Fantastic Fungi

IN THE CLASSROOM

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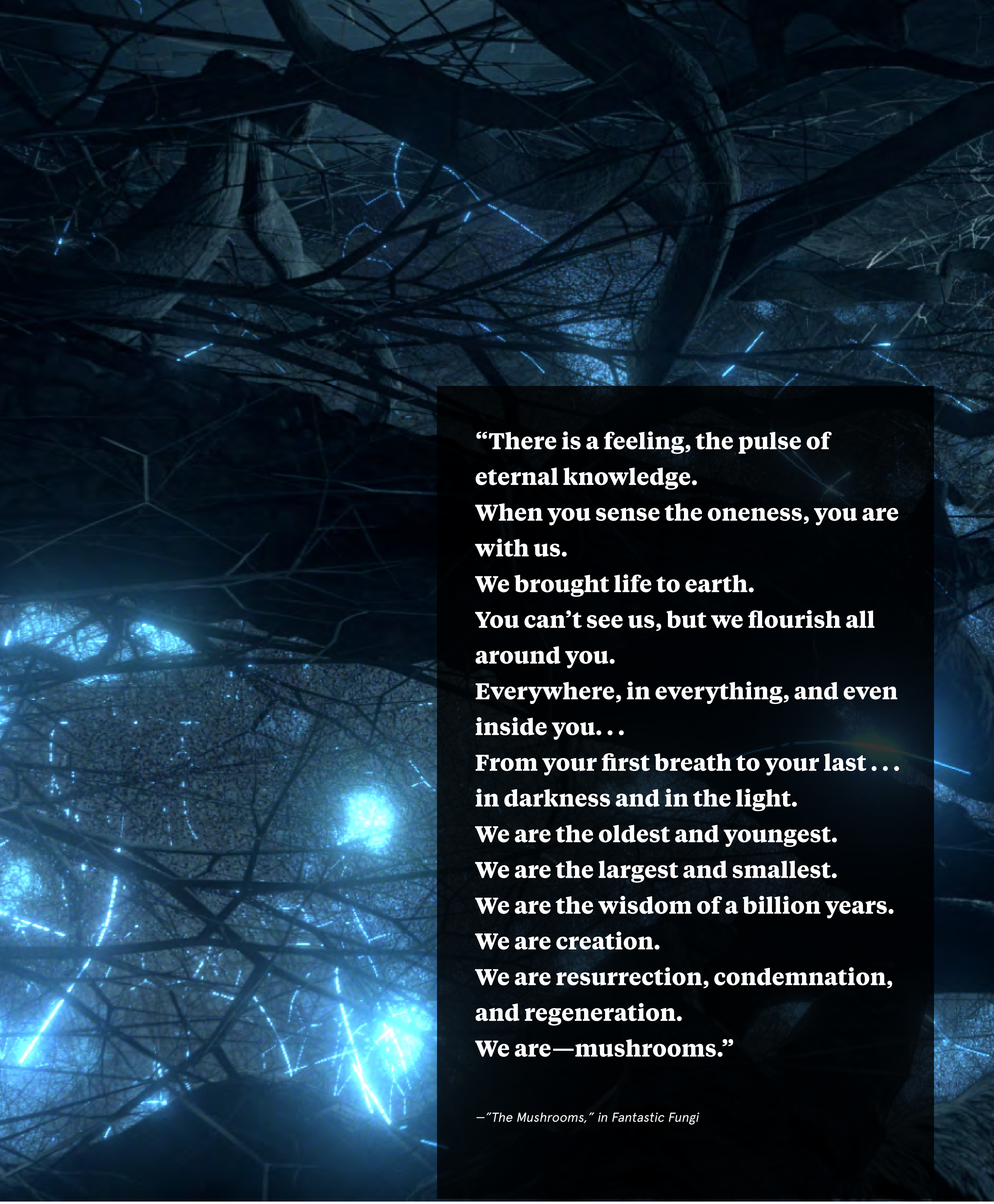


“There is a feeling, the pulse of eternal knowledge.
When you sense the oneness, you are with us.
We brought life to earth.
You can’t see us, but we flourish all around you.
Everywhere, in everything, and even inside you. . .
From your first breath to your last . . .
in darkness and in the light.
We are the oldest and youngest.
We are the largest and smallest.
We are the wisdom of a billion years.
We are creation.
We are resurrection, condemnation, and regeneration.
We are—mushrooms.”

—”The Mushrooms,” in Fantastic Fungi

INTRODUCTION

Fantastic Fungi celebrates the wonder and native intelligence of fungi. The documentary film, book, original album, and related unique educational resources deepen our understanding of the interconnected ways in which fungi live and thrive throughout our world—including in our soil, our trees, our air and water, and even inside our bodies.

Some students may know and love mushrooms, the fruiting body of fungi. Others may be aware that some fungi are medicinal and that they can be used to help support our suffering climate. This curriculum illustrates how we are interconnected with fungi. From our bodies, behaviors, and cultures, fungi derive nutrition and find ways to spread and reproduce. This symbiotic and mutually beneficial relationship has been going on for thousands of years, yet only recently have people begun to return to the native intelligence of the fungi, study their place in our ecosystem, and understand that fungi are as essential as flora and fauna. In fact, fungi's importance is now so widely accepted that the term "funga" has been coined to make it equivalent in usage to flora and fauna.

By delving into **Fantastic Fungi**, students learn that the kingdom of Fungi, or the variety of mushrooms, molds, and yeasts that are not plant or animal, are critical to human survival and to the survival of our planet. Fungi are the digestive tracts of our forests, regenerating nutrients from decomposition, and keeping the cycle of life alive. Fungi are the hidden treasures in nature connecting us with the invisible and intelligent universe below our feet. Using **Fantastic Fungi** in the classroom will inspire students to seek out those treasures and contribute their own excitement and knowledge about them to the world. Together, the educational version of the film and these lessons open the door for students to explore these core ideas:

- **The intelligence of nature**
- **The importance of fungi in ecosystems**
- **The need for a shift of consciousness, accepting that we are all interconnected parts of nature**

SEL Connections

Alongside deepening knowledge of mycology (the study of fungi) **Fantastic Fungi** offers numerous opportunities to strengthen social emotional learning. Integrated throughout the lessons are natural points where discussion, collaborative activities, and reflection allow for students to connect to one another and to the content in new and enriching ways. Through this process, students are able to forge meaningful connections with peers, increase their awareness and awe of their natural environment, while having time and space to reflect, explore, and reimagine their world through new perspectives of what is possible.

Navigating the Resources

Modules

Fantastic Fungi organized into a set of five modules, each presenting an educational vision for student learning, learning objectives, and a set of unique lessons developed to teach the specific module topic. Each module also includes a short film clip from the full-length **Fantastic Fungi** film.

Lessons include

- Specific learning objectives aligned with NGSS standards
- Essential questions to investigate and guide learning
- Scaffolded learning activities (for k-5, 6-8, 9-12) to actively engage and inspire students' hearts, minds, body, and spirit
- Extended learning suggestions and research ideas drawing from many of the leading mycologists, scientists, and artists featured in **Fantastic Fungi**

The lessons were developed for middle (6-8) and high school students (9-12), and include suggestions to scaffold elementary (K-5):

- **For K-5:** Earth, Life, and Physical Science
- **For 6-8**: Earth, Life, and Physical Science
- **For 9-12**: Biology, Chemistry, Psychology, Art

Given the time-lapse photography, gorgeous visuals, and discussion of shifting consciousness in **Fantastic Fungi**, the lessons can be easily adapted to Visual Arts and Psychology courses as well.

Standards

Depending upon the content covered, exercises completed, phenomena observed, or art completed, **Fantastic Fungi** modules are aligned with NGSS and Common Core Standards. All standards are listed at the end of each module.

OPENING ACTIVITY
GET YOUR MUSHROOMS GROWING

"If we didn't have fungi, we would get this buildup of plant matter that would choke the earth. They really are the key. They break down plant life and make it usable for new plant life and for animal life."

— Michael Polla, Fantastic Fungi

Lesson One: Observing and Identifying

As you embark on this fungal journey, we highly recommend beginning with students growing mushrooms in the classroom, observing their progress, and documenting this data throughout the course of their study.

*Note: Before using or growing mushrooms in class, ask parents about allergies to mushrooms.

By growing mushrooms, students get their hands in the dirt (or substrate) and understand that the fungi they see in the film and learn about in these modules are available to them—no matter where they live or whatever their means.

Several mushroom-growing kits are available for purchase:

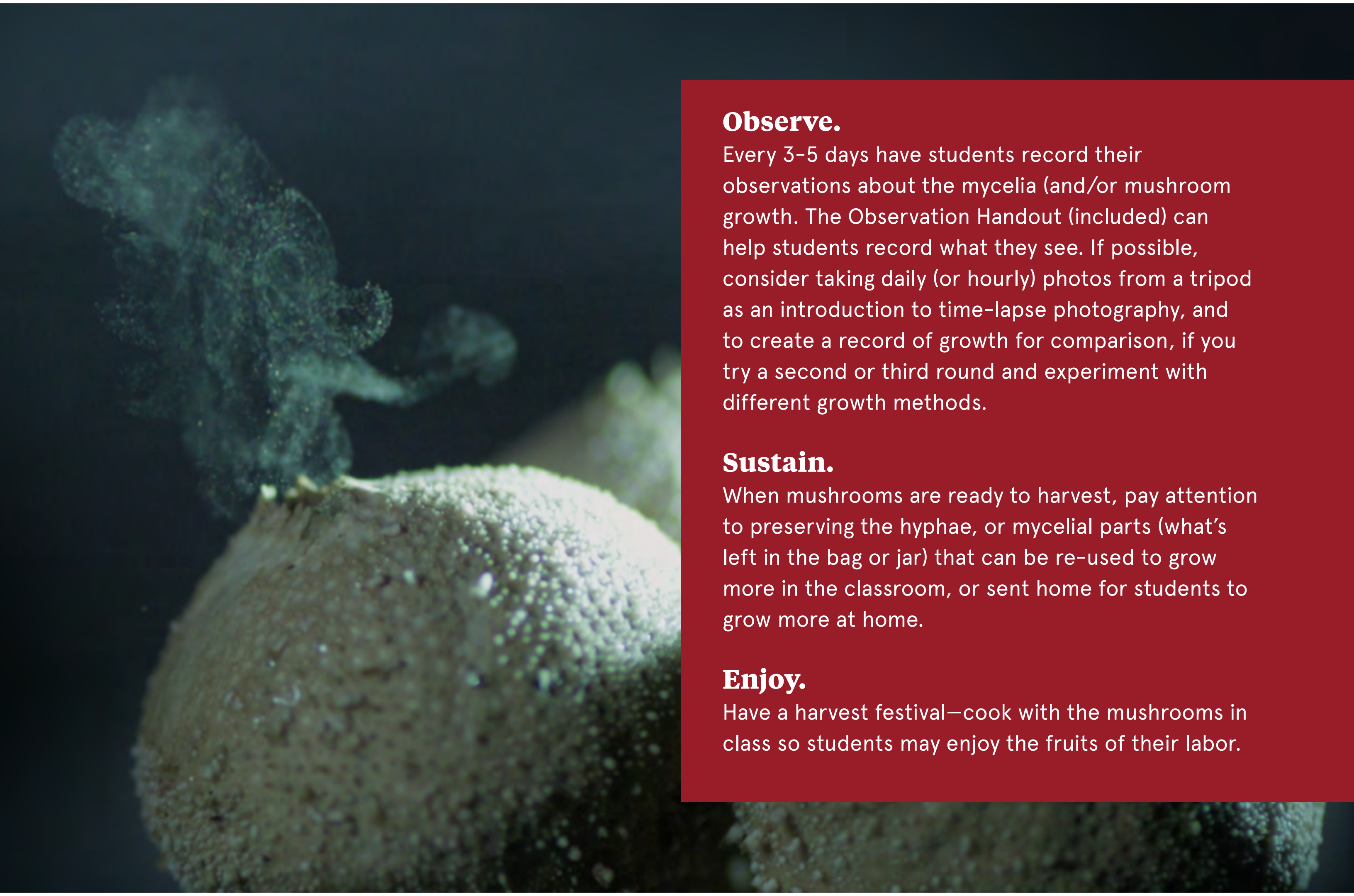
- Mycopia.com: *https://www.mycopia.com/buy-online/growth-kit*
- Nearby Naturals: *https://nearbynaturalsfl.com/collections/grow-kits*
- North Spore Grow Kits
    - Smugtown Mushrooms: *https://www.smugtownmushrooms.com/growkits*
    - Tradd Cotter's Mushroom Mountain: *https://shop.mushroommountain.com/collections/indoor-fruiting-kits*

Less expensive DIY approaches use common items such as mason jars and coffee grounds. To learn more, see: http://www.tomorrowsgarden.net/content/how-grow-mushrooms-home

The book *Radical Mycology* also describes how to grow and work with mushrooms at home or in a classroom.

Follow the instructions in the videos or in the kit to start your mushroom growth.

As the mushrooms grow, there are several activities to consider:



Observe.

Every 3-5 days have students record their observations about the mycelia (and/or mushroom growth. The Observation Handout (included) can help students record what they see. If possible, consider taking daily (or hourly) photos from a tripod as an introduction to time-lapse photography, and to create a record of growth for comparison, if you try a second or third round and experiment with different growth methods.

Sustain.

When mushrooms are ready to harvest, pay attention to preserving the hyphae, or mycelial parts (what's left in the bag or jar) that can be re-used to grow more in the classroom, or sent home for students to grow more at home.

Enjoy.

Have a harvest festival—cook with the mushrooms in class so students may enjoy the fruits of their labor.

OPENING ACTIVITY HANDOUT

OBSERVATION HANDOUT

Date:

Day of growth:

Temperature/Humidity in room: (if possible)

What do you see? Note colors, shapes, and scents.

(After Day One:) What changes stand out to you from your previous observation?

Observe and measure:

- Mycelia length
- Mushroom size: cap, gills (lamellae), stem (stipe)
- Substrates *(Substrates: The surface on which the mushrooms are growing - soil, coffee, etc.)*

Draw a picture or take a photo.

Do you see any evidence of sporulation -which may look like a white powder?
(Sporulation: mushrooms releasing spores for reproduction)

What questions do you have about the changes you see?

MODULE 1:
THE SCIENCE

Module 1 Vision

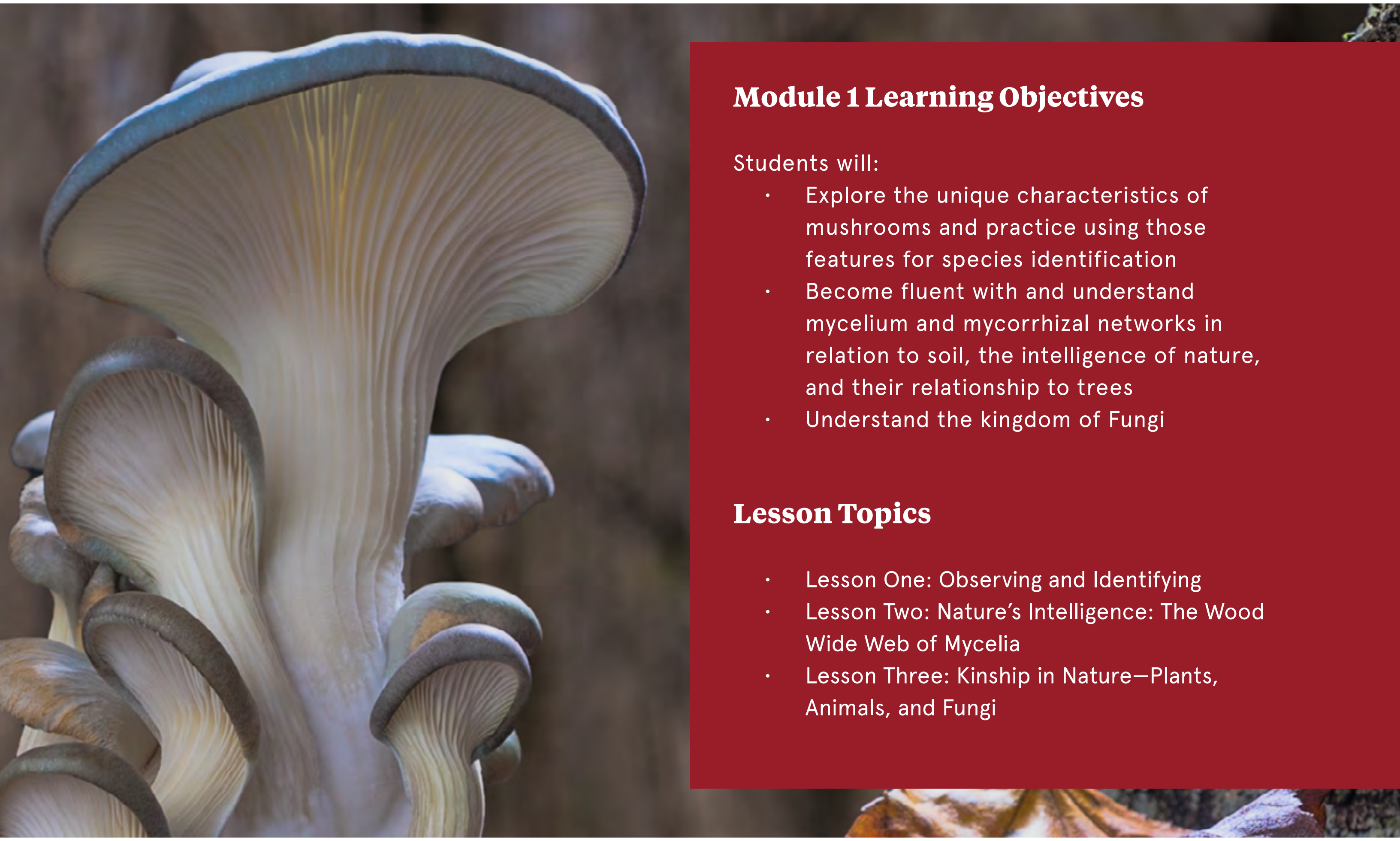
> "Mushrooms are mysterious. They come out of nowhere suddenly, with their splendid forms and colors, and just as quickly, go away. Mushrooms' startling appearances and enigmatic disappearances have made them forbidden fruits for thousands of years. Only a few of the cognoscenti—the shamans, the witches, the priests, and the wise herbalists—have gained a glimmer of the knowledge mushrooms possess. Why?
>
> It is natural to fear what is powerful yet unknown. Some mushrooms can kill you. Some can heal you. Many can feed you....Their sudden rise and retreat back into the underground of nature make them difficult to study. We have longer periods of contact with animals and plants and we usually know which ones can help or hurt us. Mushrooms are not like that. They slip into our landscape and exit shortly thereafter. The memory fades quickly, and we wonder what we saw.
>
> Mushrooms are the fruit bodies of a nearly invisible network of mycelia, the cellular fabric beneath each footstep we take on the ground. Reach down and move a stick or a log, and you will see a vast array of fuzzy, cobwebby cells emanating everywhere. That's mycelia, the network of fungal cells that permeates all landscapes. It is the foundation of the food web. It holds all life together. Yet these vast underground networks, which can achieve the largest masses of any

> organism in the world and can cover thousands of acres, hide in plain sight; silent but sentient and always working tirelessly to create the soils that sustain life....
>
> Many elderly people share joyous memories of going with their parents and grandparents on family trips into the forest to pick mushrooms. They have experienced that eureka moment of discovery and understand the challenges of identifying edibles and the danger of misidentifying toxic species. They know the reward and joy of a delicious meal foraged by their family from the natural world around them. All this can create meaningful memories that bond families across generations. Many mushroom patches are kept as family secrets, only shared with future generations. This is what the mushroom experience does—it grows on you. It is like a mycelial thread through time, a bridge from our ancestors to us and to our descendants in the future."[1]

Did you know it is estimated that only 5-10% of fungi have been discovered?

Did you know that the worlds' largest living organism is a fungus?

Did you know that without fungi there would be no bread or chocolate, among other things?



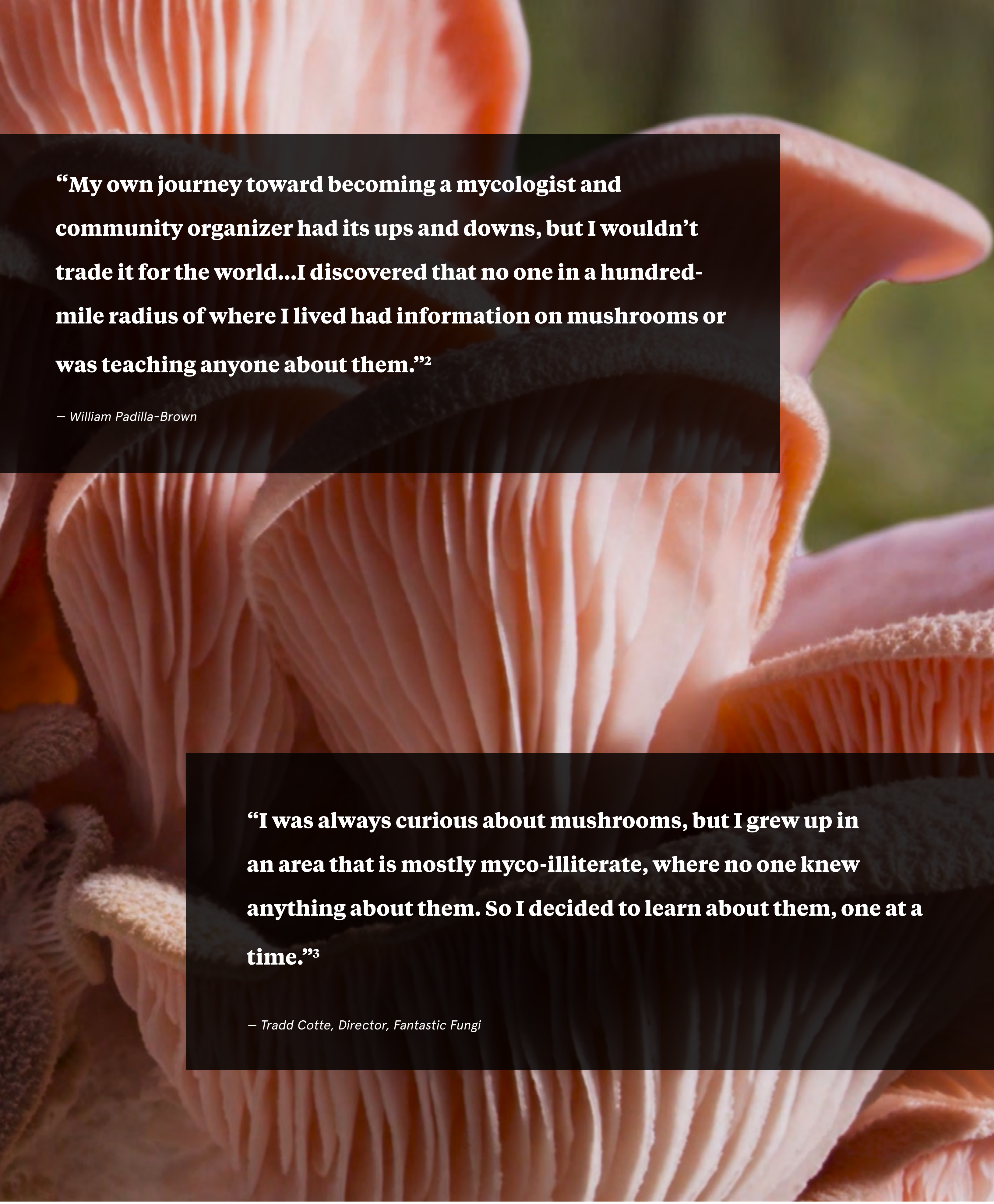
Module 1 Learning Objectives

Students will:

- Explore the unique characteristics of mushrooms and practice using those features for species identification
- Become fluent with and understand mycelium and mycorrhizal networks in relation to soil, the intelligence of nature, and their relationship to trees
- Understand the kingdom of Fungi

Lesson Topics

- Lesson One: Observing and Identifying
- Lesson Two: Nature's Intelligence: The Wood Wide Web of Mycelia
- Lesson Three: Kinship in Nature—Plants, Animals, and Fungi



“My own journey toward becoming a mycologist and community organizer had its ups and downs, but I wouldn’t trade it for the world...I discovered that no one in a hundred-mile radius of where I lived had information on mushrooms or was teaching anyone about them.”[2]

— William Padilla-Brown

“I was always curious about mushrooms, but I grew up in an area that is mostly myco-illiterate, where no one knew anything about them. So I decided to learn about them, one at a time.”[3]

— Tradd Cotte, Director, Fantastic Fungi

LESSON 1:
Observing and Identifying Mushrooms

Overview:

In this lesson students will engage in the scientific process of observation, identification, and recording of data with their mushroom specimen. Students will complete a spore print and analyze their findings based on the result.

Essential Questions

- What are mushrooms? What are the names of their anatomical parts?
- How are mushroom species identified?
- How do mushrooms reproduce?

Materials

1. Access to equipment to screen the short video "The Mushroom Waltz"
2. Whole, fresh mushrooms of several types, preferably with gills under the cap for spore prints, such as portobello or shiitake mushrooms. **If possible, take students outside to find their own mushrooms. (Make sure they don't eat unidentified mushrooms!) Otherwise, choose several types of whole mushrooms from a supermarket.*
3. Half black/half white pieces of paper (especially parchment paper), glass or plastic bowls or cups large enough to cover the mushroom caps, and a small object like a paperclip or pencil to set beneath the rim to allow some moisture to escape
4. Handout One: Mushroom Observations and Handout Two: Anatomy of a Mushroom
5. Mushroom field guides, or access to a mushroom identification website such as *First Nature-Fungi Families/Types Identity Parade*[4]
6. Tools for fine measurements of mushrooms

Length

Two 55-minute class periods, if doing spore prints. One period for classes who are unable to do spore prints.

ACTIVITY

Day One: Introduction to Mushrooms

> **1. Show the class the short film "The Mushroom Waltz"**
>
> **2. After watching, ask the class to generate a list of words they can use to describe the mushrooms they saw.**

Step One: Get to Know Your Mushroom

Distribute mushrooms to each student and have them closely observe, describe, and take notes on Handout One: Mushroom Observations.

VERY IMPORTANT: Be sure students do not taste any mushrooms, but instead use all their other senses to study and describe their mushroom.

**For classrooms without access to fresh mushrooms, use photos from the Fantastic Fungi book, refer to mushroom field guides, or project a Google search for mushroom images, and have students choose one image each to describe. Skip the spore prints section of the lesson.*

K-8 Adaptation: Consider distributing Handout One, and go over each part of the mushroom together.

Step Two: Make Spore Prints

1. After students have written down their mushroom observations, have them carefully cut the cap of the mushroom from the stipe (stem) and place the cap, gills down, on a piece of paper and cover it with a glass or plastic bowl or cup. The goal of covering the cap is to prevent air currents from moving the spores, and propping the cover with a paper clip or other small object will keep the paper from absorbing moisture from the cap as it dries.

2. Students should label the paper on which the mushroom sits with their name and leave it overnight.

3. Ask students to make predictions about what they will see the following day:

- What do they expect to find?
- What colors do they think they will see?

Step Three: Get Curious About Mushroom

et spore prints aside, distribute Handout Three: Lifecycle of a Mushroom and in small groups, have students research from a book or online[5] to answer the following questions:

- What are mushrooms?
- How and where do they grow?
- How do they reproduce?
- How are spores different from seeds

Step Three (cont'd):

(Day Two for classes with spore prints)

1. Have students study their spore prints, using magnifying glasses or microscopes.

2. Add new descriptions of what they observe from the spores to Handout One: Mushroom Observations

Discuss

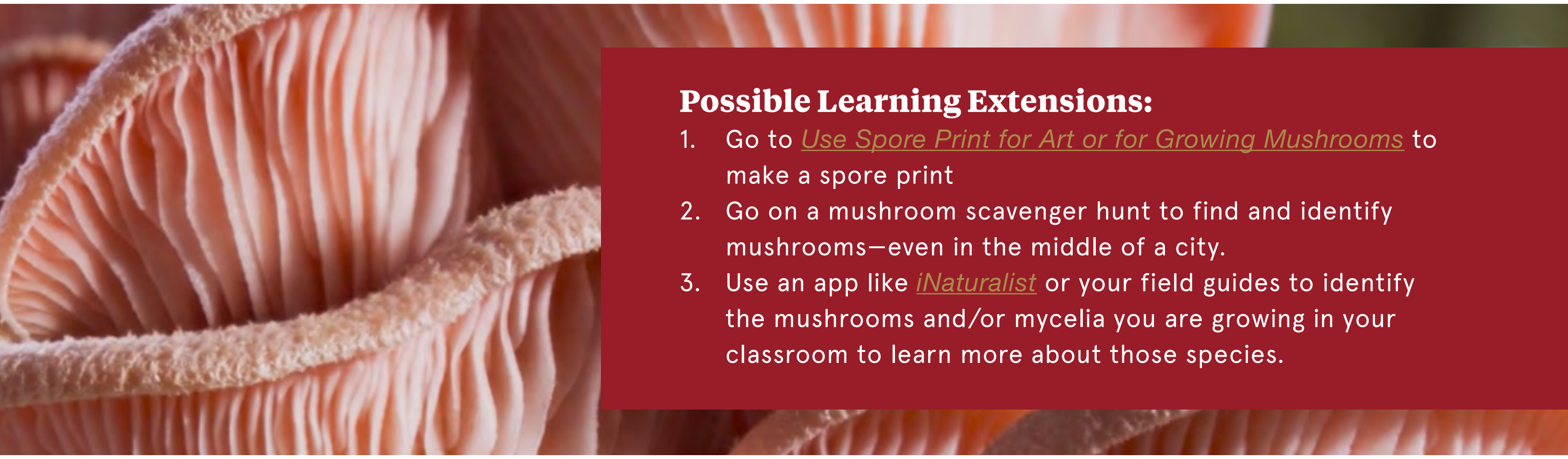
- Did they look like students expected?
- If their spore print did not turn out as they expected, why not?

3. Using a field guide, or an online tool such as *MushroomExpert.com*[6], have students use their observations and spore prints to identify their mushrooms.

Step Four: Create Mushroom Model

Using the information they learned and identified about mushrooms in their small groups, have students create a model or illustration representing how their mushroom uses spores to reproduce. The model can include:

- Words
- Images and art
- Physical reproduction (clay or other artistic medium)
- Actual mushrooms and spores



Possible Learning Extensions:

1. Go to *Use Spore Print for Art or for Growing Mushrooms* to make a spore print
2. Go on a mushroom scavenger hunt to find and identify mushrooms—even in the middle of a city.
3. Use an app like *iNaturalist* or your field guides to identify the mushrooms and/or mycelia you are growing in your classroom to learn more about those species.

MUSHROOM OBSERVATIONS

Overall, how would you describe your mushroom?

Describe what you see, and how each characteristic may vary on different parts:

Color(s):

Shape(s):

Texture(s):

Measure the different parts of your mushroom:

Cap:

Stipe (Stem):

Other:

Other observations:

Draw a picture that will help you remember what your mushroom looks like:

ANATOMY OF A MUSHROOM

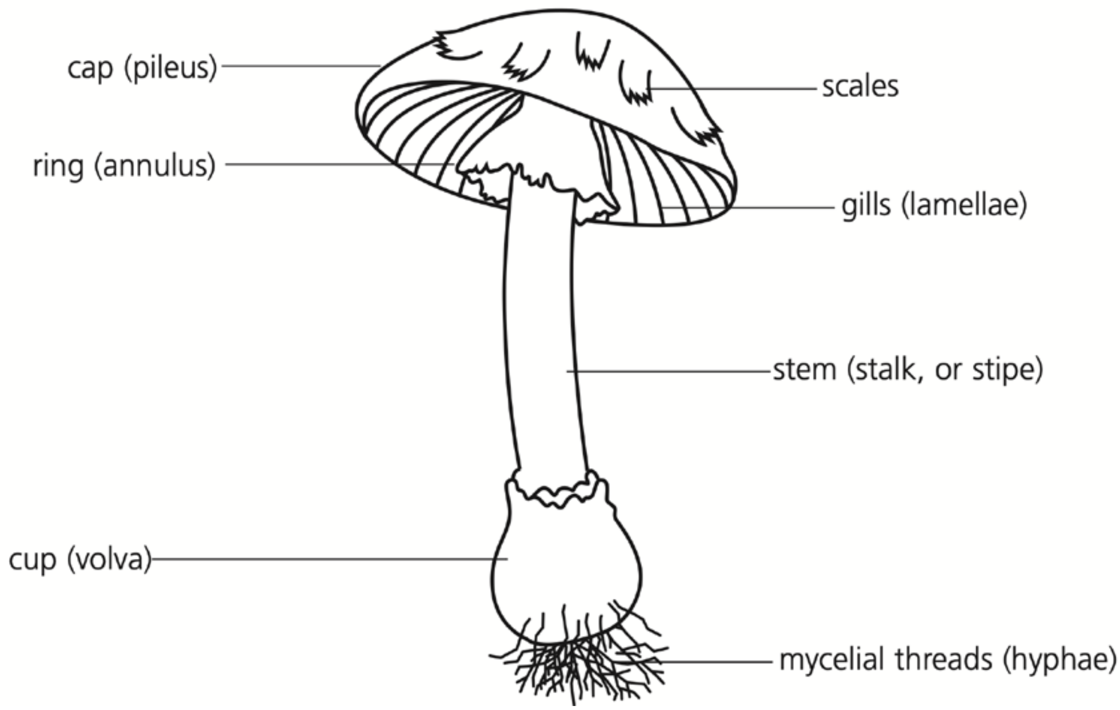
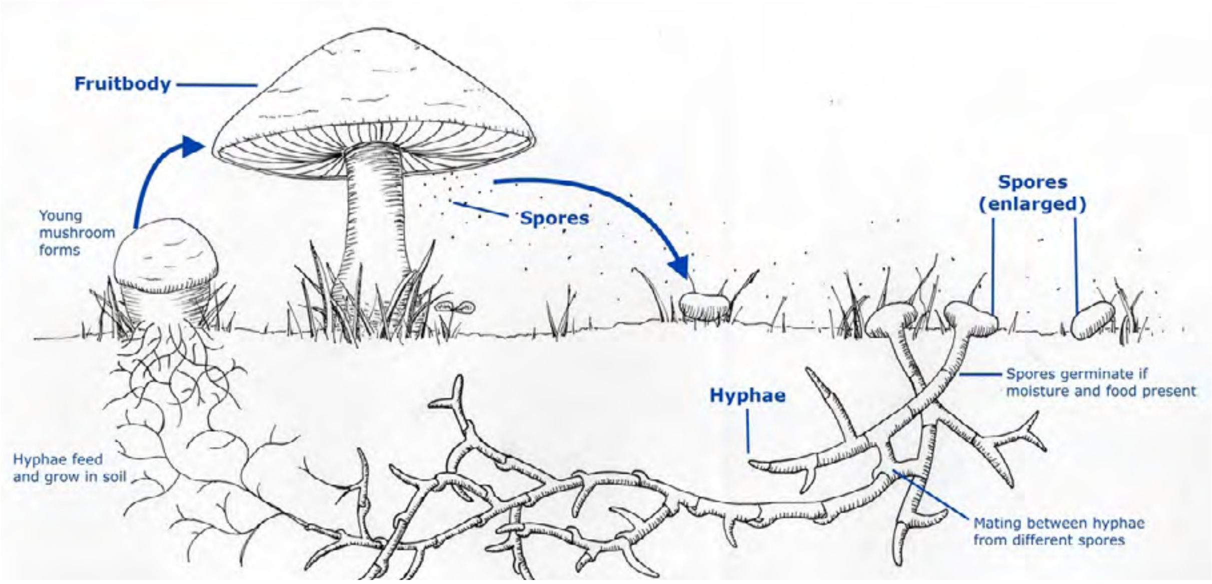


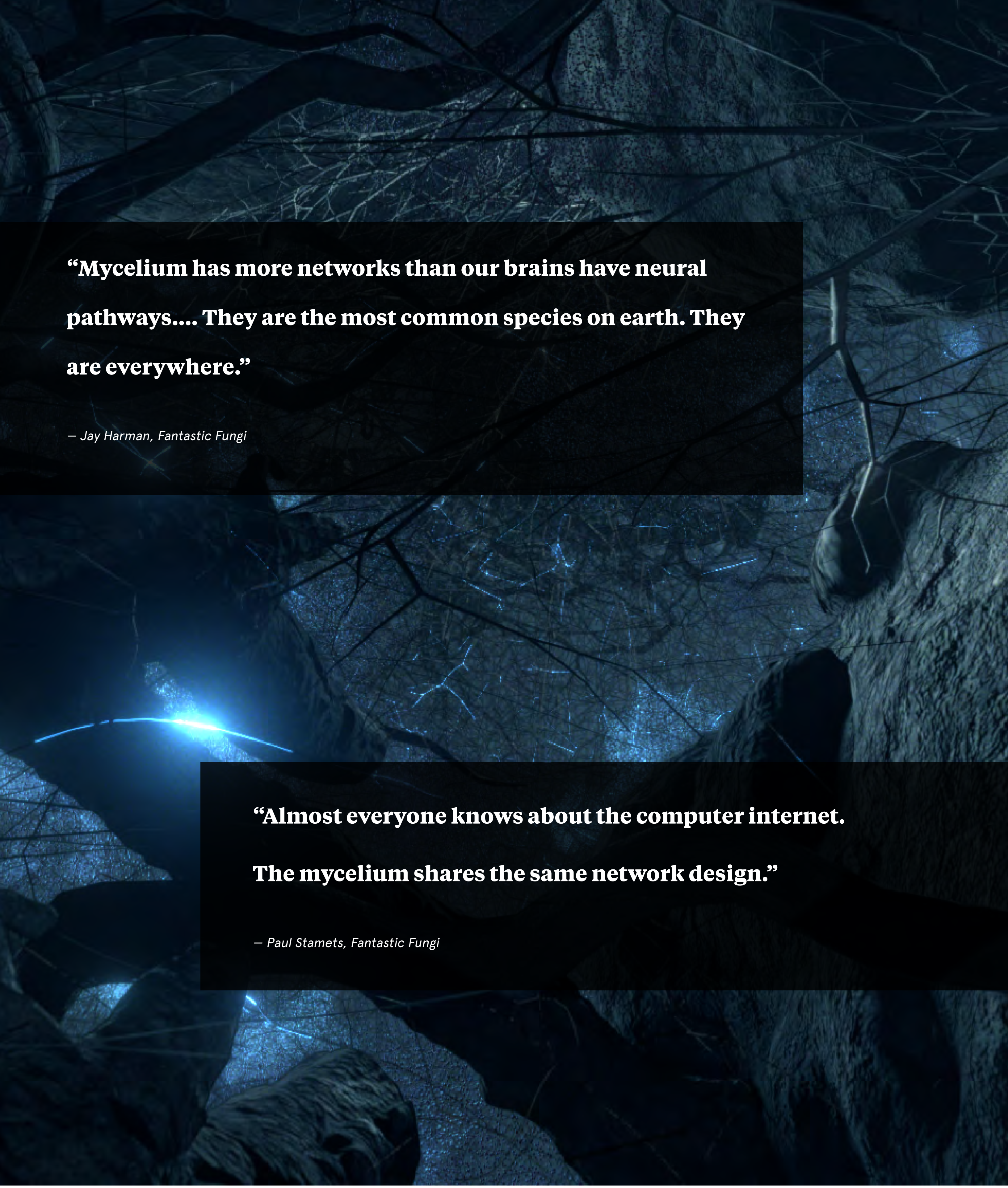
Diagram of a Generic Agaric Mushroom

From The Fungus Files: An Educator's Guide to Fungus K-6, *https://namyco.org/docs/The_Fungus_Files.pdf*

LIFECYCLE OF A MUSHROOM



https://www.sciencelearn.org.nz/images/3689-mushroom-life-cycle



> **"Mycelium has more networks than our brains have neural pathways.... They are the most common species on earth. They are everywhere."**
>
> *— Jay Harman, Fantastic Fungi*

> **"Almost everyone knows about the computer internet. The mycelium shares the same network design."**
>
> *— Paul Stamets, Fantastic Fungi*

LESSON 2:
Nature's Intelligence: The Wood Wide Web of Mycelia

Overview:

In this lesson students will learn about mycelia, explore their world (including mycorrhizal networks and mycelial intelligence), and reflect upon the importance of mycelia in the natural world.

Essential Questions

- What are mycelia?
- What are mycorrhizal networks?
- What is mycelial intelligence?
- How do mycelial networks reflect cooperation rather than competition?

Materials

1. If possible, bring in a decomposing log with some soil or take students outside and turn over a log. Alternatively, use the beautiful still images of mycelia (see assembled PowerPoint) from filmmaker Louie Schwartzberg
2. Working Fungi Glossary
3. Copies of the article "Mycelium: The Source of Life" by Suzanne Simard
4. Access to watch film clips on the intelligence of nature and how trees "talk" to each other:
5. Suzanne Simard's TED Talk, "*How Trees Talk to Each Other*"
6. Radiolab podcast "*From Tree to Shining Tree*"

Length
Two 55-minute class periods for high school. Adjust for upper elementary and middle to watch the film, supplemental video and readings, and the assigned activity.

ACTIVITY

Step One: Identifying mycelium

> **1. Choose either Variation One or Variation Two, depending upon the materials you have available in the classroom.**

Variation One: 10 Questions

Bring a decomposing log into class. Ideally, you could take the class outside and walk around to find one.

Engage students in a "10 Questions" exercise. This is an activity where students collectively ask ten questions based upon what they can observe based on a particular object. For example, "Why is this log decomposing? Why are there different colors under the log? How long does it take for wood to decompose? What makes it decompose?" etc.

Variation Two:

If an actual decomposing log is not available because of place or weather, find some photographs of one to project. If observations are solely through the photographs, explain to students that for the next few minutes they will be visually exploring images and still photographs. After each image, they will be taking a moment to write three responses to each image:

- What do you see? (Describe in literal terms. For example, "I see black dots, I see fuzzy stuff..." Resist the temptation to move to interpretation.)
- What does the image remind you of?
- What questions do you have about the image?

Project each image, giving students a few moments to look at the image before prompting them to write their response. Remind them that there are no wrong answers, and encourage them to connect with their imagination as they reflect on each image.

K-3 adaptation: There are some fantastic experiential activities to help students understand the interconnectedness of mycelium. For example, students can use twine or string to create a web by throwing the ball of strong string back and forth, and then try to unravel the web. This activity is the Closing exercise in this lesson, but it may feel right with younger students to skip right to this hands-on activity.

4-8 adaptation: Model for the class the visual analysis/connection exercise using the first image. After showing the slideshow, tell students that the pictures they were viewing were of mycelial and mycorrhizal (the symbiotic association of the mycelium of a fungus with the roots of a seed plant) networks of fungi.

2. Review Eugenia Bone's explanation: "Mushrooms are the fruiting bodies of fungi. The mushroom is like an apple. The bulk of the organism [the mushroom] is growing underground and it's composed of these long threads, and these threads grow one cell at a time. Then they branch, and re-branch in every direction—they can even branch off three-dimensionally, and this mass of threads is called mycelium"[8]

**Remind students that not all fungi fruit mushrooms. Some fungi, like yeasts and molds, have different methods of reproduction.*

Step Two: Mycelia and Mycorrhizal Network

1. Review with students:

- Mycorrhizae, and mycorrhizal networks, increase a plant's nutrient uptake and are formed from the fungi's association with plant roots. Mycorrhiza is the fungus that grows in association between a fungus and the roots of a vascular plant.
- The plant supplies the fungi with photosynthesis products for their metabolic use.
- It is estimated that 90% of living plant species have mycorrhizal fungi associated with their roots.[9]

2. Share with students two variations of explaining mycorrhizal networks and fungi:

Giuliana Furci:

"Fungi are like the egg in the cake. You have flour and sugar, but those ingredients don't stick together unless you have an egg. In a forest, plants and animals don't connect without fungi. No tree can live outside water without fungi. No plant on Earth can synthesize the nutrients from the earth that they need without the help of fungi. When life emerged from an aquatic ecosystem onto land it was possible for plants to do it because of fungi.

Fungi are giving trees nutrients like phosphorus, magnesium, and water—extending the area from which plants get water. Plants are giving the fungus sugars that they produce in the foliage that they are producing through photosynthesis. Without fungi no cheese, no beer, no wine, bread, no yogurt, no chocolate, no soy sauce, no forest. Without the forest, no oxygen and no environment as we know it."[10]

Suzanne Simard:

"So we often think of kin recognition as an animal behavior. Humans, you know, we love our babies, we know it's our baby and we're going to look after that baby. Well, we never thought that plants could do that, but we're finding in our research that plants can recognize their own kin. So these mother trees recognize their kin through their mycorrhizal networks. The mother tree and the baby seedlings are sending signals, talking to each other. When they're connected together and carbon is moving between plants, the trees are supporting the weaker ones. If she knows that there's pests around and that she's in danger, she will increase her competitive environment towards her own around and that she's in danger, she will increase her competitive environment towards her own babies so that they regenerate further away. It's a magical thing, and this could not happen without the fungi."

3. Distribute and read aloud the article "Mycelium: The Source of Life" by Suzanne Simard.
(*Fantastic Fungi: How Mushrooms Can Heal, Shift Consciousness, and Save the Planet*, p. 19-21.)

K-5 adaptation: Have students become mycelium using string or *white sweatshirts tied together* while explaining how mycelium nourishes and spreads and is EVERYWHERE.

6-8 adaptation: Read the article aloud and have students underlying key terms and circle unfamiliar words.

4. Create their Fungi Glossary. After completing the reading, explain to students that they will create a Fungi Glossary beginning with the circled words from this reading.

Emphasize that each student will be responsible for developing their own working glossary and, on an ongoing basis, adding new terms throughout this unit.

4. Watch TED Talk Videos

K-5 adaptation: Use this wonderfully adapted TED Ed video from Camille Defreene and Suzanne Simard "*The Secret Life of Trees*". (runtime: 4:33 minutes)

6-12 adaptation: Show Suzanne's Simard TED Talk "*How Trees Talk to Each Other*" (runtime: 18 minutes)

Closing: Visualizing Mycelia

1. Organize students into small groups to discuss and come to consensus with the answer to each of these questions.

- What is mycelia?
- What are mycorrhizal networks?
- What is mycelial intelligence? (e.g. trees)
- How can mycelium heal the planet?
- How do mycelial networks reflect cooperation rather than competition?

Discuss their reflections.

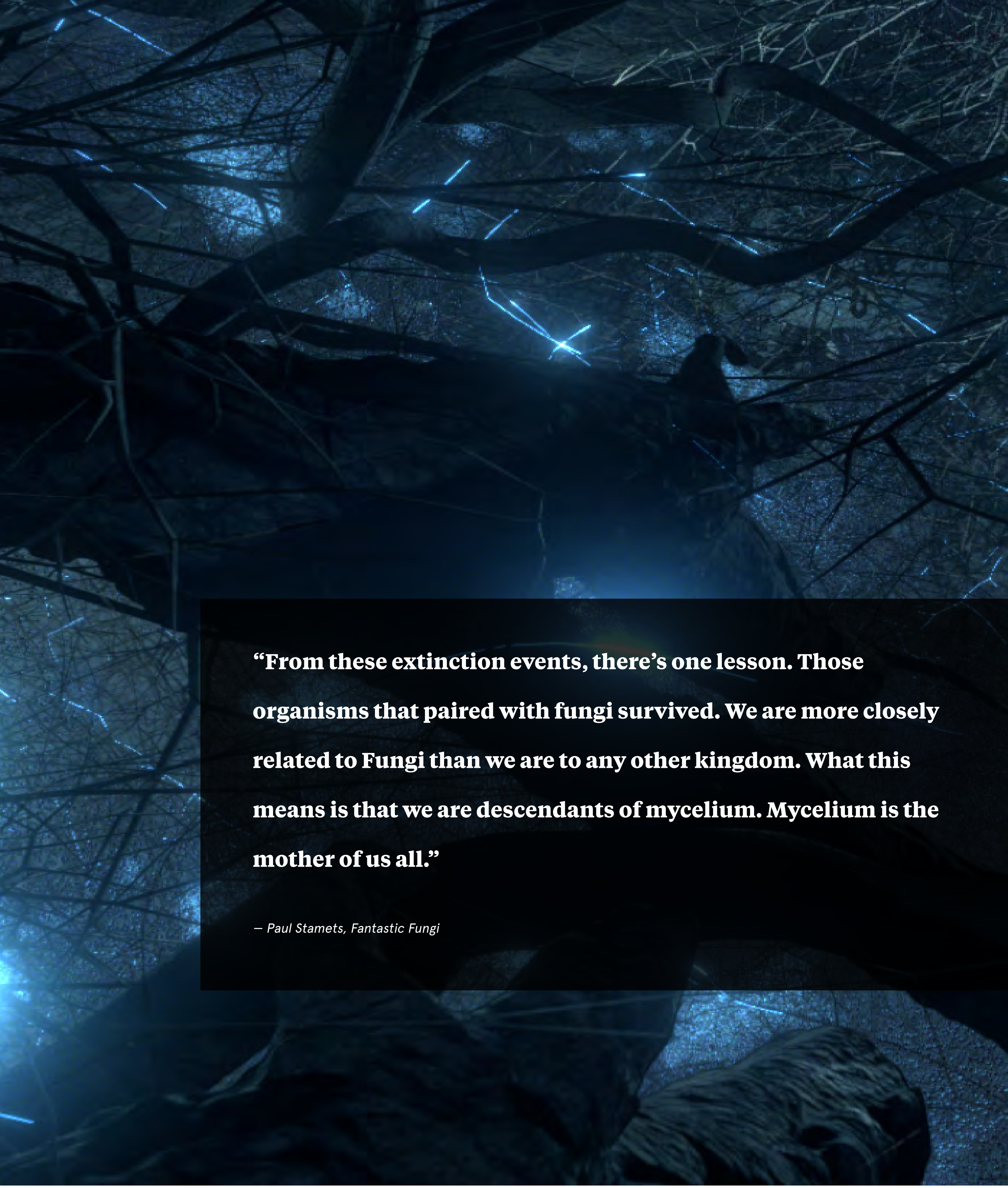
2. Next, distribute a few balls of string or a pile of white t-shirts or other textile that can be tied together. Explain that they are to visually create a mycelial network from what they just read and learned from Giuliana Furci and Suzanne Simard, using the supplied materials.

K-3 adaptation: Have on hand mycelia for students to handle before introducing the scientific names.

4-8 adaptation: Write the definition of the fungi terms on the board, or create a handout using the glossary from this unit, for the class to read aloud and to practice pronouncing.

3. After creating their visual representation of mycelia, have K-5 students discuss, and 6-12 students reply in writing, to this question:

- How do mycelial networks reflect cooperation rather than competition? (For K-5 students: Discuss the meaning of cooperation and competition and offer several examples from the natural world. You may also elect to have students role-play or express the ideas of cooperation and competition through visual art.)



“From these extinction events, there’s one lesson. Those organisms that paired with fungi survived. We are more closely related to Fungi than we are to any other kingdom. What this means is that we are descendants of mycelium. Mycelium is the mother of us all.”

— Paul Stamets, Fantastic Fungi

LESSON 3:
Kinship in Nature—Plants, Animals, and Fungi

Overview:

In this lesson students will reflect on the characteristics that identify organisms into classifications and learn about those that distinguish the kingdom of Fungi. Students will apply that understanding to analyze the evolutionary and interdependent relationships between Fungi, Animalia, and Plantae.

Essential Questions

- What defines the kingdom of Fungi?
- What are the evolutionary relationships between plants, animals, and fungi?

Materials

1. Equipment to show "Mycelium is the Mother of Us All" film clip from **Fantastic Fungi** (educational version): 13:50 - 16:23
2. Handout One: *Facts About the Fungus Among Us*[11]
3. Access to suggested research articles and/or website

Length

One 55-minute classroom period.

*** Note, this lesson is appropriate for grades 7-12. Similar lessons for grades K-6 available at https://namyco.org/docs/The_Fungus_Files.pdf*

ACTIVITY

Introduction: What's the difference...

Get students to start thinking about identifying traits of different kingdoms by asking them to brainstorm the difference between various plants, animals, and fungi. At first, the questions might feel funny, but challenge them to think deeply.

For example, what's the difference between:
- A rose and a bumblebee?
- A portobello mushroom and a worm?
- A person and a tree?

After a few minutes, tell students you will spend the class thinking about the relationships between the Animalia (animals), Plantae (plants), and Fungi kingdoms.

**This lesson assumes your class has a basic understanding of the taxonomic classification of "kingdom." If that is new for your students, consider this basic introduction: https://www.nps.gov/common/uploads/teachers/lessonplans/ClassificationActivityGuide1.pdf*

Step One: Identifying the Kingdom of Fungi

1. Show the film clip "Mycelium is the Mother of Us All" (runtime: ~3 minutes). As they watch, ask students to record what they hear and/or notice about the origins of fungi and their relationship to plants and animals.

2. Discuss:
- What does the film clip suggest about the age of fungi?
- What did you learn about how fungi are related to plants and/or animals?
- Were you surprised when Paul Stamets said, "We are more closely related to fungi than we are to any other kingdom." Why or why not?

Step Two

1. Distribute Handout One: Facts About the Fungus Among Us and have students use information in the article to define the key characteristics of the kingdom of Fungi, and distinguish them from the other eukaryote (organisms whose cells have a nucleus) kingdoms, Plantae and Animalia:

Kingdoms	Fungi	Plantae	Animalia
Cell Type:			
Nutrition Acquisition:			
Reproduction:			
Movement:			
Other Characteristics:			

Step Three: Learning About Phylogeny

1. Read aloud this quote from Giuliana Furci's "Mushroom Mad!" essay in **Fantastic Fungi**:

> "When you're looking at a plant, you are essentially looking at fungi; the two have never been separate. To speak of flora and fauna is inaccurate when describing macroscopic life forms. They are three F's: flora, fauna, and funga. If the third F were to be included wherever the first two are [that is, when protecting the environment] the planet would be in a better place."[12]

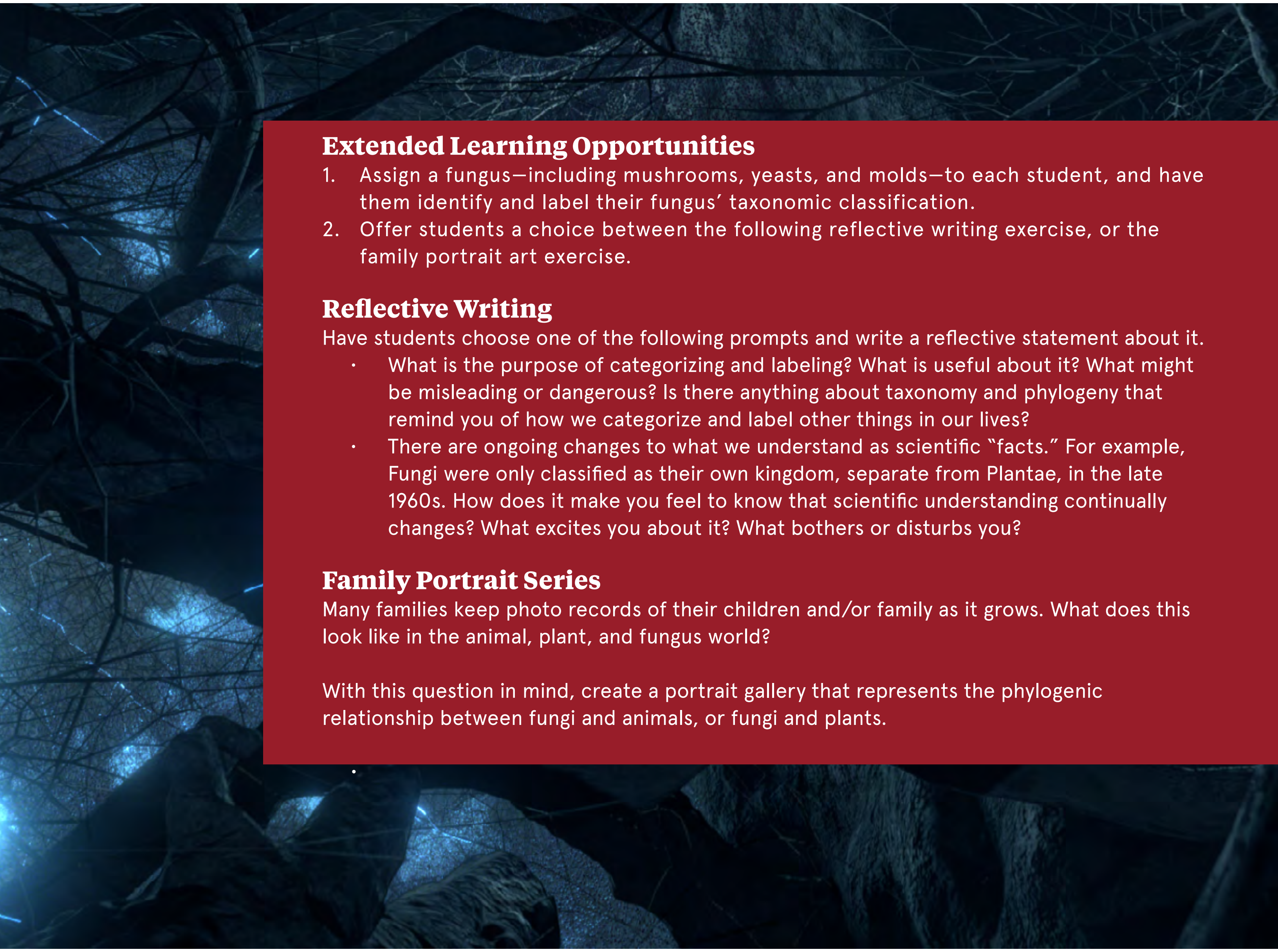
<u>Phylogeny tracks the evolutionary history of a group of organisms and can be used to identify their relationships to one another.</u>[13] Phylogeny can teach us how the kingdoms of Fungi, Plantae, and Animalia are linked.

2. In small groups:

- Have students research the following hypotheses about the evolution of Animalia, Plantae, and Fungi.
- Have them prepare to present their arguments to one another in their small groups. Students can use information from the film and/or book, from the resources listed below, or from credible resources they find on their own.
  - I. Fungi are more closely related to Animalia than they are to Plantae.
  - II. Fungi's ability to decompose and associate is the reason life is possible.
  - III. Fungi are the oldest of the three kingdoms.

Suggested Resources

- Tree of Life Web Project: http://tolweb.org
- UC Berkeley Museum of Paleontology: https://ucmp.berkeley.edu/fungi/fungifr.html
- University of Minnesota Study Press Release:
  - https://www.eurekalert.org/pub_releases/2006-10/uom-dae102006.php
  - https://evolution.berkeley.edu/evolibrary/article/phylogenetics_01



Extended Learning Opportunities

1. Assign a fungus—including mushrooms, yeasts, and molds—to each student, and have them identify and label their fungus' taxonomic classification.
2. Offer students a choice between the following reflective writing exercise, or the family portrait art exercise.

Reflective Writing

Have students choose one of the following prompts and write a reflective statement about it.

- What is the purpose of categorizing and labeling? What is useful about it? What might be misleading or dangerous? Is there anything about taxonomy and phylogeny that remind you of how we categorize and label other things in our lives?
- There are ongoing changes to what we understand as scientific "facts." For example, Fungi were only classified as their own kingdom, separate from Plantae, in the late 1960s. How does it make you feel to know that scientific understanding continually changes? What excites you about it? What bothers or disturbs you?

Family Portrait Series

Many families keep photo records of their children and/or family as it grows. What does this look like in the animal, plant, and fungus world?

With this question in mind, create a portrait gallery that represents the phylogenic relationship between fungi and animals, or fungi and plants.

https://www.livescience.com/53618-fungus.html

Facts About the Fungus Among Us

(Image: © USGS)

The Amanita muscaria mushroom, which is deep red with white flecks. Tens of thousands of organisms, from mushrooms to mold to yeast, fall under the umbrella of fungi. Once thought simply to be plants, fungi have emerged as their own taxonomic kingdom. The various fungal species are diverse, with many unique properties: some innocuous, some useful and some harmful.

Classifying Fungi

It has taken decades, as technology improved and scientific knowledge evolved, to appropriately classify this myriad group of organisms.

As recently as the 1960s, fungi were considered plants. In fact, at that time all organisms were classified into only two groups or kingdoms: plants and animals. In a 1969 article published in the journal Science, ecologist Robert Whittaker explained the basis of this two-kingdom system. For many decades in history, the only living creatures humans observed around them were either the "rooted" plants that produced their own food, or motile animals that sought out their food. Thus mobility and the method of gaining nourishment became the criteria for a system of classification. "The animals moved and plants didn't, and that's how fungi got stuck with the plants," said Tom Volk, a professor of botany at the University of Wisconsin-La Crosse.

However, unlike plants, fungi do not contain the green pigment chlorophyll and therefore are incapable of photosynthesis. That is, they cannot generate their own food —carbohydrates — by using energy from light. This makes them more like animals in terms of their food habits. Fungi need to absorb nutrition from organic substances: compounds that contain carbon, like carbohydrates, fats, or proteins.

Based on these and other properties, in 1969 Whittaker proposed that fungi become a separate kingdom as a part of a new five-kingdom system of classification. The proposed classification included a vast array of species. Among them, mushrooms, yeast, molds, slime molds, water molds, puffballs and mildews.

Since then, the system of classification and the fungal kingdom have been further refined. For example, slime molds and water molds were shuttled off to a different kingdom. Today, the members of the kingdom Fungi are also known as the "true fungi."

Characteristics of 'true fungi'

According to "Van Nostrand's Scientific Encyclopedia, Vol 1, 10th Ed." (Wiley, 2008), the numerous fungal species have "widely diverse habits and characteristics," and generalizations can be difficult. Nevertheless, there are a few key aspects common to all members of the fungal kingdom.

Cells: Fungi are eukaryotes, just like plants and animals. This means they have a well-organized cell, characteristic of all eukaryotes. Their DNA is encapsulated in a central structure called the nucleus (some cells can have multiple nuclei, according to "Van Nostrand"). They also have specialized cellular machinery called organelles that execute various dedicated functions such as energy production and protein transport.

Fungal cells are encased in two layers: an inner cell membrane and an outer cell wall. These two layers have more in common with animals than plants.

Like animal cell membranes, those of fungi are made of proteins and fatty molecules called lipids. In addition, animal cell membranes contain varying amounts of cholesterol. Similarly fungal membranes contain a unique steroid called ergosterol, according to Volk.

Plant cell walls are made of cellulose, whereas fungal cell walls have chitin, a distinctly non- plant substance. In fact, the exoskeletons, or the outer hard shell of various arthropods (insects, and crustaceans like crabs and lobsters) are made of chitin.

Structure: Fungi can be made up of a single cell as in the case of yeasts, or multiple cells, as in the case of mushrooms.

The bodies of multicellular fungi are made of cells that band together in rows that resemble the branches of trees. Each individual branched structure is called a hypha (plural: hyphae). Most often, the individual cells in hyphae sit right next to each other in a continuous line (also known as coenocytic hyphae) but they can sometimes be separated into compartments by a cross wall (septate hyphae). Several hyphae mesh together to form the mycelium, which constitutes the fungal body, according to "Van Nostrand."

"The fungi are the kings of surface area," Volk told LiveScience, explaining that hyphae expand their surface area in order to take in food, facilitate digestion and also to reproduce.

Nutrition: As mentioned earlier, since fungi cannot conduct photosynthesis, they need to absorb nutrients from various organic substances around them. This makes them heterotrophs, which literally translates to "other feeding," according to Volk.

Animals are heterotrophs as well, and need to seek out their food. But in their case, digestion takes place inside the body. "Fungi are different," Volk told LiveScience. "They find their food, they dump their enzymes out on to the food, and digestion takes place outside their body." These specialized digestive enzymes are known as exoenzymes, and are secreted from the tips of growing hyphae onto their surroundings, Volk states in the "Encyclopedia of Biodiversity, 2nd Ed." (Academic Press, 2013). These enzymes are the primary reason why fungi are able to thrive in diverse environments from woody surfaces to insides of our body.

As a result of exoenzyme activity, large food molecules are broken down into smaller ones, which are brought into the hyphae. Cellular respiration then takes place inside fungal cells. That is to say, organic molecules such as carbohydrates and fatty acids are broken down to generate energy in the form of ATP.

Fungi have multiple sources of food. Fungi that feed on dead organisms — and help in decomposition — are called saprophytes. If a fungus derives sustenance from a live host without harming it, then it is called a symbiont or a mutualist. Lichens — fungi and algae together — are an example of a mutualistic relationship. If a fungus feeds on a live host while harming it, then it is a parasite, according to the "Encyclopedia of Biodiversity."

Reproduction: The various fungi are capable of reproducing asexually or sexually. Both processes can generate spores. These are special cells, which when released into a suitable environment, can give rise to a new fungal body. Spores can be carried to new environments by air or water, according to Utah State University.

Asexual reproduction occurs through mitosis, when a fungal cell divides and produces identical genetic copies of itself. In simpler, single-celled fungi like yeast, this process is known as budding. In this case, a small offshoot or bud emerges from the parent cell, slowly growing in size. The nucleus divides into two and the bud splits off once it is the same size as the parent cell. On the other hand, multicellular fungi such as molds reproduce through the formation of asexual spores.

The duration and timing of certain steps of sexual reproduction vary quite a bit between fungal species. Moreover, the reproductive structures also vary from species to species. So much so, that these morphological differences form the basis for dividing the fungal kingdom into sub-groups or phyla, according to the "Encyclopedia of Biodiversity."

Sexual reproduction in fungi produces spores through meiosis. As a result, these spores contain half the number of parental chromosomes. Once released, the spores germinate into tree-like mycelia and are ready to "mate." In the case of mushrooms, puffballs and toadstools, the branched mycelium (also called primary mycelium) is divided into segments containing a single nucleus. Mating takes place when two primary mycelia come into contact with one another and form a secondary mycelium. Each segment of the secondary mycelium has two nuclei: one from each original segment. The individual nuclei still have half the number of chromosomes as the parent cell. In the course of several steps nuclei fuse, giving rise to cells with the original number of chromosomes. After this point, the sexual reproductive cycle begins again: meiosis occurs and spores are produced, according to "Van Nostrand."

Fungus and Us

Fungi are inextricably linked to our lives and livelihoods. They affect our health, food, industry and agriculture in both positive and vexing ways.

Fungi are sources of important medication. The antibiotics penicillin and cephalosporin, as well as the drug cyclosporine, which helps to prevent transplant rejection, are all produced by fungi, according to the "Encyclopedia of Biodiversity." Yet by the same token, fungi produce toxins called mycotoxins that are harmful to us. "Almost all mycotoxins are produced by molds," Volk said. For example, Aspergillus fungi that grow on corn and peanuts produce aflatoxins. This mycotoxin is considered a carcinogen and has been linked to liver cancer.

Yeast (Saccharomyces cerevisiae) is essential to the fermentation of wine and beer, and to the baking of raised, fluffy bread. The characteristic azure hue of blue cheeses is due to the sporulation of the fungus

Penicillium roquefortii, according to the "Encyclopedia of Biodiversity." Mushrooms such as chanterelles and morels are tasty additions to meals. Yet smut and rust fungi (named for the coaly and rust like appearance of their spores) routinely destroy food crops and plants like beans, barley and pine trees, according to "Van Nostrand."

Important scientific discoveries have been made using fungi as model organisms. The discovery that genes control the expression of enzymes, and that one gene controls one enzyme, was a result of experiments with the pink mold Neurospora. Scientists George Beadle and Edward Tatum won the Nobel Prize in 1958 for this work. Yeast has also been used as a model organism for answering questions in the field of genetics. According to a 1997 article published in the journal Science, many yeast and mammalian genes code for similar proteins, making it a useful tool for understanding the human genome and disease conditions such as Werner's syndrome.

Still, what we know about fungi today, and what we can do with fungi, is just the very beginning of all that is possible. As Volk states in "Encyclopedia of Biodiversity," there are 75,000 fungal species that are named. But this number is believed to represent only 5 percent of the species that exist in nature. "There's relatively little known about the fungi compared to the animals and plants," Volk told LiveScience. "There's still a lot of new species out there to be discovered."

STANDARDS

Standards: NGSS Standards

https://static1.squarespace.com/static/59c3bad759cc68f757a465a3/t/5a3cb71c8165f53e1ec61680/1513928478877/HS-LS4-4.pdf

MS-LS4-2: Anatomical Evidence of Evolutionary Relationship

https://static1.squarespace.com/static/59c3bad759cc68f757a465a3/t/5a2f3721419202b4787437b4/1513043745981/MS-LS4-2.pdf

K-2 NGSS Alignment

From Molecules to Organisms: Structures and Processes

K-LS1-1: Use observations to describe patterns of what plants and animals (including humans) need to survive.

1-LS1-2: Read texts and use media to determine patterns in behavior of parents and offspring that help offspring survive.

Ecosystems: Interactions, Energy, and Dynamics

2-LS2-2: Develop a simple model that mimics the function of an animal in dispersing seeds or pollinating plants.

Biological Evolution: Unity and Diversity

2-LS4-1: Make observations of plants and animals to compare the diversity of life in different habitats.

3-5 NGSS Alignment

From Molecules to Organisms: Structures and Processes

4-LS1-1: Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction.

Ecosystems: Interactions, Energy, and Dynamics

5-LS2-1: Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.

Heredity: Inheritance and Variation of Trait

3-LS3-1: Analyze and interpret data to provide evidence that plants and animals have traits inherited from parents and that variation of these traits exists in a group of similar organisms.

Biological Evolution: Unity and Diversity

3-LS4-2: Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing.

K-2 NGSS Alignment

From Molecules to Organisms: Structures and Processes

MS-LS1-3: Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

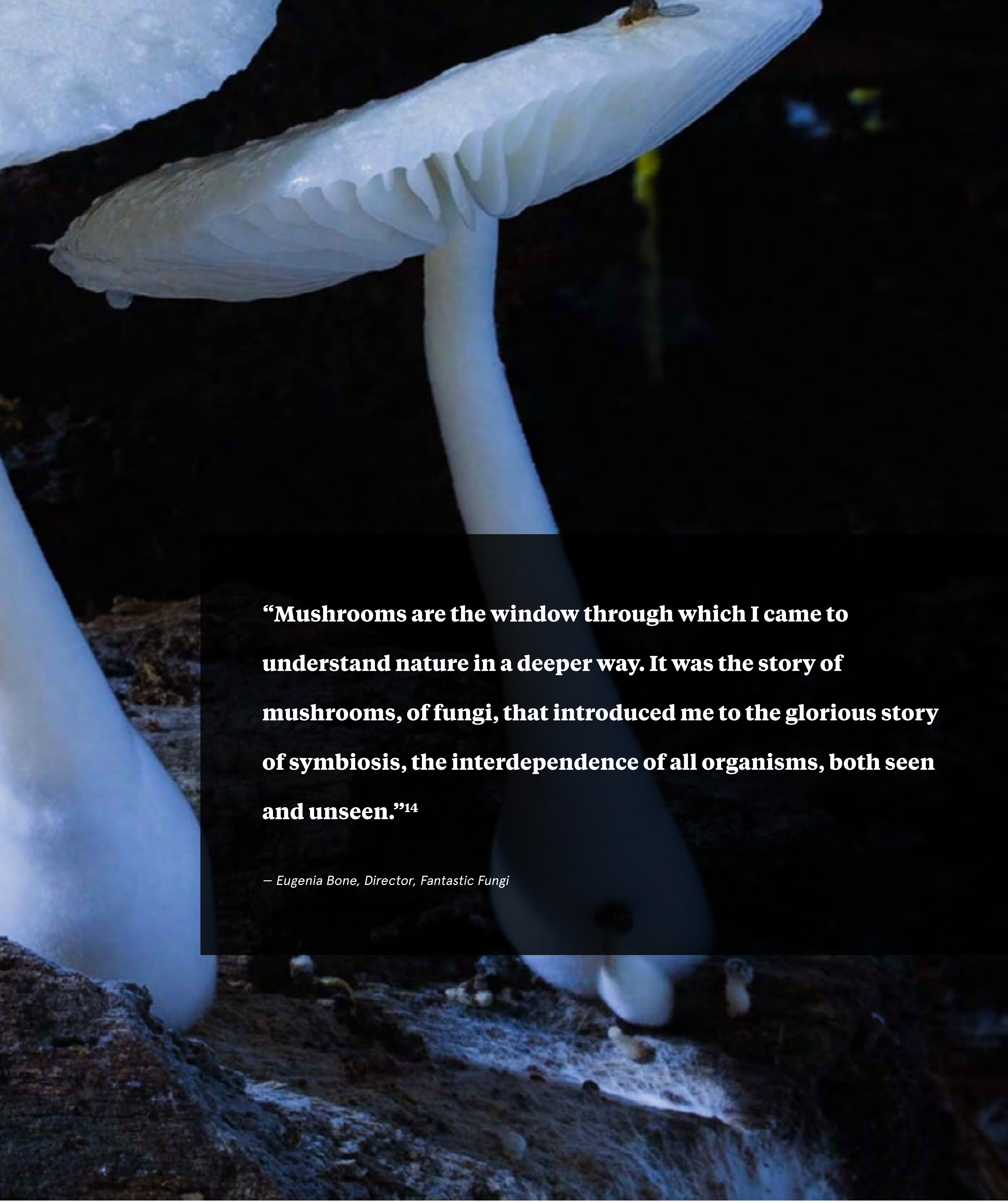
Ecosystems: Interactions, Energy, and Dynamics

MS-LS2-2: Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

9-12 NGSS Alignment

Biological Evolution: Unity and Diversity

HS-LS4-1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

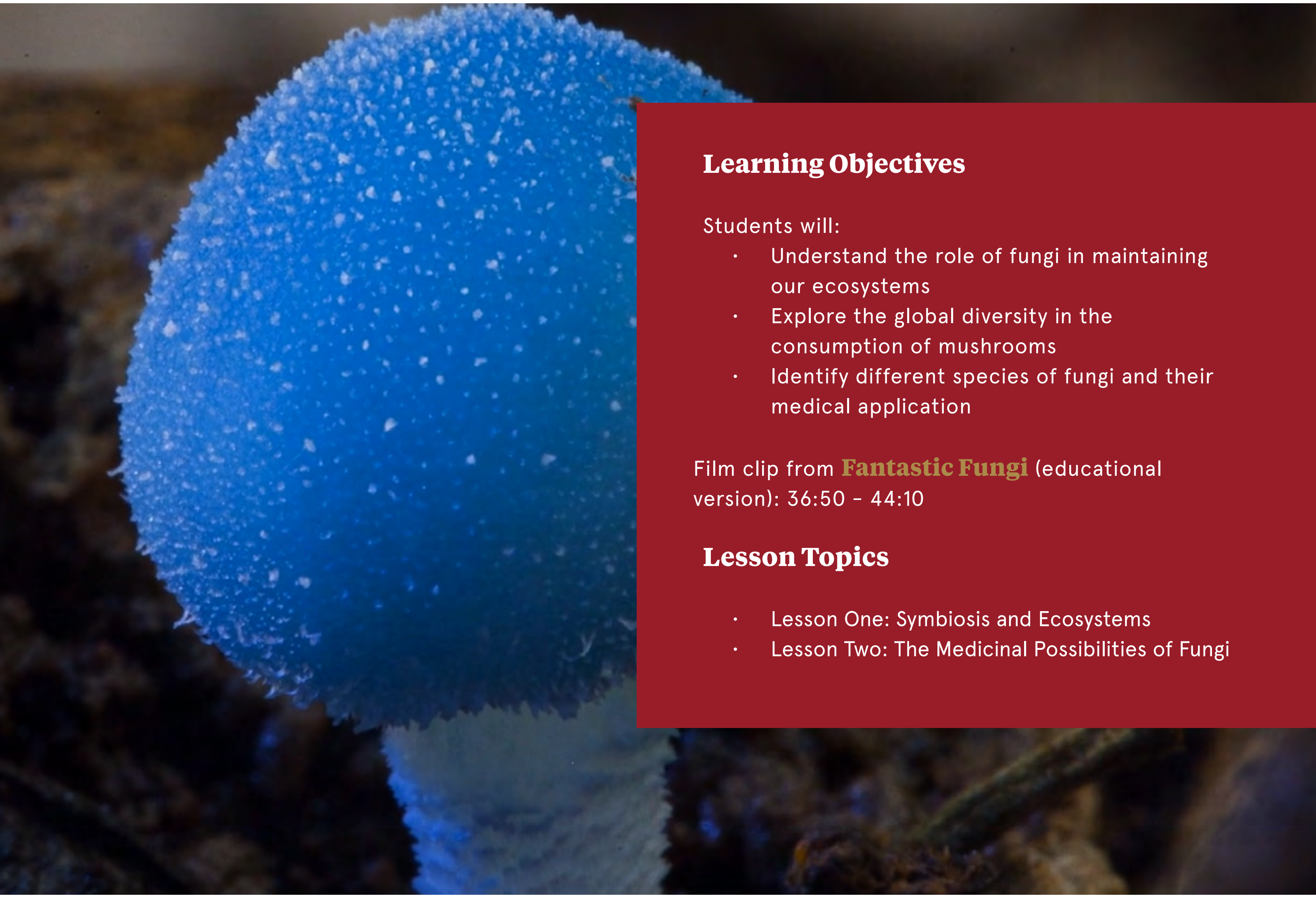


“Mushrooms are the window through which I came to understand nature in a deeper way. It was the story of mushrooms, of fungi, that introduced me to the glorious story of symbiosis, the interdependence of all organisms, both seen and unseen.”[14]

— Eugenia Bone, Director, Fantastic Fungi

MODULE 2:
FUNGI FOR FOOD, MEDICINE, AND HEALING

This module links the role of fungi in ecosystems to the many possibilities that fungi offer humans with regard to food, health, and healing. The opening lesson situates fungi as the central connectors of ecosystems—delivering not only nutrients, but also chemical messages that enable ecosystems of all kinds to survive and thrive. From understanding this connectivity, students will comprehend why fungi play a role in offering nutrients to human diets and also have profound healing power.



Learning Objectives

Students will:

- Understand the role of fungi in maintaining our ecosystems
- Explore the global diversity in the consumption of mushrooms
- Identify different species of fungi and their medical application

Film clip from **Fantastic Fungi** (educational version): 36:50 - 44:10

Lesson Topics

- Lesson One: Symbiosis and Ecosystems
- Lesson Two: The Medicinal Possibilities of Fungi

LESSON 1:

Nature's Intelligence: Symbiosis and Ecosystem

Overview:

In this lesson, students will learn about the role fungi play as the key connectors of ecosystems around the world, and about how that role relates to human perceptions and uses of mushrooms.

Essential Questions

- What are the relationships between fungi, plants, and animals?
- How have fungi been integrated into human diets around the world?

Materials

1. Paper, colored pens or pencils for drawing
2. Equipment to screen film clip
3. Access to **Fantastic Fungi** (educational version): 1:46 - 5:04
4. Student access to the internet or international cookbooks for mushroom recipe

Length

One 55-minute class period.

Key Terms[15]

(Students may add to or pull from the Fungi Glossary they created in Module 1, Lesson Two: The Wood Wide Web of Mycelia)

Ecosystem: The relationship between every living and non-living organism within a specific environment.

Symbiosis: An interaction, usually beneficial, between organisms from two different species.

ACTIVITY

Step One: Fungi—The Biological Connector

Opening

Explain that fungi are the biological connectors of nature—they enable the exchange of nutrients that nourish all plants and animals. They are the basis for the mutually beneficial ecosystems that balance life on earth.

Note: For deeper explanations on the biological processes of fungi, see Module 1, Lesson Two: The Wood Wide Web of Mycelia

Defining Fungi Type

Have students add these definitions of the three main types of fungi to their Working Glossary from Module 1, Lesson Two.[16]

Saprobic fungi: Fungi that decompose, or break down, dead logs, leaves, dung, or other organic matter.

Mutualists live symbiotically with all plants. There are two kinds:

- Mycorrhizal fungi hold soil together and act as trade pathways for the exchange of nutrients between plants (including trees). The mycorrhizal fungi are the basis for carbon exchange in ecosystems.
- Endophytic fungi live inside the cells of all plants. Some endophytes boost immune responses to viral or bacterial challenges to plant health, and some secrete chemicals to prevent animals from eating them.

Fungal Parasites: Fungi that feed off other organisms, which can cause harm to forests and farms alike.

Check for basic understanding of the concepts, especially the saprobic and mutualist fungi groups. The rest of this exercise will not focus on parasites.

Small Group Work

Split students into three groups, each one representing a different fungi group. Groups will brainstorm, discuss, and complete one of the following tasks:

- Have the saprobic group draw or describe how a forest would look if there were no fungi there to decompose dead plant and animal matter.
- Have the mycorrhizal group draw or describe a field or meadow where soil was not held together by mycelia, or where plants were unable to share nutrients.
- Have the endophytes group draw or describe a field or prairie where plants were not protected from disease or predation by endophytic fungi.

K-5 adaptation: Have students draw a maze where the mycorrhizae connect different aspects of an ecosystem of their choice.

Come back together as a group and pose the question:

- Given the fungi roles we just explored, how would you say fungi are related to our habitat and our access to food?
- How do you think fungi's role as an ecosystemic connector relates to fungi's possibilities for food and medicinal use for people?

Step Two: Fungi for Food

Watch the film clip

Watch the film clip featuring Eugenia Bone and Michael Pollan(educational version): 1:46-5:04, ending when she says, "You have to know your mushrooms."

Discuss:

- What did you see or hear about how people use mushrooms?
- What did you see or hear about how people feel about mushrooms

Share with student

As fungi play a central role in ecosystems all around the world, mushrooms and other fungi, like yeasts, have been a source of nutrition for people for thousands of years all around the globe. Some mushrooms are flavorful, and are high in protein, fiber, and vitamins and minerals.[17] Yet, because they may also be poisonous, medicinal, or have powerful psychoactive effects, they have also taken on different cultural meanings.

Small Group Work

Split students into small groups and assign each group a mushroom that is commonly used in cooking. Challenge the students to find different recipes for cooking with the following mushrooms from at least two different countries:

- Enoki
- Maitake (Hen of the Woods)
- Morels
- Porcini
- Portobello
- Shiitake
- White Button

K-3 adaptation: Use still images from the film, or a Google Image search for mushrooms, and ask students to choose one that stands out to them and make up a story that includes the mushroom and some key facts about the country or region where it grows.

4-5 adaptation: Using a globe, ask students to choose a country (or assign countries to students) and ask them to find a recipe using mushrooms from that country.

Access note: For students who may have access to different kinds of mushrooms, either through foraging or through purchase, it may be fun to have a potluck or recipe contest. If your students do not have access to mushrooms, see if a local grocery could donate some mushrooms so your students are able to cook, or at least taste, them in class.

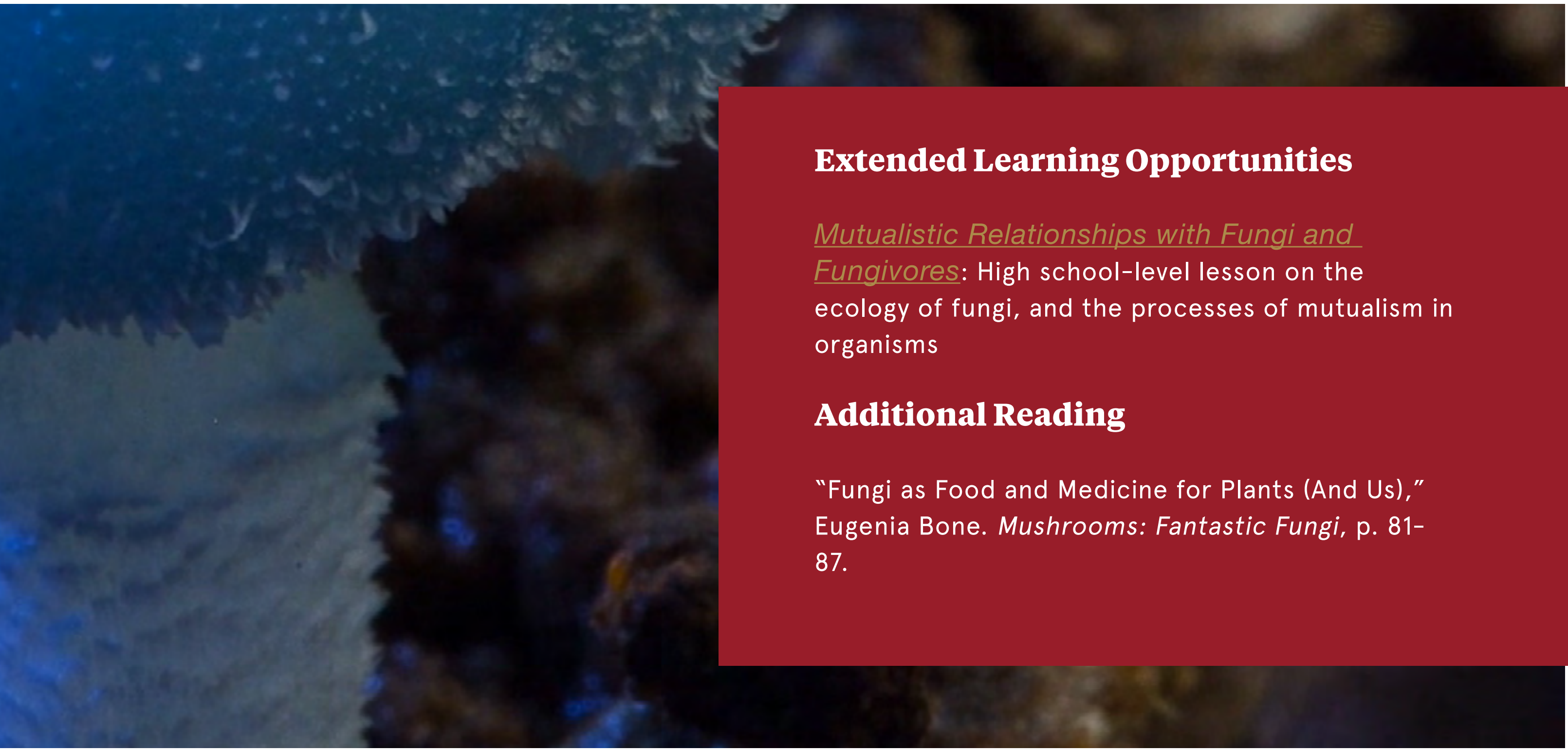
Or...check on your own classroom mushrooms and see if they are ready to cook.

Homework

Mushroom cooking party. Choose a mushroom from the group you represented in class, and make something delicious.

- We eat mostly saprobic fungi (white button, cremini, portobello), which are easy to cultivate
- Mutualists (porcini, chanterelles, truffles) are harder to cultivate and are more expensive

Discover a new recipe, or try a favorite recipe at home!

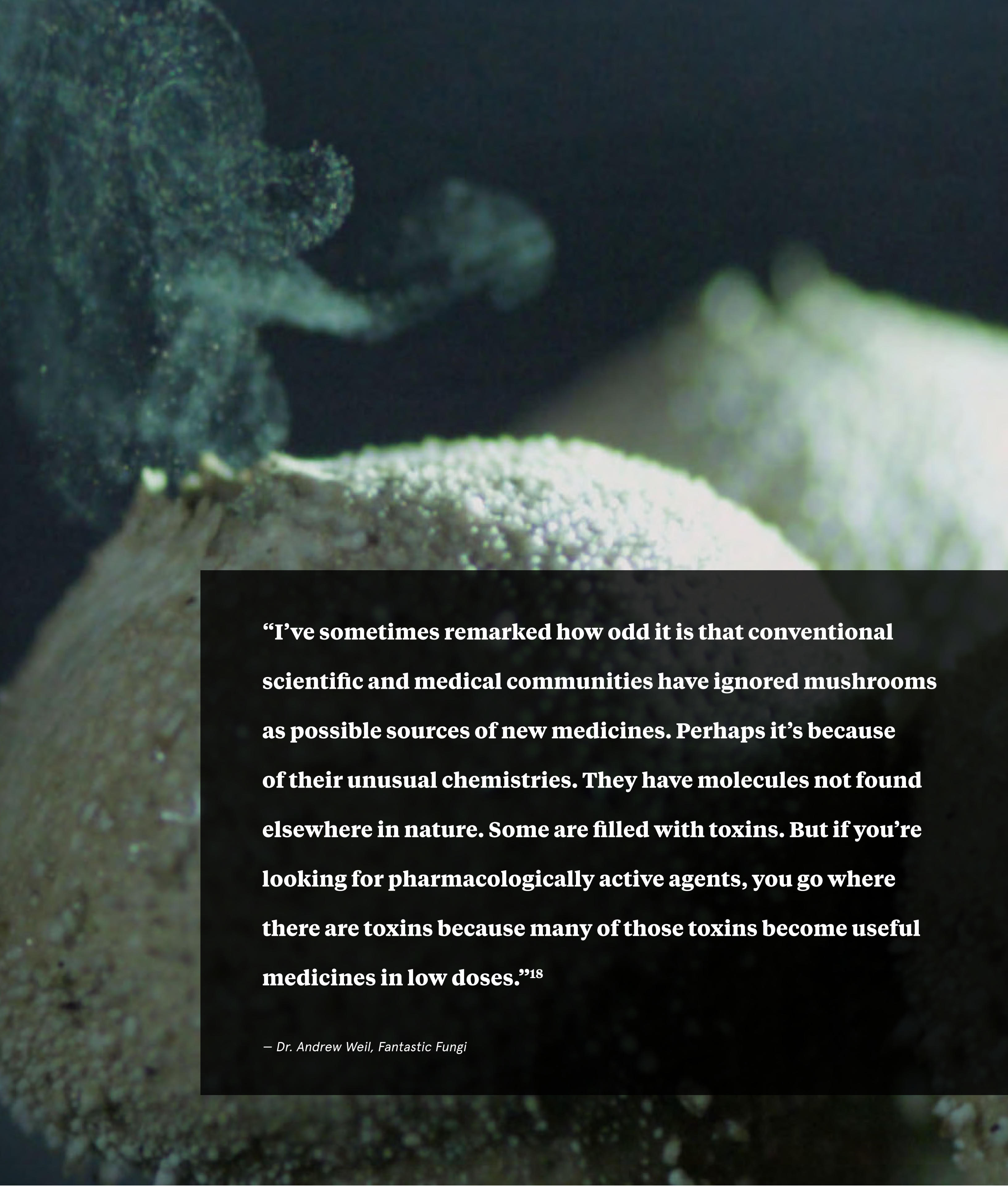


Extended Learning Opportunities

Mutualistic Relationships with Fungi and Fungivores: High school-level lesson on the ecology of fungi, and the processes of mutualism in organisms

Additional Reading

"Fungi as Food and Medicine for Plants (And Us)," Eugenia Bone. *Mushrooms: Fantastic Fungi*, p. 81-87.



“I’ve sometimes remarked how odd it is that conventional scientific and medical communities have ignored mushrooms as possible sources of new medicines. Perhaps it’s because of their unusual chemistries. They have molecules not found elsewhere in nature. Some are filled with toxins. But if you’re looking for pharmacologically active agents, you go where there are toxins because many of those toxins become useful medicines in low doses.”[18]

— Dr. Andrew Weil, Fantastic Fungi

LESSON 2:
The Medicinal Possibilities of Fungi

Film clip from Fantastic Fungi (education version): 29:43 - 35:00

Essential Questions

- What is the history of health benefits and medical uses of mushrooms across cultures and geography?
- What are the fundamental differences between the Western approach to medicine, and traditional approaches, especially Chinese medicine?
- What are the known and emerging uses of fungi in medicine?

Materials

1. Handout One: Note Catcher
2. Equipment to screen the film clip
3. Student access to the internet to enable them to develop their medicine case studies

Length

One or two 55-minute class period

Note: The cultural exploration of mushrooms in Step One is most appropriate for use with K-5 students. Steps Two and Three are recommended for middle and high school students. Clarify that students should not try any medicinal mushrooms without supervision from an experienced professional.

ACTIVITY

Explain to students that the human use of fungi to fight harmful microbes, and to generally increase human health, is not new. For thousands of years, indigenous cultures around the world have incorporated mushrooms into their pharmacopeia in many ways, as does Chinese medicine, and increasingly, Western medicine.

Day One: Introduction to Mushrooms

1. Introduce the lesson by reading aloud the following quote from Paul Stamet:

> "Modern science now recognizes that we are an ecosystem, that we live in an ecosystem, and we are born from an ecosystem. Mycelium is a foundation of nature's land-based food webs. Understanding the role of mushrooms and their mycelium in ecosystems empowers their use in naturopathic medicine in ways that bolster conventional medical practices. We are now fully engaged in a rapidly emerging scientific revolution in medicinal mushrooms. Our ancestors would be proud."[19]

Discuss:

- What does the quote mean? What questions does it bring up?

2. Distribute Handout One: Film Clip and Note Catcher Questions. Read over the questions with students before watching the clip. Students should take notes for each question. After the clip concludes, students will have a few minutes to complete the Note Catcher.

3. Show film clip from **Fantastic Fungi** (educational version): 29:43 - 35:01

4. Have students complete the Note Catcher and briefly discuss their answers to these questions:

- In your own words, describe how penicillin was discovered.
- Why does it make sense to look to fungi for medicinal purposes?
- What did you learn about the difference between the approach of Western medicine and the approach of Chinese medicine?
- What does Paul Stamets say is the difference between how shamans, or traditional healers, and Western medical doctors see sickness and disease?

5. After discussing their Note Catcher, ask students:

- What social and scientific reasons can you imagine that could explain why modern Western medicine practitioners have been slow to embrace traditional, folk, and indigenous knowledge of natural medicines

Step Two: Fungi in Non-Western Medicine

1. Read aloud the following methods, identified by doctors of Chinese medicine, as ways to identify herbal and botanical medicines:

- Traditional herbal medicine systems (practiced by shamans, curanderas, and other indigenous healers)
- Folk medicines (general knowledge practiced by the community)
- Practical experience
- Food
- Wild animal eating behavior
- Serendipitous events[20]

Check for understanding of these different methods.

Discuss:

- Which methods on this list do you believe most likely drive the development of modern pharmaceuticals? Why?
- From what you learned about the discovery of penicillin in the film clip, how would you describe its discovery? Accidental? Planned?

Step Three: Creating a Case Study

Note: Completion of case studies may be assigned as homework or continue during a second class period.

1. Explain to students that they will be researching and writing a case study of the medicinal uses of mushrooms. This case study will be a concise summary of research, written solely for informational purposes. It will pass on new learnings and questions still to be addressed. Their case study will include:

- The uses of a particular mushroom across conditions (see suggested ones below), or a condition where medicinal mushrooms are currently being used.
- Credible evidence-based research with citations including where the origin of this knowledge came from, the potential benefits, and/or the state of the research.
- Note: Completion of case studies may be assigned as homework or continue during a second class period.

Mushrooms:

- Lion's Mane
- Chaga
- Cordyceps
- Turkey Tail
- Maitake
- Reishi
- Shiitake

Conditions:

- Alzheimer's and other causes of dementia
- Cancer (multiple types)
- Chronic pain
- Nerve damage
- Inflammation
- Weakened immune system

Here are some research resources. Encourage students to find additional credible references to learn more.

- Middle School: https://grocycle.com/medicinal-mushrooms-the-complete-guide
- High School: https://namyco.org/scientific_research_and_medici.php

Additional Resources:

- Reading: "Mushrooms: Pharmacological Wonders," Andrew Weil, *Fantastic Fungi*, p. 75

Extended Learning Opportunities

Middle School: Explore the concept of immune health and create a model (in words, images, diorama, film, or another creative method) and explain how fungi are related to immune health in humans.

High School:

- Focusing on the medicinal use of mushrooms (or other fungi, like lichens or slime mold), write a well-cited scientific paper on how Western and Chinese and other traditional approaches to medicine differ, and how they may complement one another.
- Research potential treatments and vaccines that are being derived from fungi to address the COVID-19 pandemic.

AP Chemistry Extension: Read "New Perspectives on How to Discover Drugs from Herbal Medicines: CAM's Outstanding Contribution to Modern Therapeutics"[21] to learn more about how fungi and folk and traditional medicines can be clinically investigated for their potential as Western-style pharmaceuticals.

FILM CLIP NOTE CATCHER QUESTIONS

In your own words, describe how penicillin was discovered.

Why does it make sense to look to fungi for medicinal purposes?

What did you learn about the difference between the approach of Western medicine and the approach of Chinese medicine?

What does Paul Stamets say is the difference between how shamans, or traditional healers, and Western medical doctors see sickness and disease?

STANDARDS

K-2 NGSS Alignment

From Molecules to Organisms: Structures and Processes

K-LS1-1: Use observations to describe patterns of what plants and animals (including humans) need to survive.

1-LS1-2: Read texts and use media to determine patterns in behavior of parents and offspring that help offspring survive.

Earth's System

K-ESS2-2: Construct an argument supported by evidence for how plants and animals (including humans) can change the environment to meet their needs.

Earth and Human Activity

K-ESS3-1: Use a model to represent the relationship between the needs of different plants and animals (including humans) and the places they live.

Biological Evolution, Unity and Diversity

2-LS4-1: Make observations of plants and animals to compare the diversity of life in different habitats.

3-5 NGSS Alignment

From Molecules to Organisms: Structures and Processes

4-LS1-1: Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction.

Ecosystems: Interactions, Energy, and Dynamics

5-LS2-1: Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.

Biological Evolution: Unity and Diversity

3-LS4-2: Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing.

3-LS4-3: Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.

3-LS4-4: Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.*

6-8 NGSS Alignment

From Molecules to Organisms: Structures and Processes

MS-LS1-3: Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

MS-LS1-7: Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.

Ecosystems: Interactions, Energy, and Dynamics

MS-LS2-2: Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

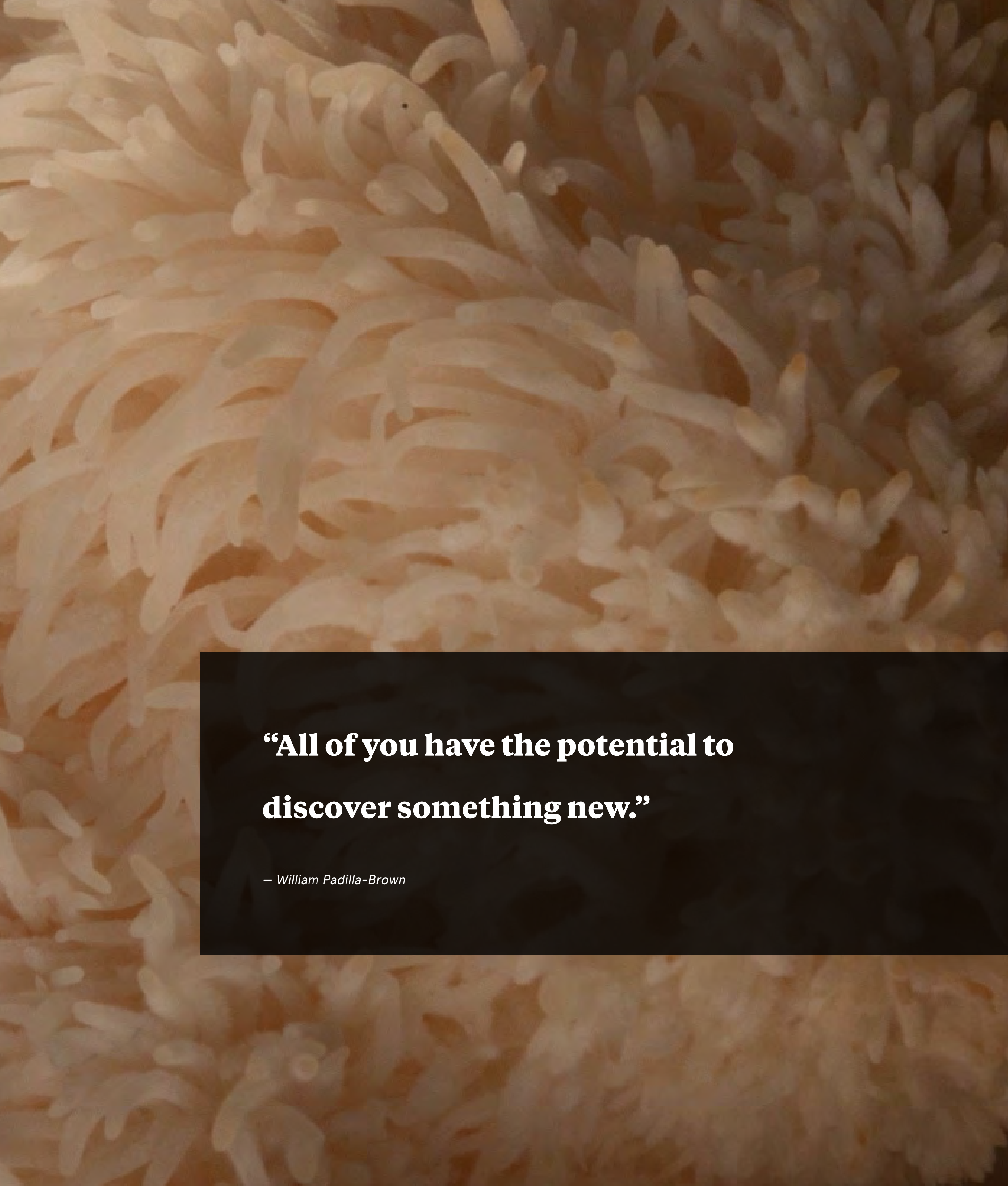
MS-LS2-3: Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

9-12 NGSS Alignment

Biological Evolution: Unity and Diversity

HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

HS-LS2-3: Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic condition.



“All of you have the potential to discover something new.”

— William Padilla-Brown

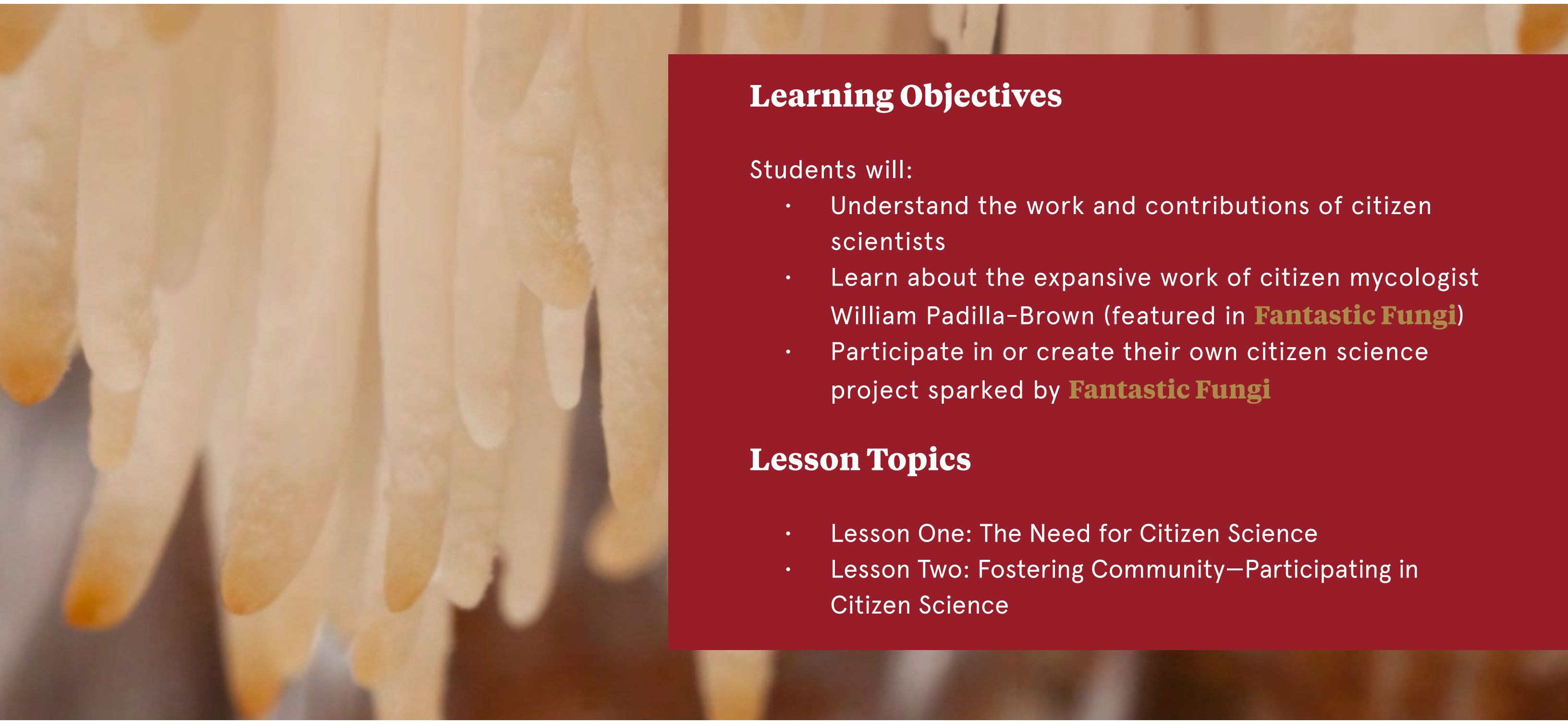
MODULE 3:
AWE AND WONDER WITH CITIZEN SCIENCE

Module 3 moves from practicing mycology to expanding students' connections with science by having them participate as citizen scientists. Alongside learning about the citizen science movement, meeting citizen scientists and citizen mycologists, and exploring the contributions their projects have made over time, students will engage with an established citizen science project or initiate one of their own design.

The link between studying science, in this instance mycology, and inspiring students to embark on their own path of discovery and connection to the greater world sits at the heart of bringing **Fantastic Fungi** into the classroom. As you plan Module 3for your students, take a moment to consider your own journey as an educator with these reflective questions:

- What questions do you love to explore?
- What are you passionate about in the world?
- What gives you a sense of wonder and awe in nature and in science?
- How can I contribute to science?

In **Fantastic Fungi** we see and learn from amazing citizen scientists—most of whom are citizen mycologists—people who like to forage, cultivate, or cook mushrooms, or are interested in academia and the development of innovative or industrial applications for fungi. In a nutshell, citizen mycologists love, respect, and are passionate about everything fungi. Their energy for this work is infectious and can be the spark to expand student's horizons on how and where they can make a difference in their world.



Learning Objectives

Students will:

- Understand the work and contributions of citizen scientists
- Learn about the expansive work of citizen mycologist William Padilla-Brown (featured in **Fantastic Fungi**)
- Participate in or create their own citizen science project sparked by **Fantastic Fungi**

Lesson Topics

- Lesson One: The Need for Citizen Science
- Lesson Two: Fostering Community—Participating in Citizen Science

LESSON 1:

The Need for Citizen Science

Overview:

In this lesson students will learn about the growth of citizen science and the important contributions of citizen scientists to all fields of science.

Citizen science is a global movement of public engagement and collaboration in scientific research to increase scientific knowledge. Formally trained scientists work together with individuals (citizen scientists) on science projects to make observations, collect data, and help answer some of our planet's most pressing issues.

Citizen science projects emphasize engagement in the process of inquiry. Citizen scientists **observe, question, plan, analyze, and communicate**—and once they learn these foundational skills, they will carry them into future pursuits, scientific or otherwise. Citizen scientists often partner with trained scientists to *achieve a common scientific goal*, and trained scientists *often rely* on citizen scientists for observation, collection, and documentation of data and specimens.

Essential Questions

- Why discover something new?
- Why are citizen scientists so important?
- What is a citizen science project?
- How can I be a citizen scientist?

Materials

1. Equipment to watch film segment from **Fantastic Fungi**
2. Film clip from **Fantastic Fungi** (educational version): 21:12 - 24:35
3. Handout One: Q & A with William Padilla-Brown
4. For Reference: Download Cal Academy of Science - *Citizen Science Toolkit*.[22]
   **Note: This is a fantastic in-depth curriculum on citizen science that goes into much more detail. Highly recommend adapting it for use with Fantastic Fungi and mycology.*

Length

One 55-minute class period K-5. Two 55-minute class periods, 6-12.

ACTIVITY

Opening

K-2 adaptation: Introducing the idea of citizen science with younger students is all about discovery, awe, and the wonder of science. It may be helpful to first tease out with younger students what it means to discover something in science through very accessible experiments.

Here are some questions to get students excited:

- Raise your hand if your answer is Yes:
  - Did you know that all scientists begin by asking questions?
  - Did you know that you can help get these questions answered?
  - Did you know that anyone anywhere can participate in science?
  - Did you know that there are many scientific questions that are still unanswered?

** Next, go directly to Step 3, "Meet William Padilla-Brown," and only watch videos.*

3-5 adaptation: Begin class by taking a poll to introduce the ethos of citizen science. Ask students with a show of hands, or if online, through a poll on Google Forms or other poll app, collect a baseline temperature or collection an overview of your students' opinions about science and what they know about citizen science.[23]

Here are some sample statements to adapt:

- Yes/No: I want to discover something someday.
- Yes/No: I have a lot of questions about science.
- Yes/No: I know what a scientist does.
- Yes/No: I love being in nature.
- Yes/No: I think it is important to contribute to something bigger than mysel

** Next, go directly to Step 3, "Meet William Padilla-Brown.*

6-12 Introduction to Citizen Science: Begin with this *pre and post survey* developed by Cal Science as a way to gauge and evaluate the citizen science lessons for **Fantastic Fungi**.[24]

Share

Share this brief explanation of citizen science used in the Lesson Overview:

> Citizen science is a global movement of public engagement and collaboration in scientific research to increase scientific knowledge. Formally trained scientists work together with individuals on science projects to make observations, collect data, and help answer some of our planet's most pressing issues.

> Citizen science projects emphasize engagement in the process of inquiry. Citizen scientists observe, question, plan, analyze, and communicate—and once they learn these foundational skills, they will carry them into future pursuits, scientific or otherwise. Citizen scientists often partner with trained scientists to achieve a common scientific goal, and trained scientists often rely on citizen scientists for observation, collection, and documentation of data and specimens.

Ask students if they have ever heard of or participated in a citizen science project. Share responses.

Meet Citizen Scientist William Padilla-Brown

- Watch **Fantastic Fungi**: 21:12 - 24:35
- If time permits, share this second video to learn more about his work. *Mushroom Farming with William Padilla-Brown* (runtime: 6:00 minutes)
- Read (with students 3-5, individually 6-12) Handout: Q & A with William Padilla-Brown. Have students underline the sentences that stand out and note any words or phrases they find confusing.

Discuss

- What was new or surprising about this citizen scientist?
- Were any words or ideas confusing? Do you need to clarify them?
- William Padilla-Brown is a self-taught mycologist and entrepreneur. What stands out to you most about his work and his success?
- One of William Padilla-Brown's goals is to make mycology and mushroom cultivation more widely embraced and accessible. What did you hear or see in the video, or from the Q & A handout, that speaks to this goal?

HANDOUT ONE

Q & A WITH WILLIAM PADILLA-BROWN[25]

- Born: Harrisburg/Central Pennsylvania
- Interest in mycology started at 18
- Founder, MycoSymbiotics, a mushroom research and production business
- Certificate in permaculture, non-formal training (2015)
- Researches mushrooms to bring new systems and new ideas to to the forefront
- Founder of MycoFest (2015) to promote ecological literacy, keeping it affordable so his community can be involved
- First person to commercially cultivate Cordyceps militaris in the U.S., first in English-speaking world to publish work on how to cultivate this mushroom (2017)

Excerpted from Permaculture Podcast Interview with Scott Mann: "Mycology and Citizen Science with William Padilla-Brown"

Why mushrooms and citizen science?

I didn't know what I wanted to do but I believed it was important to grow food, so I got to fungi through this foray into gardening. I noticed mushrooms in the garden and the natural systems on my first time hiking in the forest as a teen. I started to take permaculture classes and realized that no one had expertise in identifying or cultivating mushrooms...I built my own lab at home, got interested in microbiology, and DNA barcoding. I am completely self taught.

On the value of being a citizen scientist

I found that it is really important to (1) be able teach yourself how to do things and (2) execute the scientific method at home where you can research things outside of a university that has more structure which can be beneficial for [some] things. But the lack of structure and the lack of formal education allows more imagination and more creativity in the scientific process, which allows citizen scientists to uncover things that might have been overlooked, or might not have been looked at in an academic setting. I think it is really important to be practicing science at home to come to different conclusions that we would not have traditionally come to and provide that to the community and advance what everyone knows.

On finding new answers

I found quickly that as I was learning about all these different things that I was running to the end of what the internet had to offer me. I would research all these things and have questions and then not be able to find the answers on Google or Google Scholar or find anything online so at that point I started to say to myself, "All right, well maybe I need to start coming up with the answers myself." So that started it for me. Now I have gone down this rabbit hole and have discovered these new things which expose me to new doors that need opening and explore what is behind them. I am constantly finding weird stuff in my lab or in the forest.

Power of citizen science

When you find unidentified species or unidentifiable species it's really important to sequence the DNA to see if anybody else has sequenced it and put it online. If not, you have the opportunity to identify a new species—literally anyone can do this. I can train high schoolers to go out and do this and have young people finding and helping to catalog new species, not just mushrooms but other things. . . With those new species, if they haven't been researched at all, there is the potential to find novel compounds in them that have medicinal benefits in them or novel capabilities that might be good for biotech or new architecture with textiles that people that are doing with fungi. It is a constant quest for knowledge.

Does gene sequencing take out the guesswork?

Absolutely 100% yes . . . I upload the DNA onto NCBI BLAST and it will say this specimen is x% matched. [NCBI BLAST stands for Basic Local Alignment Search Tool. The program finds regions of similarity between biological sequences and compares nucleotide or protein sequences to sequence databases and calculates the statistical significance.][26] What you want is 98-99% for a true species identification, but even a couple letters off could mean it is a new species or different species. We have a real-time tree of life. There's lots of name changes with mushrooms because we are finding out that certain mushrooms are more related to something else than we thought they were. Which is really interesting. It takes a lot of the guesswork out and really clarifies things for us as far as evolutionary history and relatedness.

How do you do this work at home?

I bought a kit, a mini-PCR [polymerase chain reaction machine] which is what you need for doing molecular biology to extract DNA. Classrooms are equipped with these now. The PCR used to be like a big machine, now it's really small like a jewelry box and you can do [DNA sequencing] out in the open. Now I am doing field molecular biology, which is rather new. I can do sequencing anywhere. I will be able to travel and get full or partial sequences in my car or in a tent or in a hotel room, and all of it is really affordable.

Mycro-literacy, Mycology, and Access

There are a lot of people who set the groundwork for us to even be doing this stuff at home. . . Initially it came from more of an academic place that isn't digestible to the general population, who don't have that kind of jargon down, and don't know the technical terms. Now we have people like myself that come from a background of not completing high school traditionally, that are able to communicate these ideas in a language that is more digestible to the general population. This is really important and really critical in a way that mycology, as a citizen science, is growing fast. I am hoping that in the way that mycology has been grasped by the general population, other sciences might be able reach that level too. But, I do think that mushrooms are unique in the way they build community.

"When we see it, we understand it,
When we understand it, we care about it
When we care about it, we'll do something to save it."

— Suzanne Simard, Fantastic Fungi

"One of the things I learned that I didn't really expect is that the mycelia network is a network that connects plants and trees to one another to build community; communities that are shared economies not based on greed, but where everybody can flourish. We need to take that model from under the ground to above the ground because that could be a perfect model for how we can live our lives."

— Louie Schwartzberg, Director, Fantastic Fungi

LESSON 2:

Fostering Community—Participating in Citizen Science

Overview:

In this lesson students will connect citizen science to the ideas and practices of community, empathy, cooperation, and generosity. Students will explore these ideas through envisioning their own citizen science project, individually or collectively, as a class effort. If time permits and commitment is established, students and/or the class may want to embark on an original citizen science project. Resources and suggestions are included as an extension but are not within the scope of Lesson Two.

Essential Questions

- How are science and community connected?
- What is my responsibility to the natural world?
- What role can citizen science play in taking care of the natural world?

Materials

1. Equipment to watch film segment from **Fantastic Fungi**.
2. Film clip from **Fantastic Fungi** (educational version): 1:02:32-01:06:02
3. Handout One: "Mushrooms to the People," William Padilla-Brown
4. Handout Two: Citizen Science Achievements from Around the Globe
5. Access to these citizen science websites: *SciStarter*, *iNaturalist*, *Zooniverse* and *North American MycoFlora Project* (now called the Fungal Diversity Survey)

Length

One 55-minute class period.

ACTIVITY

Opening

Watch Film Clip

Begin the lesson with watching this film segment from **Fantastic Fungi** clip: 1:02:32 - 01:06:02

Connecting Science, Community, and Fungi

Ask students for their general observations and thoughts about the film segment before discussing several of the key ideas raised:

> Peter McCoy, the founder of Radical Mycology a grassroots movement and social philosophy based on accessibly teaching the importance of working and being in relationship with mushrooms and other fungi for personal, societal, and ecological health, said "Anybody can add to the science."
>
> - Do you agree with Peter? Why or why not? What do you think he means by "adding to the science?'
>
> Paul Stamets shared, "A core concept of evolution is that through natural selection the strongest and the fittest survive, but moreover communities survive better than individuals. Communities rely upon cooperation and I think that is the power of goodness. Evolution is based on the concept of mutual benefit and the extension of generosity."
>
> - In your own words, explain the last sentence of this quote. What does mutual benefit mean in the context of the natural world? What does the extension of generosity have to do with evolution?
>
> Trad Cotter said, "We need these mushrooms. We work together as a community to solve problems. We could be the community that heals the planet."
>
> - How do you understand the connections between mushrooms, working together as a community, and healing the planet?
>
> Suzanne Simard believes, "We have always thought of plants as these inert objects that don't interact with each other and build things ... they need each other, they need each other to grow in a community and to share the load. 'You do that and I'll do this and together we can build a resilient community.'. . We just have to get busy and let nature do its thing."
>
> - How does Suzanne Simard's reflection change your idea about nature, about plants, and about mushrooms and fungi?

The Mycology Community

Transition from the film to distributing Handout One: "Mushrooms to the People" by William Padilla-Brown from the book *Fantastic Fungi*.

- After reading the article, how does William Padilla-Brown connect fungi, science, and community?
- How does he see his work benefiting his community?

Barometer Activity

Set-up: Post four pieces of paper around the room in this order: Strongly Agree, Agree, Disagree, and Strongly Disagree.

One at a time, share the Citizen Science Value statements from *Cal Academy of Science—Citizen Science Toolkit*, p. 5-6.

Directions:

- Step 1: Read aloud one statement. Instruct students to stand in front of the sign that best reflects their current belief about the statement.
- Step 2: After students have chosen their position, ask each group to share the reasons for their selection with each other.
- Step 3: Ask one student per position to share a summary of their group's discussion. Step 4: After all statements have been shared, students can decide to change positions if they have been persuaded by a peer's position.

Debrief with the class:

- What process did you go through to decide where to stand?
- Which value statement was the most difficult to decide? Why?
- After hearing the groups share their positions, were you persuaded to change your mind?

Barometer Statements:

- Anyone, anywhere can be a scientist.
- There are unanswered questions remaining in science.
- Science serves society. Society needs a scientifically literate populace.
- Curiosity and fun drive scientific research.

Share Handout—Citizen Science Achievements from Around the Globe

Assign one student at a time to read a project to the class. After reading through the projects, ask students to rank 1-3 which citizen project they would most like to be involved in. Go through each project and see which are the most popular.

Closing

To end this module have each student:

1. Focus on their #1 choice and come up with three questions they would most want to explore and collect data on in relation to this citizen science project.
2. If they were to design their own citizen science project, what would be their project's goals?

LONGER TERM EXTENDED LEARNING

Planning a Citizen Science Project

6-12 Grade Level

A natural extension of this introduction to citizen science and citizen mycology is to plan and engage the class in their own citizen science project. This is a more extensive commitment but one that yields tremendous learning opportunities.

One of the core values of citizen science, particularly in a classroom setting, is the commitment to the intrinsic sense of curiosity that fuels student engagement. If possible, decide as a class how you want to engage.

It may be helpful to have students begin collecting ideas and questions to investigate in pairs/small groups first and then share with the larger class.

You can also have students spend some time exploring several websites dedicated to citizen science projects to see examples or possible projects to join. If computer access is not available for all students, it may be helpful to project the sites so the class has an opportunity to explore and discuss options: *SciStarter*, *iNaturalist*, *Zooniverse* and *Fungal Diversity Survey*.

Remind students that their project needs to include these steps:

- Observation
- Questioning
- Planning
- Analyzing
- Communicating

The Cal Academy of Science—Citizen Science Toolkit offers a well organized set of resources to use as you plan out the steps for students. These are teacher facing but the planning and organizing handouts can be easily adapted for your students if this is the route you choose.

NGSS Standards—Module Three (Excerpted from *The Cal Academy of Science--Citizen Science Toolkit*.) Citizen science projects fulfill the scientific inquiry process and support the Next Generation Science Standards (NGSS)'s Scientific Practices and Crosscutting Concepts, as well as some Common Core State Standards (CCSS).

Crosscutting Concept: A Framework for K-12 Science Education (*NGSS Appendix G*)

Examples of Citizen Science

Project Patterns

> "Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them."

In projects where students are making and submitting regular observations using a set protocols, there are opportunities to identify patterns across observations, and begin to consider factors that might influence these patterns.

Cause and Effect —Mechanism and Explanation

> "Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given context and used to predict and explain events in new contexts."

For example, Arthropods in Your Schoolyard on iNaturalist focuses on gathering observations of arthropods in a variety of habitats. As students collect a larger number and wider variety of observations, they might begin to be able to predict the type of organisms they will find in a certain location, based on various environmental conditions (e.g. temperature, moisture, light). This type of prediction makes way for exploration into what arthropods need to survive in general, and how and why that might vary from species to species in scale, proportion, and quantity. "In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

Exploring Organizations for Citizen Mycologists

Citizen Science/Mycology

- *Fungal Diversity Survey* is a collaborative project between Mycological Society of america (MSA), North American Mycological Association (NAMA), and many other individuals and clubs whose goal is to document the entire diversity of macrofungi of North America.
- *iNaturalist*: This is a citizen science platform where one can upload pictures of observations (of fungi or any other organisms) and people across the world work together to identify your find if it is not in the database.
- *Mushroom Observer*: Like iNaturalist, this is a platform to upload photos of observations, but is dedicated to fungi. There is a very active community of mycologists who work together to identify your observations. This platform is a great learning tool for mushroom identification.
- *MyCoPortal*: MyCoPortal is centralized collection where users can explore fungal collections from all the different herbaria in the United States including an awesome map feature that shows where a given species has been collected in the United States and where that collection is now deposited.

Fungal Taxonomy

- *MycoBank*: See the currently accepted name and taxonomic history of any fungal species.
- *Index Fungorum*: This site, like MycoBank, shows the currently accepted name for any given species.

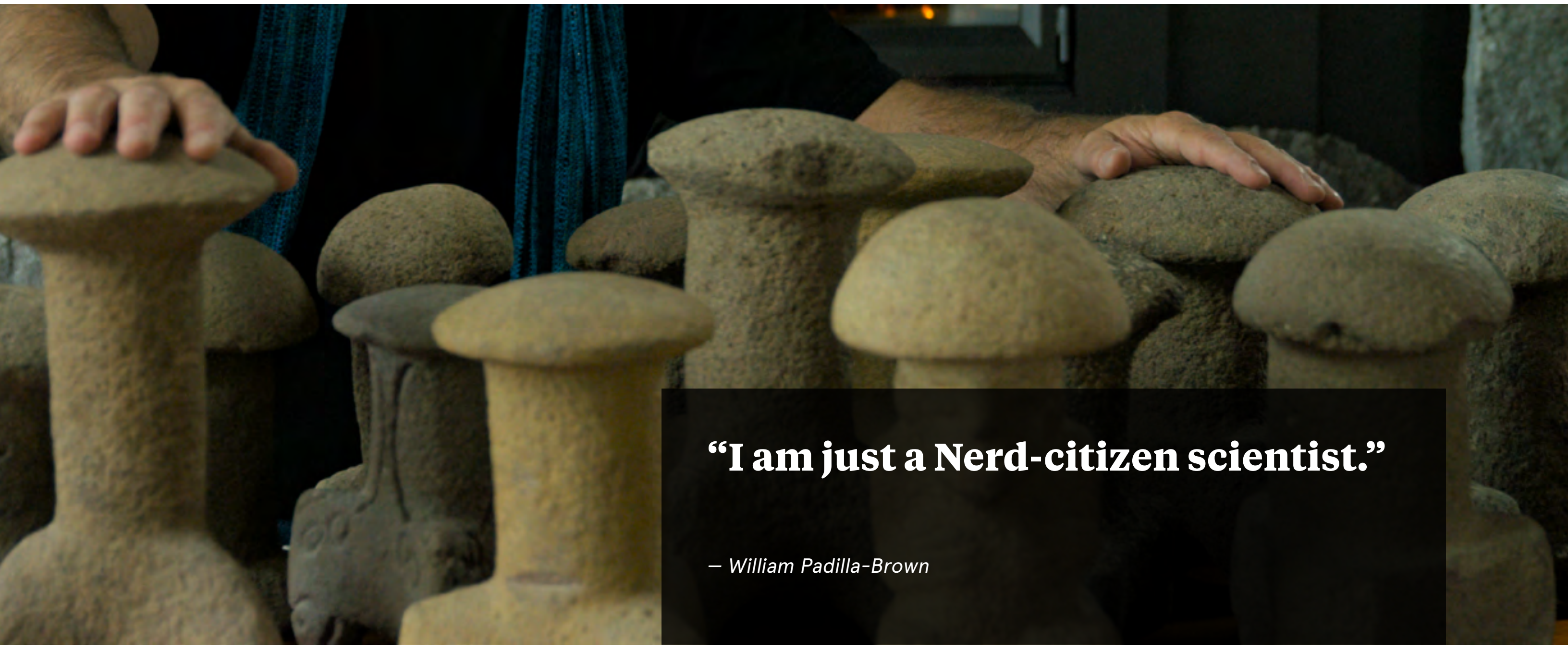
Key Mycology Organizations

- *North American Mycological Association (NAMA)*: An organization of professional and amateur mycologists across the continent.
- *Mycological Society of America (MSA)*: The professional mycological society of the United States.

More Resources from William Padilla-Brown

He is prolific, so all these sites continue to evolve. These resources speak specifically to his citizen scientist work.

- Many videos on his YouTube channel: *Apex Grower*
- His website and work: *MycoSymbiotics*
- Podcasts (one of many): *William Padilla-Brown—The Self Taught Scientist*
- Follow along on Instagram & TikTok: @Mycosymbiote



"MUSHROOMS TO THE PEOPLE," WILLIAM PADILLA-BROWN

WILLIAM PADILLA-BROWN is a social entrepreneur, citizen scientist, mycologist, amateur phycologist, urban shaman, poet, father, and founder of MycoSymbiotics LLC, a mycological research and mushroom-production business based in New Cumberland, Pennsylvania.

It's never too late to follow your dreams. My own journey toward becoming a mycologist and community organizer had its ups and downs, but I wouldn't trade it for the world. I dropped out of high school when I was sixteen because it was interfering with my education. I realized at a young age that a lot of people weren't learning what they really needed in order to live a successful life, so I started to seek an alternative lifestyle. Mushrooms and permaculture design science became the key to unlocking that potential for me.

I started by doing a lot of internet research and attending workshops and ultimately developing a nontraditional, independent education system for myself. I met a lot of gardeners and permaculture scientists in my area, and as I got more involved with them, I realized that most knew little about mushrooms, and yet every single one had mushrooms in their garden. So I researched some more and discovered that no one in a hundred-mile radius of where I lived had information on mushrooms or was teaching anybody about them.

Now I'm a mycologist, a mushroom farmer, a certified permaculture designer, and an educator. I focus a lot of my time on understanding patterns and then designing techniques to bring that knowledge into urban settings. I focus on teaching people in inner cities how they can use this information and these sciences to alleviate economic stress and build a better life for themselves. I go to farmers markets and work with children to increase their ecological literacy. I'm basically exposing these people to new realities, showing them that there are other ways to live that won't get them arrested. I see a lot of people who don't know where their food comes from, who don't know how they're connected to their community, who don't know how they're connected to the environment. In the inner city, most folks haven't had the opportunity to walk out in nature, and those that have often haven't had the education to understand what it is they're experiencing.

I also see a lot of food deserts in urbanized areas where there aren't a lot of grocery stores, and when there are stores, you see mostly packaged and processed foods—certainly not a lot of fresh food. Local folks have no relationship with the food they eat. So if I can show them real food, especially food that's grown right there in their community, they start to get it, they start to understand the holistic world they live in. Seeing healthy, nutritious food right in front of them—especially mushrooms, because they are so nutrient-dense—and knowing where that food comes from, that is the way to open people up to new possibilities that will have a very real and positive impact on their lives.

I implement a lot of my work through MycoSymbiotics, a mycological research and production business I started in 2015. We don't have a website per se, but we do have a comprehensive blog, podcasts, and a robust social media presence. Our home base in Lemoyne, Pennsylvania, just outside of Harrisburg, has a laboratory and a mushroom farm that we utilize for educational purposes. People can tour our facilities and get hands-on with the science there, but I also take everything on the road. A lot of people can't afford to get out of the city on a regular basis, so I teach at schools and various events to bring this information to places that otherwise would never get it. I'll also go to urban farms and inner-city permaculture farms like Baltimore's Charm City, where I teach or plant mushrooms and learn what others are doing.

I first started growing mushrooms in a closet, then expanded into my home, and became very passionate about cultivating gourmet and medicinal mushrooms in small spaces. And so my approach to mushroom farming is different from conventional methods that use multi-million-dollar laboratories and farming operations. I focus on developing low-tech techniques that anyone can apply. I know of other mycologists who are experimenting with similar techniques, and we share our knowledge and experience. Bringing this work and these mushrooms to more people reflects the spirit of what we're all doing. These new techniques utilize agricultural wastes and urban wastes like coffee grounds and cardboard to create low-cost environments for cultivating mushrooms. Mushroom "farms" can then be built in barns and sheds and basements, all places that are easily accessible to most people. For a little bit of money you can get a very big yield.

I also have a strong interest in mycomedicinal mushrooms. Both of my grandparents on my mother's side passed away from cancer; they were taking all sorts of pills and living very uncomfortably by the end of their lives. If only they'd known about some of these immunomodulators, like the reishi mushroom. I'm especially interested in the cordyceps fungi, specifically Cordyceps militaris, which is another powerful immune system booster. People from all over the world send me specimens. I'm looking to create resilient commercial strains for an emerging microculture of cordyceps farmers. This sort of farming is very new to the United States. People have been farming cordyceps mycelium for medicinal products for some time, but the farming of the actual cordyceps fruit body was initiated by myself over the past two years. My goal is to increase its production and get it out to the masses.

In addition to that, I'm always seeking gourmet and medicinal cultures everywhere I go. If I find a fungal specimen that's doing something interesting, maybe growing in an odd location or playing some kind of mycoremediation role, breaking down something funky, I bring it back to the lab and study it. I share the information with my friends in this wonderful mycelial network that I've become a part of to see what they can figure out. Our objective is to identify different genetic barcodes and see if maybe we've found a new species or something to add to the developing phylogenic tree. I believe that DNA analysis will just keep getting bigger as an analytical tool.

Follow Your Bliss

Many people around me thought mushrooms were weird, but that's where my passion went, and I followed it. The journey has been incredible and fulfilling. I feel like I'm really helping people in my community, feeding them and providing medicines that might heal them. My experience has taught me how important it is for individuals to follow the things they're interested in, regardless of what others say, especially when it's something that is ethical and ecological and that can help us all live more holistically on the planet. Do what you love, give it your best, and share it. The people who will support you may not be in your immediate community, but they're out there.

CITIZEN SCIENCE ACHIEVEMENTS FROM AROUND THE GLOBE

Canadian scientist Fred Urquhart's 40-year search for the wintering grounds of millions of Monarch butterflies included data from thousands of citizen scientists across North America who tagged and tracked the insects during their fall migration. (This work continues today through *Monarch Watch*.) In fact, it was a pair of citizen scientists Cathy and Ken Brugger, working with Urquhart in Mexico City who first discovered the monarch's haven on a remote Neovolcanic Plateau 3048 meters (10,000 feet) above sea level and 240 km (149 miles) from Mexico City. In 2008, the United Nations Educational, Scientific and Cultural Organization (UNESCO) declared this monarch butterfly sanctuary a World Heritage Site.[27]

Einstein@Home: Three citizen scientists—an American couple and a German—discovered a new radio pulsar in data gathered by the Arecibo Observatory. This is the first deep-space discovery by Einstein@Home, which uses donated time from the home and office computers of 250,000 volunteers from 192 different countries. This is the first genuine astronomical discovery of a computing project collected and distributed by public volunteers.[28]

Myco-remediation (using mushrooms to help clean up lands and waters polluted by oil spills. See Module 5, Lesson One.) Paul Stamets has used mushrooms in many ways including myco-remediation techniques. To learn more see *Myco-remediation and oil spills* "The Petroleum Problem".[29]

ZomBee Watch is a citizen science project tracking the honeybee parasite Apocephalus borealis, the Zombie Fly, which is parasitizing honeybees in California and possibly other areas of North America. Citizen scientists watch for strangely behaving "zombie bees." Watch this *introductory video* to see how this project is working.[30]

The Lost Ladybug Project: The nine-spotted ladybug (Coccinella novemnotata), the state insect of New York, had not been seen since 1982. The species was thought to be extinct until a citizen scientist participating in the Lost Ladybug Project rediscovered it in 2011 on a sunflower at an organic farm on Long Island, NY.[31]

Foldit: Scientists had been struggling to model an enzyme critical to AIDS research for 10 years. Once they brought their problem to the online protein-folding game community Foldit, players found the solution in only three weeks. See the story in *Scientific American* to learn more.[32]

Digital Fishers invites citizen scientists to help classify organisms seen in videos taken of the seafloor off Vancouver Island. A teenager in Ukraine was watching a clip of a hagfish swimming along, when a whiskery nosed animal suddenly came into frame and slurped the fish up. His curiosity piqued, the student contacted researchers to ask what he had seen. It turned out to be an elephant seal, and scientists had never before known that they dive so deep or that they eat hagfish![33]

Intertidal Biodiversity Survey at Pillar Point documents the biodiversity of Pillar Point Reef, south of San Francisco, through large-scale bio blitzes, or an intense period of biological surveying in an attempt to record all the living species within a designated area. Their citizen science project monitors a suite of species—both invertebrates and algae—in six permanent plots on the reef and occasionally do all-reef surveys for sea stars, to monitor how Pillar Point stars are doing in light of the sea star wasting disease. "All information is important!," they say.[34]

iNaturalist: A very robust online community to log your citizen science work. iNaturalist is one of the world's most popular nature apps, and *the Seek app* for youth, helps you identify the plants and animals around you. Over a million scientists and naturalists are part of the community and they create research-quality data for scientists working to better understand and protect nature. iNaturalist is a joint initiative by the California Academy of Sciences and the National Geographic Society.[35]

STANDARDS

K-2 NGSS Alignment

From Molecules to Organisms: Structures and Processes

K-LS1-1: Use observations to describe patterns of what plants and animals (including humans) need to survive.

Earth's System

2-ESS2-1 : Compare multiple solutions designed to slow or prevent wind or water from changing the shape of the land.

Earth and Human Activity

K-ESS3-3: Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment.*

Engineering Design

K-2-ETS1-1: Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.

3-5 NGSS Alignment

Engineering Design

3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Earth and Human Activity

3-ESS3-1: Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.*

4-ESS3-2: Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.*

5-ESS3-1: Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Biological Evolution: Unity and Diversity

3-LS4-4: Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.*

6-8 NGSS Alignment

Engineering Design

MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem

MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Earth and Human Activity

MS-ESS3-3: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.*

9-12 NGSS Alignment

Earth and Human Activity

HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*

HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*

HS-ESS3-6: Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

Ecosystems: Interactions, Energy, and Dynamics

HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*

Biological Evolution: Unity and Diversity

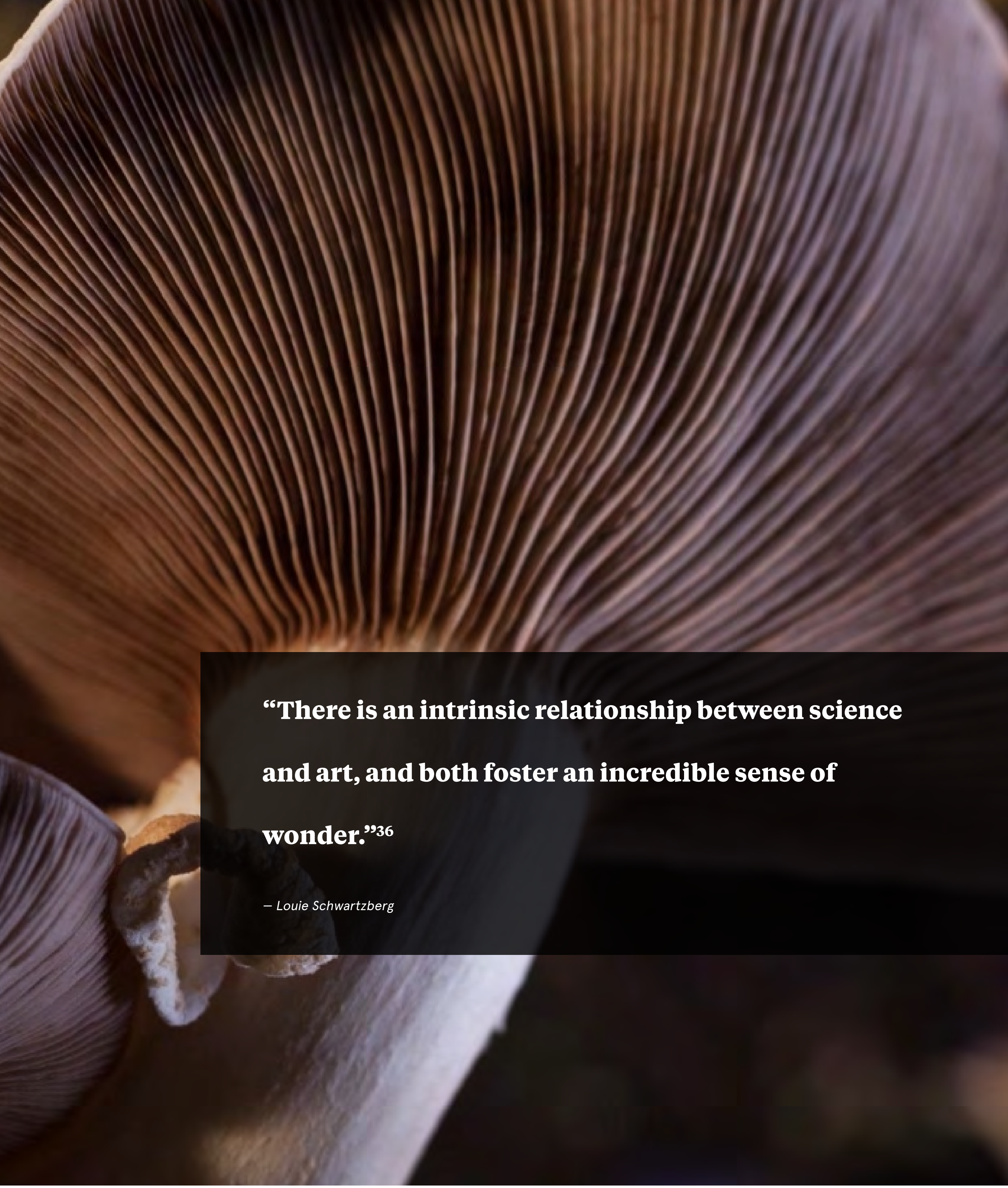
HS-LS2-6: Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*

Engineering Design

HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.



“There is an intrinsic relationship between science and art, and both foster an incredible sense of wonder.”[36]

— Louie Schwartzberg

MODULE 4:
THE ART OF NATURE

This module draws students in to think about how the documentary **Fantastic Fungi** was made, and to consider the artistic decisions the film team made as they connected the scientific information to the fungi imagery and time-lapse videos. Students will build their critical media literacy skills as they think about their responses to the art of the film, and how that influences their perceptions about the fungi themselves.

In these lessons, students will study time-lapse photography to learn about how the images are created, and they will look at art as a means of human expression and examine how it can connect people to the wonder and beauty of nature. Students will also consider artistic expression as a means to communicate their own sense of connection to the natural world.

Learning Objectives

Students will:

- Identify film techniques used in the imagery of **Fantastic Fungi**
- Study fungi art from ancient cultures
- Create a piece of art inspired by **Fantastic Fungi**

Film Clips

- Clip 1: 0:00 – 1:41
- Clip 2: 2:49 – 4:00
- Clip 3: 1:05:29 – 1:06:57

Lesson Topics

- Lesson One: Time-lapse Photography and the Art of Nature
- Lesson Two: Storytelling and Fungi
- Art Exhibition: Finding Inspiration in Nature

LESSON 1:

Time-Lapse Photography and the Art of Nature

Overview:

In this lesson students will learn about time-lapse photography and study its use in **Fantastic Fungi**. They will connect the artistic nature of the film to the content it communicates. Students will also study several other examples of artists whose work illuminates some aspect of the natural world.

Essential Questions

- What is time-lapse photography?
- How does the way the film was made communicate the wonder of nature?
- In what ways are art and science connected?

Materials

1. Day One: Equipment to show video clips; sticky notes or quarter pieces of notebook paper for class collage; pens, colored pencils, oil crayons, or markers; and carpenters' tape. Access to the internet to project examples of time-lapse videos.
2. Day Two: Cameras or mobile devices with appropriate free apps (Lego Movie Maker for K-5, Motion Pics for MS and HS), and materials to capture motion (see Time-Capture Ideas: ice, boiling water, food coloring, oil, seedlings, balloons, etc.)

Length

One 55-minute class period, plus extra day for classes creating time-lapse projects.

Note: These lessons can be easily adapted for all grade levels

ACTIVITY

DAY ONE: Clips and Collage

Grade 6-12

1. Read aloud the following quote from director Louie Schwartzberg:

> "My passion for capturing imagery that inspires wonder and awe, and for capturing subjects that are too slow, too fast, too small, or too vast for the naked eye to see, is what led me to filmmaking. I love taking audiences through portals of time and space. These immersive experiences are transcendent and broaden our worldview."[37]

2. Discuss as a class what the quote means, and ask, "How might seeing what is normally invisible change a person's perspective?"

K-5 adaptation: Start here: Before showing the film clips, invite students to focus on the images in the film as they watch. Ask them to notice any physical or emotional responses as well as where their thoughts take them.

3. Watch Film Clips:

Between the clips, have students write down words or phrases, draw images or shapes, or otherwise find a way to represent their reactions, each one on a separate sticky note or piece of paper.

Film clips from **Fantastic Fungi** (educational version):

- Clip 1: 0:00 - 1:41
- Clip 2: 2:49 - 4:00
- Clip 3: 1:05:29 - 1:06:57

4. Sticky Note Collages:

After showing the clips, have students come together in several small groups at different designated spaces on the wall in the classroom. The small groups will stick their notes to the wall to create collages out of the words, phrases, and images they created.

After the collages are made, have the students do a silent gallery walk of all the different collages.

Large group discussion:

- Did you notice any patterns in the responses?
- Were these responses different from ones you've had as you've watched clips of the film in other lessons? Why or why not?
- Did you learn something new or different by focusing on the images in this way?
- What do you think about art as a way to represent ideas in science?

5. Define and Explore Time-Lapse Photography

Let students know that the method of photography used to create the images in the film is called "time-lapse:"

- Show Louie Schwartzberg's 8-minute film explaining time-lapse photography: https://vimeo.com/436241530 (password: louiefilm)

Share these definitions:

- For K-5: Time-Lapse is used to describe a way of filming something in which many photographs are taken over a long period of time and are shown quickly in a series so that a slow action (such as the opening of a flower bud) appears to happen quickly.[38]
- For 6-8 and 9-12: "Time-lapse cinematography is a motion-picture technique by which a naturally slow process, such as the blossoming of a flower or cloud-pattern development, [is] seen at a greatly accelerated rate. Normal cinematography reproduces movement by recording and projecting it at 24 frames per second. In time-lapse cinematography, single frames are exposed at much greater time intervals (usually minutes) and then viewed at the standard 24 frames per second. Most often the technique uses a *camera* that operates automatically upon the signal of a timing device."[39]

6. Louie Schwartzberg on Time-Lapse Photography:

Time permitting, screen "*Hidden Miracles of the Natural World*," a TED Talk by Louie Schwartzberg (director of **Fantastic Fungi**) (runtime: 6:32) in which he describes why he believes the technique is such a useful tool for science.

Check for understanding of the definition of time-lapse and discuss how it is made.

Discuss:

- What did you learn about mushrooms and mycelia from watching the clips that you might not otherwise known or noticed?

Small Group Work

In small groups, have students create questions and hypotheses about what they will see when the watch the following natural processes through time-lapse photography:
https://thewonderofscience.com/phenomenon/2018/5/14/melting-and-freezing-time-lapse?rq=time-lapse

- Ice cream melting
- A glass of water freezing
- A candle burning

Discuss:

- What did they learn from the time-lapse videos?
- Did they experience similar responses to these videos as they did when watching **Fantastic Fungi**? Why or why not?

Closing: Art and Science Reflection

Post the following statements around the room. In Round One, ask students to stand near the statement they are most aligned with, and ask a few students at each statement to explain why they chose to stand where they did.

In Round Two, have students move to the statement they want to learn more about.

Statements:

- Science and art are interrelated
- Science does not require creativity
- Art does not require an understanding of science
- Time-lapse photography and cinematography are a form of art
- Time-lapse photography and cinematography are tools of science

DAY TWO

1. Create a time-lapse project

Display items, or photographs of the subjects, the class used to capture a time-lapse video in the classroom.

Time-Capture Suggestions:

- Plant leaves moving towards the light
- Cloud patterns
- Ice melting
- Steam evaporating into the air
- Color diffusing through water
- Oil diffusing through water
- Air releasing slowly from a balloon

Many types of cameras and even smartphones can be used for time-lapse photography. The following guides are for different kinds of cameras and/or phones.

Use one of the following resources to support the process:

- https://www.stem.org.uk/elibrary/resource/32071
- Smartphone + App: https://www.youtube.com/watch?v=q8REDQvehXg
- DSR Camera + Interval Setter: https://www.youtube.com/watch?v=yrEyaXXfRaU

2. As the camera or device is recording the phenomena, ask students to generate hypotheses about what they think they might see.

Time permitting, use a textbook or the internet for students to research the phenomena they will be observing.

When the phenomena are complete, watch the time-lapse video in real time and discuss what the class learned.

Closing:

Plan a long-term time-lapse video. Based on what they learned in this short-term project, what other phenomena might the class work on recording with more time?

Suggestions:

- The growth of your class' mushrooms and mycelia
- The passage of stars in the sky during the rise of a specific constellation
- Weather phenomena

LESSON 2:

Storytelling and Fungi

Overview:

In this lesson, students will reflect on storytelling as a part of human culture, and how we use stories to understand our past, our present, and the world around us. They will examine the narrative tools in **Fantastic Fungi**, in particular the narration by the mushrooms themselves, and learn how that choice influences the experience of watching the film. Students will then create their own mushroom stories, choosing a point of view and a theme to communicate in a children's book.

Essential Questions

- Why is storytelling a useful tool for understanding our world?
- What tools of storytelling does **Fantastic Fungi** use to communicate?

Materials

1. Equipment to project the film clip
2. Copies of Handouts One and Two
3. Projections or print-outs of *Beatrix Potter's mushroom drawings*
4. Construction paper or cardstock, three-hole punch, and ribbons or twine to bind their stories

Length

Two 55-minute class periods.

ACTIVITY

Opening: Pair-Share Interview

1. Have pairs interview one another in class about storytelling with the following questions:

- What is your favorite story?
- What do you like about it? Where do you first hear/read/see it? What does it mean to you?
- What makes a great story?
- Why do you think humans tell stories?

Ask a few willing volunteers to share their answers.

2. As a large group, ask the group to think about story narration.

- In their favorite stories, from whose point of view is the story told?
- What does the narrator's identity tell you about the story itself?

K-5 adaptation: How do you know who is telling a story?

3. Mushroom Narration

If they haven't watched the full film of **Fantastic Fungi**, let students know that the mushrooms themselves are narrating the film.

Distribute Handout One for a reading exercise. Have students take turns reading the narration out loud, then have students complete a close read, where they circle words that are unfamiliar, underline main ideas, and star thoughts or images that excite them.

Discuss:

- What do you think it means that **Fantastic Fungi** is narrated by the mushrooms?
- What story do they have to tell?

4. Create a Children's Book

Many students may be familiar with the author Beatrix Potter and her children's book *The Tale of Peter Rabbit* (1901). What may be less known is that Beatrix Potter was also an "amateur" mycologist—amateur only in the sense that during her lifetime a formal scientific education for women was largely prohibited. Nonetheless, Potter dedicated herself to mycology and to drawing beautiful portraits of fungi and to studying how mushrooms reproduce. (If possible, show several examples of Beatrix Potter's mycological illustrations of mushrooms found *here*.)

For more information, see the Fantastic Fungi Mush Room blog post, "*The Mycology Adventures of Beatrix Potter*," featuring an interview with Lindsay H. Metcalf, author of Beatrix Potter, Scientist.

Translating her love of nature into imaginative children's tales, Beatrix Potter remains one of the most famous and successful children's book authors and illustrators of all time. With *The Tale of Peter Rabbit* in mind, have students write a children's story that interweaves their understanding of the importance of mycelia and its central role in our ecosystem. The title of the story should be some variation of the *Wood Wide Web of Mycelia*.

Students may use Handout Two, Story Outlines, to generate ideas for their stories. Use images from Beatrix Potter, or images you create yourself, and pair them with your story to create your book.

Think carefully about who you choose for your narrator, and incorporate these or other facts about fungi into your children's story:

1. Mycelium and hyphae:
   "Mycelium is a vast underground network … that are composed of hyphae, the tiny cobweb-like threads of organic life. The network of mycelium uses the fungi to send out enzymes and organic acids to decompose organic matter such as a log. Through the process of decomposition, nutrients are released and distributed through the network of mycelium."[40]
2. Soil:
   "Only 10% of fungi produce mushrooms. When you pick a mushroom you are standing on the ground of a vast network of mycelium—these networks are the foundation of life. They create the soil that nourishes all life on land. Without fungi we do not have soil. Without soil, there is no life."[41]
3. Regeneration:
   "When each organism reaches the end of its life, it returns to the soil and continues replenishing the cycle."[42]

> "In all ecosystems, death and decay are the fundamental beginning of life. If a forest never went through this process, it couldn't regenerate. It would crowd near big trees, leaving few gaps for young ones. The big trees would soak up the light, water, and nutrients. Decay organisms like fungi are crucial for that process of regeneration. They are the building blocks of the ecosystem, the fundamental starting place for how a forest grows."[43]

MUSHROOM NARRATION

DIRECTIONS:

As you read through, circle words that are unfamiliar, underline main ideas, and star thoughts or images that excite you.

"There is a feeling, the pulse of eternal knowledge. When you sense the oneness, you are with us. We brought life to earth. You can't see us, but we flourish all around you. Everywhere, in everything, and even inside you whether you believe in us or not. From your first breath to your last, in darkness and in the light. We are the oldest and youngest. We are the largest and smallest. We are the wisdom of a billion years. We are creation. We are resurrection, condemnation, and regeneration. We are mushrooms.

We are all of the stars. My kingdom was born from the heavens four and a half billion years ago. We are the pioneers. We climbed out of the sea to create the fertile soil and set the stage for all of life.

We are on a never-ending search for partners, life affirming relationships, or at the very least nourishment for the next leg of our journey. We have flourished side by side with your species symbiotically for millennia.

This world of ours is always changing, not for the better or for the worse, but for life. If the storms come and the water rises, if fire scorches the land, or darkness descends, we will be here working as we always have. Extending the network. Building community. Restoring balance. One connection at a time. It may take a million years, or a hundred million, but we will still be here."

STORY OUTLINE

Main Character (Protagonist):

- Who is your character?
- What is their motivation? (Are they trying to achieve a goal, solve a problem, learn a lesson?)
- How will they grow?

Supporting Character/Antagonist:

- What is their relationship to the main character?
- How do they move the story forward?

Plot:

- Beginning - Set up the story
- Middle - Something happens, often a challenge, threat, or problem
- End - The problem is resolved

Setting:

- Where does the story take place?

Time:

- When does the story take place?

ART EXHIBITION: FINDING INSPIRATION IN NATURE

Art is one way for human beings to express our connection to the natural world. Create a class art exhibition inspired by fungi, or by any other aspect of the natural world that excites and inspires students.

Remind students that artistic expression can take many forms. Lesson Two covered stories, but also consider music, poetry, visual arts, photography, and dance.

Here are some connections to create a nature art installation, beginning with inspiration from the following artists:

Music:

- *Fantastic Fungi: Reimagine*
- S.O.S. (Mother Nature) by will.i.am
- Nothing But Flowers by the Talking Heads

Visual Art:

- *Claudia Fontes' Fungi Sculptures*
- *Andy Goldsworthy*

Poetry:

- "*For Calling the Spirit Back from Wandering the Earth in its Human Feet*" by Joy Harjo
- "*The Forest*" by Susan Stewart

Photography/Film:

- "*The Waltz of the Mushrooms*" by Louie Schwartzberg
- *James Balog*
- "*Mammas: Cuckoo*" by Isabella Rossellini

Dance:

- "*Cliff Dancers*" Bandaloop Dancers, presented by KQED
- "*The Umbrella Project*" by the Pilobolus Dance Company

Explore these and other artists with students, and invite students to begin to think about their own work of art, inspired by something they love in nature. They can use any medium, including fungi. These works will be displayed together in an exhibition to which you can invite other classes, parents, community members, and local mycophiles.

Each student will create an artist's statement to accompany their work that includes:

- Their subject and why they chose it
- Their medium and how their creative process
- Their message for the viewer

STANDARDS

K-2 NGSS Alignment

From Molecules to Organisms: Structures and Processes

K-LS1-1: Use observations to describe patterns of what plants and animals (including humans) need to survive.

Biological Evolution: Unity and Diversity

2-LS4-1: Make observations of plants and animals to compare the diversity of life in different habitats.

3-5 NGSS Alignment

Ecosystems: Interactions, Energy, and Dynamics

5-LS2-1: Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.

Earth's Systems

5-ESS2-1: Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.

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6-8 NGSS Alignment

From Molecules to Organisms: Structures and Processes

MS-LS1-6: Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

Ecosystems: Interactions, Energy, and Dynamics

MS-LS2-3: Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

9-12 NGSS Alignment

Ecosystems: Interactions, Energy, and Dynamics

HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

> **"I think the future of fungi is bright and moldy and symbiotic and full of life. One of the perks of being really in tune with fungi is that wherever everyone sees death you see life, where people see rot you see life, where people see decomposition you see composition …When it's about fungi, the future is wonderfully moldy and symbiotic."[44]**
>
> *— Giuliana Furci, Fantastic Fungi*

MODULE 5:
JUSTICE FOR THE FUNGI: CONSERVATION, EDUCATION, AND SOLUTIONS

Module 5 looks to the future of fungi and to the ways policy, education, and innovation work together to achieve justice for the kingdom of Fungi and to support regeneration.

As **Fantastic Fungi** shows, the kingdom of Fungi is no longer hidden in the shadows of plants and animals—or underground. Fungi and mushrooms are more visible, more valued, and more understood as essential to the survival of our planet. But there is still a lot of work to be done. Mycologists, citizen scientists, and conservationists continue to innovate and discover new species and new solutions to work with the fungi to solve some of our planet's most pressing problems. Their work is based upon a regenerative model, not extractive or finite, and it goes beyond sustainability. It is a relationship based on respect and knowledge that all ecosystems are dependent upon one another. Without the fungi there would be no forests, and without forests there would be no air. As we pass on nutrients, we pass on knowledge, inspiration, and a mutual understanding of living in balance with all of the natural world.

This understanding of regeneration is the inspiration for the final module for **Fantastic Fungi**. K-5 students will learn about two examples where fungi addressed and mitigated an environmental problem explored in **Fantastic Fungi**, and middle and high school students will "forage" and collect samples of knowledge through a self-guided exploration of resources focusing on fungal global policy, fungal education, and fungal innovations.

To celebrate their "forage," and to demonstrate the culmination of their fungal learning, all students will choose one area of interest from their exploration, and then create/design/build/propose a fungi project to share with the class and community. Hosting a "Mushroom Mad" Fungi Celebration at your school is highly encouraged!

Learning Objectives
Students will:
- Learn how policy can be one step to achieving justice for the kingdom of Fungi
- Understand the relationship of fungi conservation
- Examine industries and economies using innovations developed with fungi
- Explore ways our communities can learn from and mirror the mycelial communities' practice of mutual support
- Create and share their "future of Fantastic Fungi"

Film Clips
These clips are for K-5 learning and for 6-12 Foraging Station 3: Innovation, Climate & the Economy
- Clip 1: 8:23 -10:40 (myco-remediation)
- Clip 2: 26:40 - 29:10 (termites)
- Clip 3: 35:10 - 38:17 (bees and virus)

“Being completely mushroom mad is not something you choose. It’s an overwhelming feeling of dependence on fungi, of devotion to fungi, of being at the service of fungi. I sometimes speak to people of us, of the fungi and our interconnection.”[45]

— Giuliana Furci, Fantastic Fungi

“We do more than make mushrooms. We have the ability to do so much more than just break down matter. Like the fruit of our labor, most of you have only scratched the surface of our usefulness. We are the changers.”

— Brie Larson, Fantastic Fungi

LESSON 1:
"Foraging" for Fungi Policy, Fungi Education, and Fungi

Overview:

In this lesson students will have the opportunity to absorb new knowledge at their own pace, examine the intersection of policy for the conservation and protection of fungi, reaffirm the importance of education as essential to the health of fungi and our planet, and have fun discovering new inventions and innovations that apply the intelligence of fungi.

To absorb all of these possibilities, over the course of several days students will rotate between several stations, collect ideas, explore resources, and be inspired by the future of fungi. The stations:

- Station 1: Policy & Strategy: Exploring legal protection and national policy
- Station 2: Education: Creating curriculum for K-12 students
- Station 3: Innovation, Climate & The Economy: Tapping into our imagination and creativity to create new economies and address pressing environmental, health, and climate issues

While this exploration isn't exactly field mycology, it is an opportunity for students to synthesize all they have learned in the previous modules, explore the wonder of fungi, discover new information, re-imagine their future, and reaffirm their connections to the kingdom of Fungi.

Essential Questions

- How can fungi save the world?
- What does "justice for the kingdom of Fungi" mean?
- What policies and educational initiatives are critical for the health and future of fungi?
- How are fungi an integral part of solutions for our climate and for the future health of our planet?

Materials

For K-5: Hard copies of two readings

- "Fungi: A Bee's Best Friend," Steve Sheppard, *Fantastic Fungi*, p. 49-52
- "Spotlight On: The Amazon Mycorenewal Project," *Fantastic Fungi*, p. 59

For 6-12 students, upload the following content on a shared drive for students to access virtually as they rotate through each station.

- Equipment to show Paul Stamets' TED Talk "*6 ways mushrooms can save the world*."
- Access to film clips from **Fantastic Fungi** (educational version)
    - 26:40 - 29:10 (termites)
    - 35:10 - 38:17 (bees and virus)
    - 8:23 - 10:40 (myco-remediation)
- Handout One: Foraging Tracker

Resources for Each Station

- Via Computer Shared Drive: Create a folder titled with each of the station topics and upload the links of the resource to a shared drive.
- Via Hard Copies: Print several hard copies of each resource for each station. Place signs at tables designating the topic covered.

Teacher Note: Review these resources regularly to make sure that links work and that materials have not become dated.

Station 1: Policy & Strategy

Resource A:

- Summary of the *UN Convention on Biological Diversity*, Encyclopedia Britannica
- Summary of *The Fungal Conservation Committee* of the International Union for Conservation of Nature (*IUCN*)
- *The Micheli Guide to Fungal Conservation*

Resource B:

- *Poster*: IUCN Red List
- *Global Fungal Red List*
- Chilean Legislations Summary (Created the document)
- *Conservation Chapter 10*: Kew State of the World's Fungi Report, 2018

Station 2: Education

- *MacroFungi Field Guide*: United States Department of Agriculture
- *Fungi Families Field Guide*: First Nature
- *The Fungus Files*: Publication of the North American Mycological Society

Station 3: Innovation, Climate & the Economy

- "A Bee's Best Friend" Steve Sheppard, *Fantastic Fungi*, p. 49-52
- Access to website *CoRenewal Project*
- Chapter 4: "*Useful Fungi*" in Kew State of the World's Fungi Report, 2018
- "*Student Makes Chess Pieces Out of Fungi as a Plastic Supplement*"
- "*Reishi Mushroom Protects Against Air Pollution*"

Handout

Foraging Tracker and read over the parameters of the activity.

Length

Module: At least one week: ~2 days to "forage" content, 2 days to create their fantastic fungi, and 1 day to share

ACTIVITY: FORAGING STATIONS

Day One

Opening

1. Read this passage from the documentary **Fantastic Fungi** aloud to students to introduce them to the process of pulling out important information from a single resource.

> "CO2 is our biggest greenhouse gas. As plants photosynthesize, they literally inhale CO2 while exhaling oxygen. CO2 is what plants photosynthesize, and they take that carbon, and they put it in different places. They put it in their leaves and their trunks, but they put 70% of it, we're finding, below ground. And the root systems treat that carbon [as] nutrients. The carbon ends up in the fungal cell walls where it's stored.
>
> This fuels the microbial community and all the other parts of the food web, like the mites and nematodes, and they start cycling nutrients through that eating process. So the fungi are really important in stabilizing carbon in soils. Once the carbon is stable, it can stay there stored for thousands of years. We know, for example, that carbon can move from plant to plant and it evens out the distribution of carbon in that system. The plants are working really hard. If we maintain the plants, the forest, and the natural fungal community, we've got a natural engine that's just storing carbon below ground. So it's essential. It's there for us, right? It's right in front of us." —Suzanne Simard

Discuss:

- What important information do you learn about fungi from this quote?
- What does Suzanne Simard use as an example of fungi's intelligence?
- Does the intelligence of the mycelia inspire any ideas or connections?

2. Explain to students that they will be assuming the role of a hypothetical combination mycologist, citizen scientist, policy maker, educator, inventor, and entrepreneur such as Paul Stamets, Suzanne Simard, William Padilla-Brown, Giuliana Furci all wrapped up in one. Their job is to "forage" for information just as they saw these individuals learn, discover, innovate, collect, reimagine, and be in community with one another throughout the film.

3. Distribute Handout One: Foraging Tracker and share these talking points with your class:

- With your Foraging Tracker in hand, have students rotate around to four stations at their own pace.
- Each station is marked with a sign and has one or more tables with a collection of resources for students to examine, read, learn from, discuss with peers, and take notes on. is marked with a sign.

- Explain to students the two expectations to fulfill during the rotation days:
  - Rotate to all four stations and take notes on the Foraging Tracker. Students do not need to look at every element of every resource at each station, but do need to have circulated to the four stations in order to gain a sense of the topic to discuss, if asked.
  - At each station, note ideas or questions and particular areas of interest about fungi. These ideas will be the basis for the final project.

Distribute Foraging Tracker

Explain instructions, clarify questions.

Begin Rotations

HANDOUT ONE

FORAGING TRACKER

DIRECTIONS:

- Rotate to all four stations at your own pace. Check and make sure all the resources are at the table (or on the drive) before you begin exploring.
- Read, discuss as you rotate, and complete your notes on the tracker. Use the Notes question as a prompt if helpful.
- Pull out other critical information from each document for your notes in the space provided. Write questions that come up as you read to return to and research.

STATION 1: POLICY & STRATEGY

Resource A: Summary of International Agreements

- *Summary of the UN Convention on Biological Diversity*
- Summary of *The Fungal Conservation Committee* of International Union for Conservation of Nature (*IUCN*)
- *The Micheli Guide to Fungal Conservation*

Notes: What do you conclude about policy and international protection of fungi?

Resource B

- View Poster: IUCN Red List
- Visit *Global Fungal Red List*

Notes: Why is a red list for fungi necessary?

Resources C: Spotlight Fungi Protection and Legislation in Chile

Read: Chilean Legislations Summary

Notes:
Why is the Chilean legislation so important? What precedent does it set?

Guiliana Furci also shares that in Chile "policies for fungal conservation create jobs, engage people, are a driver for taxonomical needs, and establish educational needs."
Is this a new angle or idea?[46]

Resource D: Reading

- Conservation Chapter 10: Kew State of the World's Fungi Report, 2018 (*Download Conservation of Fungi Chapter*)

Notes:
What is the relationship between conservation and policy?

How does policy and conservation and protection achieve justice for the fungi?

STATION 2: EDUCATION

Flora, Fauna, Funga

> "We don't safeguard mushrooms in an herbarium but in a fungarium. Fungi don't have fruit bodies like a plant, or stalks or roots. We create reality through language."
> —Giuliana Furci

More advanced students may be interested in "*Delimitation of Funga as a valid term for the diversity of fungal communities: the Fauna, Flora & Funga proposal*": IMA Fungus

Resource 1: Several Pages of from a Field Guide

- *MacroFungi Field Guide*: United States Department of Agriculture
- *Fungi Families Field Guide*: First Nature

Notes: What do you learn about fungi from a field guide?

Resource 2: Review Curriculum

- "*The Fungus Files*": Publication of the North American Mycological Society

Notes:
Why is it as important to learn as much about fungi as about plants and animals?

When you get to college what do you think should you know?

STATION 3: INNOVATIONS, CLIMATE & THE ECONOMY

> "My team and I have discovered, over decades of study, that mushroom mycelium is a rich resource of new antimicrobial compounds which work in concert, helping protect the mushrooms—and us—from microbial pathogens."
> —Paul Stamets

Set up several laptop computers with earphones for students to watch the following two segments on innovations from **Fantastic Fungi**.

**Resource 1 and 2 can be adapted for a K-5 classroom.*

Resource 1: Film Clips

- Film Clips from **Fantastic Fungi** (educational version):
  - 26:40 - 29:10 (termites)
  - 35:10 - 38:17 (bees and virus)

Notes: What is so cool about these discoveries?

Resource 2: Reading

- "A Bee's Best Friend" Steve Sheppard, *Fantastic Fungi*, p. 49-52.

Notes: How did the researchers use mycelia to address the global die-off of bees?

Resource 3: Environmental Justice

- Explore Case Study: *CoRenewal Project*: Go to Our Work - Explore Current Projects

Notes: What is interesting about the work of CoRenewal?

Resource 4: Myco-remediation

- Read "Spotlight On: The Amazon Mycorenewal Project," *Fantastic Fungi*, p. 59.
- Watch film clip **Fantastic Fungi** (educational version): 8:23 - 10:40

Notes: What can fungi build and create that is an alternative to current materials?

Resource 5: Fungi and New Discoveries

- Download Chapter 4: "Useful fungi" in *New Discoveries Chapter: Kew State of the World's Fungi Report*, 2018

**For educators: If student internet access is limited, print out each short summary of the innovation. If internet access is available, have students explore these innovations online.*

General notes on innovations:

Biofuel

Vitamins

Research

Agriculture

Detergent

Paper Manufacturing

Beverages

Leather Processing

Cotton Processing

Cultural Uses

Resource 6

Read: "*Student Makes Chess Pieces Out of Fungi as a Plastic Supplement*."

Notes: What do you think about the application of technology and mycology?

Resource 7

Read: "*Reishi Mushroom Protects Against Air Pollution*."

Notes: What will be important to keep in mind for using fungi and to address environmental and climate related problems?

LESSON 2:

Sharing The Future of Fantastic Fungi

Overview:

Given the awe and glory of the different types of fungi, mycelium, the web of mycorrhizal networks, nature's intelligence, and the myriad of connections that students will have made over the course of this study, the Future of Fantastic Fungi Project is an opportunity to have students share their learning, express their appreciation, and demonstrate their understanding of the innovative applications of everything fungi.

The sky's the limit for this project. Students can focus on a new use of fungi that could potentially address an environmental issue or medical ailment, a new international policy for the protection of fungi, or an innovative way to teach young children about mycelia, and more.

Student Directions

- After listening and learning about fungi, you will now have the opportunity to celebrate your learning and access your imagination.
- Choose one area of fungi innovation that was interesting and/or inspiring. Over the next two days you will be given time and support to create and/or propose your own fantastic fungi innovation.
- Think about a new use of fungi that could potentially address an environmental issue or medical ailment, a new international policy to protect something, or a piece of art that could teach young children about mycelium, etc...
- The project can be shared in a variety of forms — 2D or 3D visual art, poetry, film, photography, digital media, or other formats.
- Each project needs to include:
  - A title.
  - A written and printed artist's statement explaining your intent, rationale for your choice, choice of media, and other details your peers need you want to share about your piece.

Consider displaying and/or having students present their learning to their community, and invite parents, local artists and mycologists for a "Mushroom Mad" Night at your school.

Length

At least two 55-minute class periods (plus time at home to complete the project).

SAMPLE GLOSSARY

Endophytic fungi live inside and throughout the host plant and inhabit plant tissues without destroying or producing substances that cause an infection for the host cell.
See *Endophytic Fungi: The Biology Dictionary* for images and more details.

Mycelium/Mycelia (pl.) Mycelium produces small molecules of food—typically sugar and often from sources such as wood or plant waste—by excreting enzymes that break these materials down into digestible morsels. As mycelia grow they assemble a dense network of interconnecting long, microscopic filaments that spread through the substrate like a superhighway system or the internet.

Mycorrhizal fungi in the soil form beneficial connections with plant roots. These partnerships occur mostly with trees, and they significantly increase the roots' effectiveness. Fungi send their tiny cobweb-like threads of organic life (hyphae) in and about the little rootlets of the tree until it's difficult to tell them apart. The tree supplies the mycelia with moisture and carbohydrates, and the mycelia return the favor with minerals and other nutrients from the surrounding soil. Mycorrhizal fungi are beneficial both in nature and agriculture; plants with them tend to grow better than those without.

Parasitic fungi are the second largest group of fungi. Some can do a lot of serious damage. Rather than obtaining their food from dead animals or plants, they prefer a living host, often attacking and killing it, then living on as a saprobic fungi.

Saprobic fungi are the largest group of fungi, growing on dead organic matter such as fallen trees, cow patties, dead leaves, and even dead insects and animals. These fungi have enzymes that work to rot or break down materials found in organic matter. Without the digestive activities of saprobic fungi, organic material would accumulate until the forest became a huge rubbish dump of dead leaves and trees.

STANDARDS

K-2 NGSS Alignment

Earth's Systemss

K-LS1-1: Use observations to describe patterns of what plants and animals (including humans) need to survive.

Earth and Human Activity

K-ESS3-1" Use a model to represent the relationship between the needs of different plants and animals (including humans) and the places they live.

K-ESS3-3: Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment.*

Engineering Design

K-2-ETS1-1: Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.

3-5 NGSS Alignment

Biological Evolution: Unity and Diversity

3-LS4-4: Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.*

Earth and Human Activity

4-ESS3-2: Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.*

5-ESS3-1: Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Ecosystems: Interactions, Energy, and Dynamics

5-LS2-1: Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.

Earth's Systems

5-ESS2-1: Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.

Engineering Design

3-5: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

6-8 NGSS Alignment

Earth and Human Activity

MS-ESS3-3: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.*

Engineering Design

MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Ecosystems: Interactions, Energy, and Dynamics

MS-LS2-4: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

MS-LS2-5: Evaluate competing design solutions for maintaining biodiversity and ecosystem services.*

9-12 NGSS Alignment

Ecosystems: Interactions, Energy, and Dynamics

HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*

Engineering Design

HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

ENDNOTES

1 Paul Stamets, *Fantastic Fungi: How Mushrooms Can Heal, Shift Consciousness & Save the Planet* (Earth Aware Editions, San Rafael, CA., 2019), p. 11-12.parts of an ecosystem.

2 William Padilla-Brown, "Mushrooms to the People," in Paul Stamets, F*antastic Fungi: How Mushrooms Can Heal, Shift Consciousness & Save the Planet* (Earth Aware Editions, San Rafael, CA., 2019), p. 109.

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5 Recommended sites: https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_General_Biology_(Boundless)/24%3A_Fungi/24.1%3A_Characteristics_of_Fungi/24.1C%3A_Fungi_Reproduction

6 https://www.mushroomexpert.com/major_groups.html

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8 Eugenia Bone, quoted from Fantastic Fungi.

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10 39th Telluride Mushroom Festival, Keynote Address, "Faith and Fungal Education," https://www.youtube.com/watch?v=sg__yj0mSGc

11 https://drive.google.com/file/d/1vdLpm41n0jdl-60wpaDiSILbW9Of2KhQ/view

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13 https://www.biologyonline.com/dictionary/phylogeny

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21 Ibid.

22 https://www.calacademy.org/educators/citizen-science-toolkit

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25 Biographical information compiled from this podcast interview "Mycology and Citizen Science: William Padilla-Brown.

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30 https://www.zombeewatch.org/

31 http://www.lostladybug.org/

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36 "Afterword," Louie Schwartzberg, in *Fantastic Fungi*, pp 174-175.

37 Ibid

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41 Ibid., p. 19.

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43 Ibid., p. 20.

44 https://www.mushroom-revival.com/conservation-of-fungi-with-giuliana-furci-episode-19/

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46 Giuliana Furci, 39th Telluride Mushroom Festival, Keynote Address, "Faith and Fungal Education," https://www.youtube.com/watch?v=sg__yj0mSGc

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