nutritional yeast, Marmite/Vegemite
- an example of a plant. Consider: a head of lettuce, some carrots or beets with their tops
- Anatomical Anagrams worksheet from page 25

TEACHER INSTRUCTIONS

1. Place all the objects on a table. Ask the students to point out the item that does not belong (*the plant*). At first everything might seem edible, but guide students to thinking in terms of the biological kingdoms. Emphasize the mould on the citrus fruit rather than the fruit itself. This is a tricky question!
2. Once the outsider is identified, get the students to group the remaining items into three categories: mushrooms, moulds, and yeasts. Tell them that even though these items look very different, they do in fact have a lot in common; they are all members of the same biological kingdom.
3. Review the characteristics of the Kingdom Fungi. It may help to contrast the plants. These differences are illustrated in the text body of the activity Fungi--The Hidden Kingdom on page 8.
4. Share some information about moulds and yeasts. Remind students that mushrooms are like the fruit of a fungus and are analogous to an apple on an apple tree. It is also interesting to note that from only a small piece of mushroom stem or cap, a whole new organism can grow! This is because a mushroom is just an extension of the fungal body, which usually hides underground.
5. Next, hand out copies of the worksheet, Anatomical Anagrams, and have the students complete the worksheet. Go over the answers as a class.
6. While students are working on their worksheet, draw a simple diagram of yeast budding on the board. Point out the little "bud" and explain why it is called budding. If students get a chance to view active baker's yeast under the microscope at 400X magnification, they will mainly be viewing budding which is the fastest way to reproduce.
7. Have the students copy down the diagram on the back of their Anatomical Anagrams worksheet. Ask them if they have ever watched a person make bread or if they have done it themselves. Touch on the idea of just how fast yeast can reproduce under the right conditions. The faster they bud, the more gas they release, and the faster the bread will rise!

ACTIVITY 2: MOLD GARDEN

Materials:

- bread. Consider a variety: organic whole wheat, "Wonderbread", sourdough, rye, etc.
- variety of foods both organic and containing preservatives. Consider: cheeses, fruits, salad, meats
- items from living origins. Consider: fabric scraps, leather, paper, wood
- items from non-living origins. Consider: plastic utensils, wire, old batteries...
- traditional preservatives: salt, vinegar, sugar
- large jars or transparent plastic containers
- water sprayer
- plastic wrap

TEACHER INSTRUCTIONS

1. Begin with a brief discussion about spores. Explain that mould spores are everywhere and, in fact, most of the flecks we see when sunlight enters the room are actually spores. Remind students that unlike seeds, spores need to land on a suitable food source in order to germinate; seeds carry a "packed lunch" with them but spores do not.
2. Ask students if they have ever seen bread go mouldy. When did this happen? Why do they think it happened?
3. Refer them to the diagram of the mould on their worksheet. Explain that when moist bread is left of a table, it becomes a very inviting meal to spores. Spores will land on the bread and germinate into hyphae and form a mycelium. Then some of the hyphae extend upwards and form spore cases at tips of each upright hyphae. When spores are ripe, walls of spore cases split and the spores are released into the air and the cycle begins again.
4. Tell the students you are going to make a series of mould gardens to discover where moulds will grow-- in other words, their habitat.
5. For each mould garden, students will need to write a hypothesis comparing the likelihood of mould growth. There are so many variants for "themed" gardens. For example, in a "bread garden", students could predict which types of bread would develop mould the fastest. Have students read the labels and look for preservatives that may retard mould growth. There could also be two alternative bread gardens to compare to a control; one in which the bread was misted with vinegar instead of water and another misted with salt water.
6. To prepare the items for gardening, gently mist them with water and leave them exposed for 30 minutes.
7. Place them in the jar or plastic container and cover with plastic wrap; poke a few small holes for air circulation.
8. Put the containers in a warm, dark place and observe after a few days. Have the students record their initial observations. DO NOT open the containers once mould has started to grow.
9. Continue to observe the gardens every few days.
10. Some of the conclusions that students should draw is that mould grows best on moist foods such as soft fruits. Salt and vinegar should inhibit or delay mould growth. Mould also has the potential to grow on things that are made from materials that were once alive. It is highly unlikely mould will form on any plastics in the time frame of the experiment.
11. Discuss with the class things they can do to minimize the chance of mould invading their favourite foods. You can talk about refrigeration and putting lids on things to prevent air circulation. You may also want to talk about the use of salt and vinegar to make pickles as a way of traditionally preserving vegetables and meats/fish and sugar in the preserving of fruit as jam.

EXTENSIONS

1. Place a few dead flies in a jar with some stream water and wait 3 weeks. Students will observe that insects can also be a food source for fungi.
2. Start a compost in an aquarium. Not only will moulds grow, but the whole family of decomposers will come out to play!

ACTIVITY 3: YEASTS GONE WILD!

Part 1 Materials:

- 3 balloons
- 3 empty pop bottles (500mL)
- electrical tape
- funnel

- sugar
- dry baker's yeast (quick rise is good!)
- a warm place, tub with warm water or heating pad
- a thermometer

TEACHER INSTRUCTIONS

1. Remind students briefly about the release of gases during budding. If you capture these gases, you can blow up a balloon BUT you need to give yeast the right conditions in order to do so. (*happy yeast will blow bubbles!*)
2. Mix together 1-1/2 cups warm water, 3 Tbsp sugar and 3 Tbsp dry yeast and using a funnel, pour the mixture into 3 pop bottles.
3. Blow up the balloons a few times to create some "give" in them; then place a balloon over the mouth of the bottles and seal it with electrical tape.
4. Put one bottle in a warm place such as on a heating pad on a low setting or in a warm water bath with the target temperature between 24-30 degrees Celsius.
5. Leave another bottle at room temperature and place the third one in a cool place.
6. Have students make predictions about which yeast will be happiest and which balloon will blow up the fastest.
7. Discuss your observations. What does this say about the conditions yeast needs to multiply? Ask your students if they have ever seen anyone make bread. Where do they put the bread to rise? A warm place or a cool place?

Part 2 Materials:

- variety of natural and artificial sweeteners. Consider: honey, maple syrup, molasses, fruit juice, corn syrup, brown sugar, Splenda, aspartame
- beakers, jars or glasses to correspond to number of sweeteners
- masking tape to label jars
- dry baker's yeast
- a warm place, tub with warm water or heating pad to target 24-30 degrees Celsius
- a thermometer to check ambient temperature
- rulers

TEACHER INSTRUCTIONS

1. Tell students that you will be conducting an experiment to discover yeast's favourite foods. Imagine they are gourmet chefs serving up delicacies to their yeasty patrons. The way they will be able to tell if the yeast is enjoying their meal is by the amount of foam that forms on top of the liquid.
2. Add 1 Tbsp of sweetener and 1 Tbsp of dry yeast to 1/2 cup of warm water. Stir thoroughly. Leave one jar without any sweetener at all.
3. Label the jars.
4. Record the class predictions about what food source the yeast will prefer.
5. After 15 minutes and 30 minutes, measure the amount of foam that has formed.
6. Explain why the yeast did not grow in the jar without sweetener (*no food, no reproduction*). How is this different from plants? (*plants don't need an external food source as they make their own*) Then explain that the yeast did not like the artificial sweeteners because they do not have very much energy in them (which is why people on diets sometimes use them).

Part 3 Materials:
- dry baker's yeast
- a banana

TEACHER INSTRUCTIONS
1. Slice the banana in half lengthwise.
2. Put some dry yeast on one half and nothing on the other.
3. Have the students predict what they think will happen to the banana after a few days.
4. Cover the banana slices.
5. Observe after a few days. The yeast will have gobbled up a lot of the banana as food.
6. Have the students draw the banana slices and compare their prediction to the results.
7. Dispose of the bananas when finished observations. Do not eat!

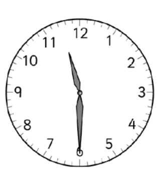
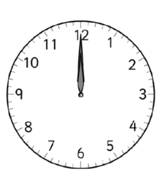
DISCUSSION
1. Review what yeast need to survive (*food, water, warmth, oxygen*) and compare this to what we need to survive.
2. Given the right conditions, some yeast are able to reproduce at rates that approach exponential growth. See handout "Exponential, My Dear Watson". Instruct students to draw two new yeast cells (for each previous single one) every 30 minutes. It may be helpful to use a stack of pennies (or nickels, or buttons) to help keep track of the yeast replication. For example, start with **one** penny (yeast cell) at 9:00am. One yeast cell buds and becomes two yeast cells so at 9:30am, there are **two** pennies. At 10am, have the students stack a penny onto each of the previous pennies. There should now be a total of **four** cells. Have students count and right down the number of pennies at each time slot before stacking more pennies and moving on. You will need a minimum of 64 pennies per student (or pair of students) to complete the activity.
3. You may want to do the activity together as a demonstration if it seems too complicated for your class. The purpose of the activity is to illustrate the magnitude of yeast reproduction.

Answer key:
9:00 - **1** cell**;** 9:30 - **2** cells; 10:00 - **4** cells; 10:30 - **8** cells; 11:00 - **16** cells; 11:30 - **32** cells; 12:00 - **64** cells

EXTENSIONS
1. As a complement to any of these yeast activities, students could view yeast under the microscope. If you have access to a microscope, set the magnification to 400X. Prepare a wet mount from a solution of yeast in warm water and sugar. Students will be able to observe phenomenal growth right under their eyes! Note that baker's yeast reproduces by budding.
2. Yeasts have a very high nutritional value. Research the role of folic acid, niacin, riboflavin, pantothenic acid, B1, 6, 12 in the body.
3. You could bring in some samples and talk about sourdough bread. Sourdough was the main bread made in Northern California during the California Gold Rush, and it remains a major part of the culture of San Francisco. The bread became so common that sourdough became a general nickname for the gold prospectors. Sourdough "captures" wild yeast and causes the dough to rise.

Exponential, My Dear Watson! 2.2

Directions **Yeast cells are able to reproduce very quickly. Imagine that you had a pet yeast cell and that you fed her a lot of sugar before leaving for school at 9:00am. If she budded a new yeast cell every 30 minutes, and each of her "buds" did the same, how many cells would there be when you arrived home for lunch at noon? (**Be prepared to expect a really big party!)

The Fung from the Dung Flipbook

Activity 2.3

GRADES
K-6 (Care partners for K-2)

TYPE OF ACTIVITY
Flipbook

MATERIALS
- letter sized paper (cardstock would be ideal)
- pencil crayons, crayons, or markers
- copies of page 45-46 for each student
- scissors
- heavy duty stapler
- copies of the poem, "Pilobolus, the Fung in the Dung" from Tom Volk's website (see "Extensions")

VOCABULARY
adaptation
coprophilic
spores

Scientific Classification
Kingdom: Fungi
Phylum: Zygomycota
Class: Zygomycetes
Order: Mucorales
Family: Pilobolaceae
Genus: Pilobolus

OBJECTIVE
- To illustrate how one fungus disperses its spores

BACKGROUND INFORMATION
Fungi have developed many bizarre and interesting **adaptations** to disperse their spores. The hat thrower fungus, *Pilobolus,* is especially intriguing. This mushroom is **coprophilic** which means it likes to live in dung. *Pilobolus* has evolved a way to shoot its **spores** onto the grass where it is eaten by cattle. Its "shotgun" is a stalk swollen with cell sap, with a black mass of spores on the top. Below, the swollen tip is a light-sensitive area. The light sensing region affects the growth of *Pilobolus* by causing it to orient toward the sun. As the fungus matures, water pressure builds in the stalk until the tip explodes, launching the spores into the daylight at speeds up to 50km/hr and for distances up to 2.5m! Shooting the spores into the daylight gives them a better chance of landing in a sunny place where grass is growing. When the grass is eaten by the cattle, the tough spores pass through their digestive system and begin to grow in a pile of dung where the cycle begins again.

TEACHER INSTRUCTIONS
1. Make copies of pages 45-46 and handout to each student. The flipbook works best if it is photocopied onto thicker paper.
2. Open a discussion with your students about spore dispersal. Remind them that, unlike seeds, spores need to land on a direct food source in order to germinate and grow.
3. Hand out copies of pages 45-46 to each student and have them cut out the squares and stack them in numerical order.
4. Once the squares are assembled, staple the flipbook on the left margin and flip away to see a mini-movie of *Pilobolus* throwing its hat!

EXTENSIONS
1. There is a really cute poem about *Pilobolus* on Tom Volk's website at http://botit.botany.wisc.edu/toms_fungi/mar2006.html Encourage students read the poem after making their flipbooks. Another idea would be to turn the poem into a skit!

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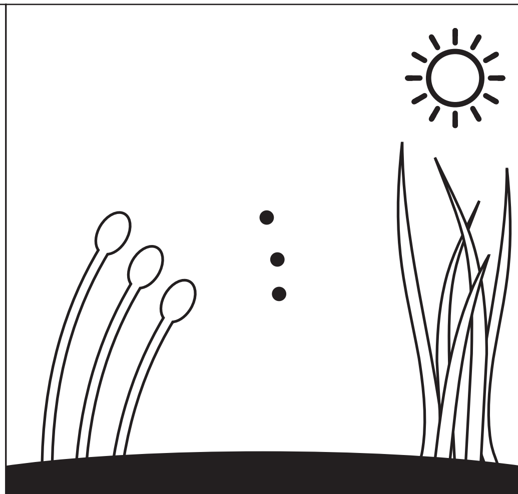

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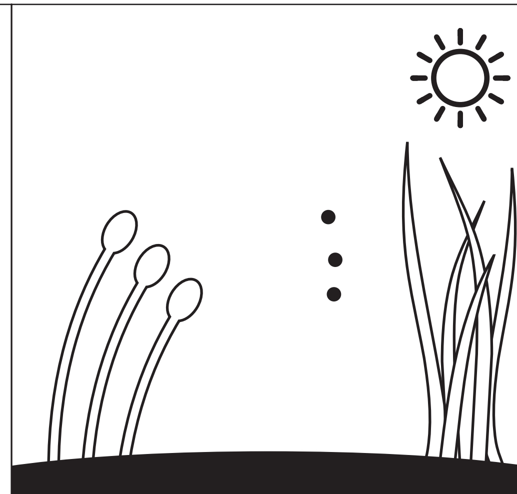

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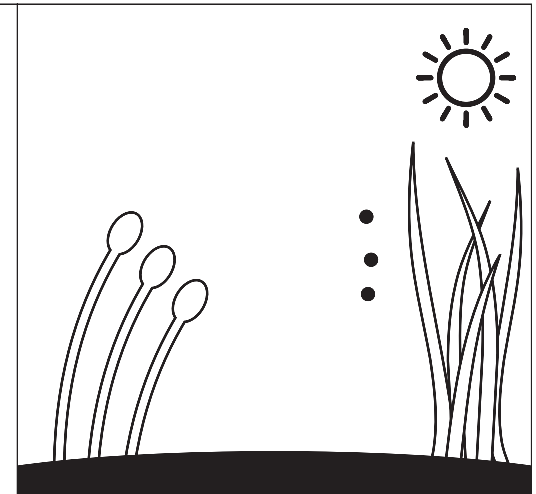

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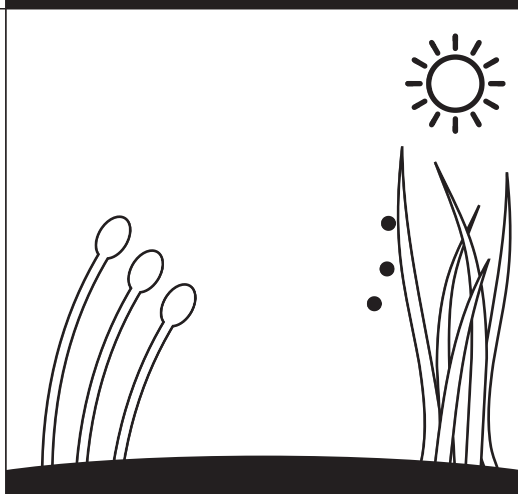

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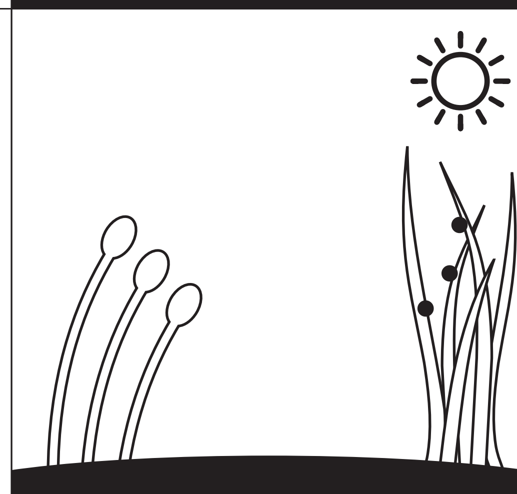

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The Fung from the Dung

Starring *Pilobolus*,
the Hat Throwing Fungus

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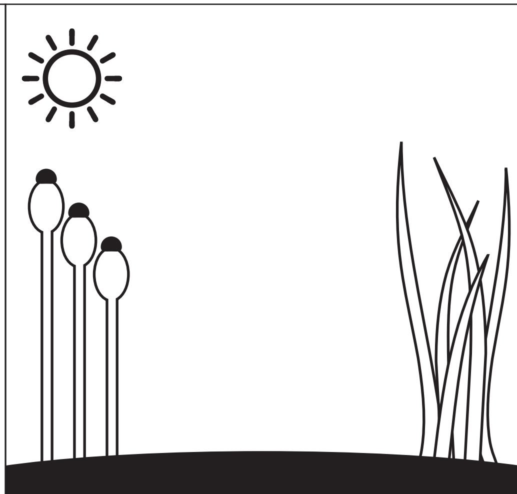

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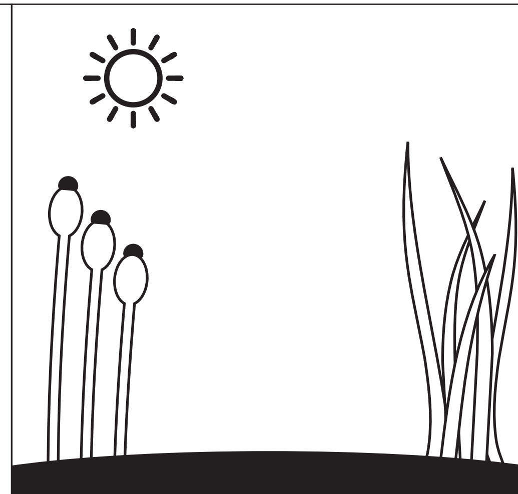

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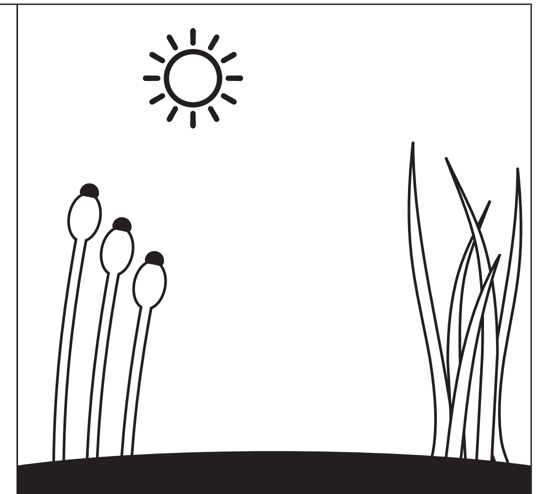

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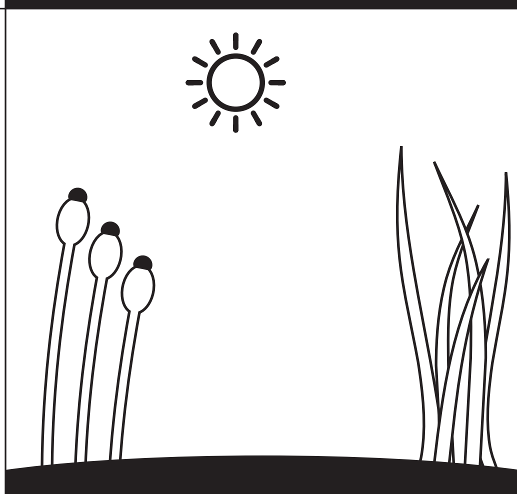

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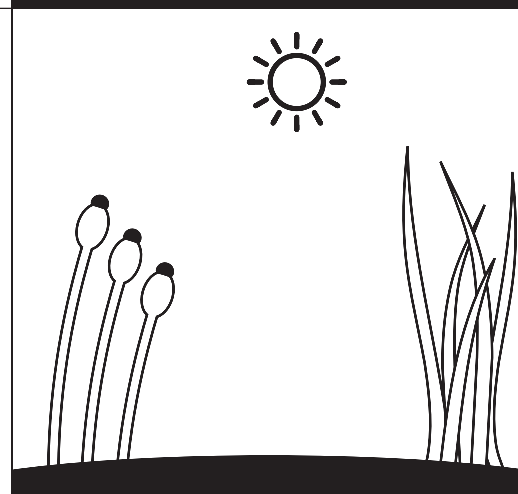

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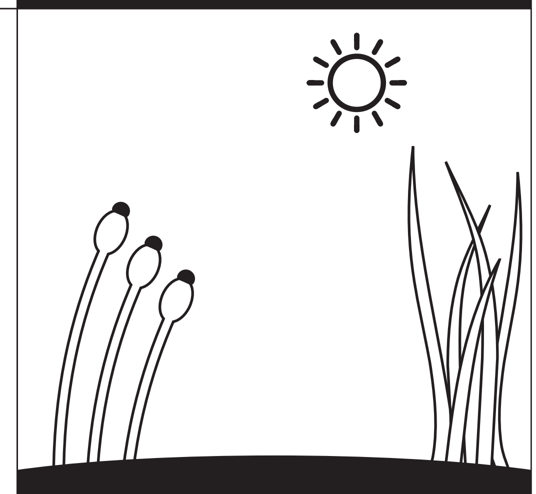

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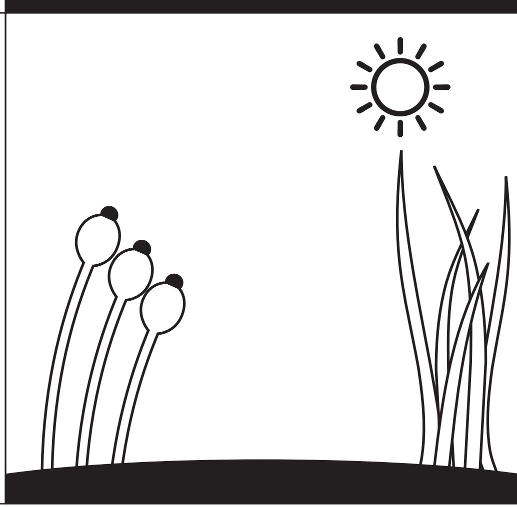

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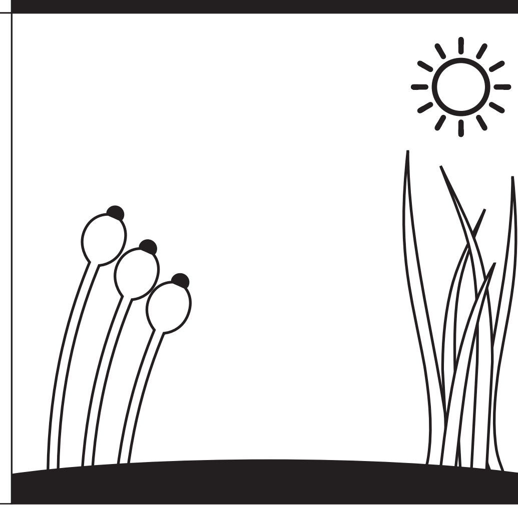

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