**Slide 1**

Good evening everyone, good to see you all. I’m Lauren Abraham and I’m taking an independent study course this term where I’m designing an open education resource, OER, for publication. These types of educational resources are stored on a website commonly referred to as OER commons. The materials that I’ll be publishing include the slides you’ll see today, the narrative that I’m reading from, and formal lecture notes for use by the educator.

The goal of this project was to design and produce an open access online introductory mycology lesson for use by educators anywhere in the world. Open access meaning anyone with the internet can utilize this resource. Unfortunately, not everyone has institutional access to college libraries, so OER commons provides a needed tool to educators. This is the second open education lecture resource that I’ve designed under Professor Marja Bakermans. I’m privileged to have this opportunity to put together this introductory class on a subject that I personally find interesting and is actually extremely topical today.

**Slide 2**

Now, let’s talk about structure. I’ve structured this lecture into five sections so that educators can run through all five sections in sequence, or an educator can pull out whichever section they find most relevant to their course at their school. Sections one through four introduce fundamental concepts and information, and section five provides a social context to what’s happening in mycology today. The way I’ve structured the class is that section five can be updated and modified by an educator to reflect current trends in mycology. This introductory seminar is intended to spark interest, to inform, and to engage the student. As I walk through the lecture, if you think of any questions, please write them down so that I can answer them afterwards. And if everyone could put their phones on silent, that would be appreciated.

**Slide 3**

As I mentioned, this lecture will be placed in an open education resource, or OER, database. You would search for your subject matter, your target audience, and resources such as this (point to screen) will show up under each search result. The audience for this OER is first or second year biology college students.

I’ve invited you all here today so that I can test run the lecture that I’ve put together and collect some feedback from you, the audience, about how the lecture is received from a student perspective. As students, you have some activity materials that we’ll discuss in a bit and a survey to fill out at the end.

**Slide 4**

So let’s begin. Section 1- Here, the educator gives a broad overview of the field.

**Slide 5**

Mycology is the study of fungi, fun-jai or fun-gee. I’ve spoken to a few mycologists and it seems that not many agree on how to pronounce it, but they’re all correct. There are three types- mushrooms, molds and yeasts. Humans have been using mushrooms for millennia. About 30 years ago, hikers found a glacial mummy with three types of mushrooms on or in his person- likely used for fire starting and for their beneficial health properties(Peintner, 1998)**.** The tinder fungus was one of the three types of mushrooms found on the mummy. It is a very flammable mushroom when dried and the picture on the right is of a tinder fungus.

**Slide 6**

Why is mycology an important field of study? Fungi are essential for healthy ecosystems because they break down dead matter and recycle the carbon back into the environment. They are an important food source for humans and other animals. Many fungi are also useful in medicine and industrial purposes, and some are known for their psychedelic properties as seen here on the right.

Fungi are everywhere. There are 150,000 known fungi species today (Phukhamsakda et al., 2022) and it is estimated that there may be up to 3.8 million undescribed species around the globe. (Hawksworth & Lücking, 2017). Fungal spores, not unlike the seeds of a plant, are also everywhere. These spores are in the air we breathe- in every breath we take, we breathe in one to ten fungal spores. (Fröhlich-Nowoisky, 2009).

**Slide 7**

Let’s take a look at some fundamental biology concepts. An educator may want to refresh their students' knowledge of where fungi fall in a phylogenetic tree. I have found in conversations with people that there is a misconception that fungi are plants just because they grow out of the ground. This slide is here in case an educator wants to refresh students who may not realize that fungi have their own kingdom and are entirely separate from plants.

**Slide 8**

Now understanding that fungi have their own kingdom, let’s take a quick look at the different methods of fungal reproduction. First, some fungi are grouped into four divisions based on the shape and structure of the spore-making machinery, or sporangia, within the fungi.Most fungi reproduce by forming and releasing mass quantities of spores. These spores can be produced through asexual or sexual means of reproduction. Chytridiomycota here are aquatic fungi that produce flagellated spores that are able to move on their own, zygomycota are your bread molds, ascomycota include yeasts, and basidiomycota are filamentous fungi like mushrooms you may see on the forest floor or buy for cooking.

**Slide 9**

There are two other groups of fungi that prefer to remain outliers and not fall into any of the four categories we discussed in the previous slide. The first group here, Deuteromycota, which include molds, reproduce only asexually. Lichens, shown on the right, reproduce differently than the fungi on the last slide because they must associate with an algal partner before reproduction can occur.

**Slide 10**

Educators, if they so choose, can now do a deeper dive into lichens by discussing further the fungal-algal partnership. This partnership is a unique relationship among fungi in that the lichenized fungi requires association with an algae or cyanobacteria before growth can occur. The algae provides the sugars- the food source- from photosynthesis *to* the lichenized fungi, while the lichenized fungi give the algae a structure to grow on. This fungal-algal partnership is an important concept for an educator to relay to students so that the students can appreciate this symbiotic relationship.

These photos of lichen were taken during my IQP last term in Hawaii. On the right we have *Parmeliella mariana*, a lichen found in the windward forests of Hawaii that I saw during many different hikes. The orange-red dots in the center of the lichen are what hold and disperse the spores. This picture on the left is an unidentified lichen that I saw at my project site in Hawaii. These lichens have different structures, and I have an example of the differences between lichen structures up here in the front that anyone can check out after the lecture. I also spent some time before this presentation gathering some lichen samples from across the street at Institute park. If you’d like to see them, they’re on the table here that you can look at after the lecture.

**Slide 11**

One major benefit of this fungal-algal partnership is the ability of lichen to measure pollutants in the air. Amazing, right? This can be an effective tool in lichens as a bioindicator of air quality.

**Slide 12**

So how is this done? In order to measure concentration of accumulated metals in a lichen, scientists typically dry up a lichen sample and run it through a machine called an atomic absorption spectrometer (Klimek et al., 2015). By taking multiple samples, scientists are able to

see the concentration of metals that a lichen has absorbed during its lifetime on a tree or rock.

This slide is an example of a think-pair-share activity where an educator can have the students discuss with each other the meaning of a figure or graph. So let’s try it!

Take a minute to look at this graph. The picture to the right of the graph is an image of the lichen species that the samples were collected from. Interpret the graph’s pattern, think about what underlying causes may have led to this pattern, and talk with each other for a moment or two if you care to. (US National Park Service, n.d)

**Class discussion and learning ensues!!**

Anyone want to share their thoughts on the graph? (call on a student)

**Slide 13**

The highest lead values were observed after the completion of a bridge that carried traffic over an island where this lichen was growing. Then, the graph declines at the same time when leaded gasoline was phased out. Subsequent measurements of lead concentrations in lichens declined sharply. This think-pair-share activity is how the educator illustrates to the students the ability of lichen to act as a bioindicator for air quality.

**Slide 14**

The educator now concludes the basic information section by highlighting a few other key historical points about fungi as a kingdom. Fungi have been on the planet for an estimated 1.5 billion years (Wang et al., 1999). Fungi have the ability to dissolve rock through secretions of enzymes and acids (Leeds, n.d). This millions of years long process of enzymatic breakdown of rocks and minerals, along with the flaking off of rock in a process called fungal weathering.)

allowed fungi to play an essential part in the creation of soil (Appalachian Voices, n.d; Hall, 2021).

**Slide 15**

That brings us to section two. This section discusses mushrooms, their structure, how they reproduce, how they interact in the soil, and their role in ecosystems as a whole. This section may be most useful in a course that focuses on a holistic, interconnected ecological view of mycology.

**Slide 16**

To bring students into this section, the educator may want to cover some basic structural points about mushrooms. Mushrooms each have 2 sections, a sporing body and the mycelium. The mycelium is the web-like network that extends from the sporing body, effectively functioning as roots, and gathering nutrients and water from its environment. The sporing body is the part of the mushroom that you’d typically see on a hike in the woods. Both the sporing body and mycelium are made up of the same material called hyphae, represented here with thin brown lines.

**Slide 17-**

Now that the students understand the basic structure of a mushroom, they may be curious about details regarding the sporing body and how mushrooms reproduce. The top of this hand-drawn diagram reviews asexual reproduction, or “budding”. In budding, a cell replicates itself to create a genetically identical cell which then produces a genetically identical sporing body.

Asexual reproduction does not allow for genetic diversity, which poses a disadvantage for asexually reproducing fungi because they may be unable to adapt to future environmental changes.

Sexual reproduction, covered on the bottom part of this diagram, allows for genetic diversity and opportunities for genetic recombination. This process is important because it allows for better species adaptation and higher survival rates in new or changed environments. In the “heterokaryotic stage” genetically different spores fuse their nuclei and create genetic diversity.

The common theme between both asexual and sexual reproduction is this “mycelium”, where fungal cells fuse together.

**Slide 18**

Now that the above ground portion of the mushroom and its reproduction has been discussed, the educator will move onto discussion of the web-like structure beneath the ground called mycelium. On the right is a picture of some mycelial growth on a tree trunk. How this mycelial network came to be was that a spore landed in the middle of this central area when the conditions were right. These favorable conditions allowed the spore to send out hyphal “fingers”' in its search for water and nutrients.

**Slide 19**

Students may then wonder, how does this mycelial network grow? The placement of a spore in a favorable environment triggers hyphal growth, and the hyphae continue this growth as they search for more water and nutrients within the soil. Hyphal tips replicate and continue to extend the web in all directions until the network finds nutrients or water. Here is a cross section of hyphae, which shows all of the organelles within the cell. You may remember some of the terms from high school biology. During this process, mycelium aids tremendously in creating soil structure by releasing a sticky substance called glomalin at its hyphal tips.

Glomalin is a protein that binds particulate matter together within the soil to create structural soil stability. This process of mycelial growth is like using eggs in a cake, where the eggs function to bring the mixture together (Sheldrake, 2020). The growth of mycelium provides a protection against erosion and also aids in carbon storage. A mycelial network is created through the relationship between a spore and its environment.

**Slide 20**

As the mycelial network interacts with plants, a different network is created. This network is called a mycorrhizal network. The mycorrhizal network is a fascinating and essential linkage between many plants and the mycelium that link them. The fibers in a mycorrhizal network connect plants to one another, knitting them together. Trees in mycorrhizal networks have been known to transmit nutrients to other trees that have less access to sun in order to keep the forest alive.

This picture on the right is an example of mycorrhizal fungi. I took this photo in the Kaumana caves in Hawaii. The orange and tan roots belong to a plant above the surface of the cave. The roots extend into an underground cave, and this root was covered with the fuzzy and cottony mycorrhizae. The concept of mycorrhizal networks is important for students to understand because it illuminates the importance of fungi in forest ecosystems.

**Slide 21**

Within a forest ecosystem, fungi operate at both ends of life. They create mushrooms through growth of sporing bodies and also function as decomposers, or the cleanup crew in an ecosystem. The takeaway from this slide that students should gather is that by being decomposers, fungi recycle carbon back into the environment by breaking down dead organisms and plant matter. Without decomposers, dead organisms and plant matter would accumulate and no carbon would be recycled back into the environment. The food web on the right side of this slide illustrates the interconnectivity of fungi within a forest ecosystem.

**Slide 22**

The earlier slides in section two had a lot of visual elements- diagrams and pictures of typical mushrooms and mycelium. The purpose of the next few slides is to show the amazing variety and structures of mushrooms. Here are examples of gilled mushrooms with the spore-making structure, or sporangia, located on the gills under the cap. The spores drop from the gills when they mature and travel out into the air. The stipe, a stem-like structure, holds the cap up.

The photo on the right and in the middle of the slide are examples of fairy inkcap mushrooms. I observed these mushrooms in the Kaumana cave system. These were the first mushrooms that I saw during my time in Hawaii- really exciting! Notice the fairy inkcaps are growing out of a piece of wood in a cave that lacked any other noticeable indication of life. You can see the immature mushrooms of the same species developing in the back.

**Slide 23**

In more examples of mushroom variety, here we have mushrooms that grow directly on a tree. These mushrooms are called shelf mushrooms or polypores. Polypores lack a stipe since there is no cap to hold up. Spores from polypores are dispersed from the underside of the shelf structure.

**Slide 24**

And here’s the last slide showcasing the morphological variety of mushrooms! (Point and talk about each mushroom on this slide).

**Slide 25**

Now we’re going to take a break from the lecture content to discuss a class activity that an educator could do with their students. When everyone first came into the lecture hall, you should have received a sheet, two dice, a small wooden mushroom and a pencil. These elements are part of the activity that bridges sections 2 and 3. I’ve given you these elements so you can get a sense of what a classroom activity setup may look like. In this activity, students roll dice and determine whether or not their spore becomes a sporing body. Rolling one on the dice means that a student would receive a wooden mushroom, indicating that their spore has landed in favorable conditions and germinated into a sporing body. The probability of rolling a one with a 20-sided dice is low. In the second half of the activity, students receive a six-sided dice. Students are more likely to roll a one if they are rolling six-sided and 20-sided dice at the same time. The six-sided dice represents a rainy season where spores are more likely to germinate. The main takeaway from the activity is that students learn that most spores do not make it to ideal germination conditions.

This activity is meant to be flexible for different educator budgets and resource access. Buying the wooden mushrooms is optional- if an educator would rather a lower-cost option, I have created a sheet with some mushroom drawings that students can cut out to use as sporing bodies. An alternative to buying dice is a random number generator that only selects values between one and twenty or one and six.

**Slide 26**

The students have now completed the activity and are ready to move onto the next section, molds and slime molds. Molds are multicellular while slime molds are unicellular, and both germinate where moisture is present.

**Slide 27**

To start this section, I’ve included a few examples of mold on food and under a microscope. Mold gets a bad rap in the home, with its colorful and fuzzy appearance, but it has a lot of positive attributes; it’s in some foods we eat such as soy sauce and blue cheese. Adding molds to soy sauce and blue cheese gives foods new flavors or aromas. Certain molds are capable of making antibiotics like penicillin. Molds are important for the food industry and biotechnology applications, like antibiotics.

**Slide 28**

Slime molds, on the other hand, are not like the other molds- they're unicellular, and within their one large cell are many nuclei. Mushrooms, as you all know, have a body plan, a defined structure and shape. Slime molds, in effect, are one large organism that continues to grow without a body plan. Here you can see the slime mold running rampant on some branches on the forest floor.

**Slide 29**

Now the educator can do a quick deep-dive into slime molds and their “intelligence”. A really intriguing characteristic of slime molds is that without a brain, slime molds appear to possess an innate ability to navigate an area to access a food source. Then, in order to transport nutrients through its network, the slime mold can prune its network to change and optimize how nutrients are transported through its own internal system. Let's take a look at how this works.

This six part visual shows the growth progression of a slime mold over a 26 hour period. The yellow circle that transforms into an intricate web by the last panel in the lower right shows that the slime mold grew in the area that it was allowed to grow in with the goal of accessing each white dot. The white dots are the food source for the slime mold. After reaching all of the food dots, the slime mold then curates its internal web structure so that nutrients are carried to all areas of the slime mold. In doing so, the only pathways left from the slime mold’s initial position in panel 1 to each of the food sources end up being the shortest and most efficient pathway. (Tero et al., 2010)

The slime mold is such an efficient designer of its own internal network that transportation professionals and urban planners have taken note. In 2010, a team of researchers from Japan and the UK fed a slime mold with food sources laid out in the same pattern as the stations of the Tokyo subway system (Tero et al., 2010). The network that the slime mold created was remarkably similar to the Tokyo subway system. The Tokyo subway system was designed to have the most efficient paths from one station to another, and slime molds grow in a similar manner in search of food.

Subsequent research with slime molds has been conducted by creating computer models that simulate how slime molds fabricate their networks. These models were validated by comparing the computer models to those of a real slime mold grown in the lab.

**Slide 30**

Now we’ll take a look at yeast, another subset of unicellular fungi. Yeast, like slime molds that we just reviewed, are unicellular.

**Slide 31**

The function of section four is to instruct students about the importance of yeast. Humans have been using yeast for its molecular machinery in alcohol brewing since 7,000 BCE and in baking bread since 1500 BCE. (Bai et al., 2011; Samuel, 1996). This is the essence of biotechnology at work in its beginning years. Harnessing that molecular machinery of organisms, like yeast, to create a new product, like alcohol, is an example of biotechnology. It’s a combination of function and science. By understanding the importance of this unicellular organism, yeast, the educator and student gain an appreciation for these fungal workhorses.

Yeast is also used in more advanced biotechnology areas of science like synthetic biology and genetic engineering. Yeast is a favorite model organism for biological research because of its ease to grow, similar to bacteria in a flask, and its structural similarity to animal cells.

**Slide 32**

In addition to being found in the air and in foods, yeast is present in our stomachs. The gut microbiome is a diverse environment that includes fungi, bacteria, viruses, and other organisms. Let’s talk about yeast in the gut microbiome environment. Yeast and bacteria have a delicate balance within the gut. When antibiotics or steroids are taken, stress is experienced, or when an individual has a weak or compromised immune system, the microbial population within the gut falls out of balance.

How this works is that when bacteria dies after, say, antibiotic use, it leaves open spaces and resources within the gut. This additional space and resources gives yeast the power to replicate exponentially. This then leads to a yeast infection or some type of other opportunistic fungal infection. An opportunistic infection is when an organism that is normally present in a healthy person’s system overgrows and becomes a pathogen.

**Slide 33**

The next two slides review medical mycology which is the study of fungal disease. Microbial imbalance within the body can trigger fungal disease. Health fungal issues include thrush, ringworm, fungal nail infections, and yeast infections. The images on the right show yeast on the left picture, and bacteria on the right picture. When either of these are out of balance, infection can occur.

**Slide 34**

After learning about the causes of fungal disease, students may begin wondering how fungal diseases are treated and the educator can take the time to discuss combating fungal infections.

How do we treat these yeast and other fungal infections? It’s not easy. Why? Damage can occur to the human host cells from the antifungal drugs or treatments (Seneviratne et al., 2016). You can see on the slide the similarities between the structure of the animal cell and fungal cell. With treatments produced to target the fungal cell, human cells can also be impacted, causing side effects. This makes creating and developing novel antifungal drugs a difficult process, but highly profitable when successfully put out for large-scale consumer use (University of California-Davis, n.d)..

**Slide 35**

In the last section, we have an opportunity for the educator to highlight mycology focused scientists to discuss their career path. The educator can then go on to discuss current trends in mycological research. Section five is designed this way to be modified by the educator based on what’s happening in the field.

**Slide 36**

I had the privilege of having a conversation with WPI’s own Biology and Biotechnology department head, Dr. Reeta Rao. Professor Rao is here today- thank you for your time and for joining us today!

Professor Rao has been a member of the WPI faculty since 2004 and has been head of the department since 2022. She is also a visiting scientist with the BRODE Institute in Cambridge and was named a fellow of the American Academy of Microbiology in 2018.

She is a leader in the field of molecular genetics and genomics. Her primary research has been focused on infectious diseases, particularly fungal diseases. Professor Rao’s lab, the Rao lab, located in Gateway Park, researches understanding and managing fungal infectious diseases.

During our conversation, I asked Professor Rao how she started her academic and professional pursuits in fungal diseases.

She spoke about her research work in yeast biology when she was a doctoral student. She continues to be a leader in this field through her teaching and research work. Some of her current research focuses on fungal pathogens under grant funding from the National Institutes of Health. One of her achievements involved the factors that influence fungal infection of macrophages.

Professor Rao and I concluded our conversation by talking about her ability and openness of mentoring students to help them to their academic and professional goals.

**Slide 37**

I also spoke to a PhD candidate at Duke studying mycology in a lichen-focused lab. He told me about his research where he compares lichen samples collected in the 1800s with lichen samples collected today. An overarching goal of his research using historical lichen samples is to inform current lichenology diversity. An educator can appreciate the energized and vibrant community that is mycology from connecting with scientists within the field.

**Slide 38**

We conclude section 5 with some discussion about how fungi are playing an important role today and into the future with helping our environment heal from the negative impacts of human engagement and interference.

This quote is from the book *Entangled Life: How Fungi Make Our Worlds, Change Our Minds & Shape Our Futures* by Merlin Sheldrake. It’s currently the number 1 best seller in the Environmental Science category on Amazon. It’s a great book for both experienced and amateur readers in the mycology field.

“The algal partner in a lichen can’t make a living on bare rock without striking up a relationship with a fungus. Might it be that we can’t adjust to life on a damaged planet without cultivating new fungal relationships?”

As we’ve discussed so far in this lecture, scientific literature points to how important fungi and mycology are to understanding, working with, and creating solutions for some of the problems and challenges facing the planet today.

**Slide 39**

This slide shows examples of mycorestoration, an umbrella term that refers to the use of fungi to help a degraded environment.

Mycofiltration is the use of fungal mycelium, the stringy web that we covered earlier, as a biological filter for removing contaminants out of a water source.

Mycoforestry is the use of a mycorrhizal network to improve forest health. As a refresher, mycorrhizal networks use the mycelial web to connect plants together within a forest ecosystem. This mycorrhizal web is the agent that can improve plant immunity, increase plant access to nutrients due to the extended reach of the web, and improve overall forest health.

For an example of mycoforestry in action, the educator would turn to an example like the following:

In an experiment with cedar and fir trees, half of the trees were dipped in a mycorrhizae rich solution before planting, and the other half received no such treatment. Another variable was that a certain amount of trees had wood chips and some did not for moisture retention. After 10 months of growth, the trees that were dipped in the mycorrhizal solution were eight percent taller and seven percent thicker than the non dipped trees. This research is critical for forest managers to help restore forests and clear cut areas. (Stamets, 2005)

Mycoremediation is the use of fungal mycelium in a soil environment to degrade or isolate contaminants like bacteria, heavy metals, or chemicals.

The photo on this slide shows an ongoing mycoremediation experiment where researchers placed contaminated soil and fungi in containers and waited to observe the fungi isolating the soil contaminants.

Lastly, Mycopesticides are pesticides in which the main active ingredient is a fungus. These Mycopesticides function as a biological control for pests such as insects or nematodes. They can be a more sustainable supplement or alternative to chemical pesticides.

I brought the book that inspired the addition of this slide- *Mycelium Running* by Paul Stamets- to this presentation. If anyone has questions about this slide after the lecture, this book is an excellent resource that dives deeper into the four pillars of mycorestoration.

**Slide 40**

This slide is a catch-all of suggested topics that an educator might want to incorporate in a future lecture or to use as an add-on to this lecture. I came across all of these ideas prior to or during the creation of this lecture, and if I was making a longer lecture series, I’d incorporate more of these fascinating topics.

**Slide 41**

I appreciate your attention this evening. I’d like to extend my sincerest gratitude to a few individuals that helped make this OER lecture possible.

First, my heartfelt thanks to Professor Bakermans for giving me the opportunity to design an online course lecture on a topic that I’m very passionate about. Professor Bakermans has provided guidance, feedback, and support in helping see this project to fruition.

I’d also like to thank Professor Rao for her time in meeting with me for an engaging and insightful conversation about her career path and work in fungal research.

I’d like to thank Ian Medeiros, for taking the time for a zoom meeting to let me know about an area of fungal research, historical comparisons, that I didn’t even know existed. He was also forthcoming with advice for further academic pursuits in mycology.

Finally, for my friends and family- thank you for coming tonight and for supporting me with my love of mycology.

**Slide 42**

That brings us to the end of this lecture! I’d like to open up the floor to questions, and after questions are finished, please fill out a survey before you leave regarding the quality of the lecture. Your feedback is greatly appreciated. I also brought myco-cookies (mycelium-free!) for all of you as a surprise- help yourself!