Bridging the Gaps in Elementary Life Science Lessons

Kaitlin Cook

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Bridging the Gaps in Elementary Life Science Lessons

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Abstract

The United States is experiencing a rise in science, technology, engineering and mathematics (STEM) careers while facing a shortage of STEM workers. This could partly be due to a decline in the amount of time allowed for science in elementary schools or possibly because many life science lessons in elementary school lack originality and may not stimulate an interest in science. Lack of captivating STEM education prior to college may be contributing to the decline of students graduating with STEM based degrees. My thesis focuses on getting out of the routine of using monotonous life science lesson plans. I identify gaps within science education of how life science is currently taught in elementary classrooms by compiling a literature review and develop an example lesson based on real-world scientific experimentation. I use my undergraduate research growing milkweeds with and without mycorrhizae, a symbiotic fungus that grows on plant roots, as an example for how elementary students might conduct real-world science experiments. I grew milkweed plants in a greenhouse setting and added mycorrhizae to half of the plants. I measured plant growth using stem width, leaf length, height, and leaf count. My experiment would be easy to replicate in a classroom because milkweed is easy to grow and the measurements easy to take. The experiment looks at relationships between species. The mycorrhizae benefit the milkweed by supporting nutrient uptake, and the milkweed provide food for Monarch butterflies. I connect the lessons to the Massachusetts Science Technology Engineering standards, as well as writing, math, and reading standards. I have explored what is missing in teaching life science in elementary classrooms today and have provided a lesson unit on milkweed and mycorrhizae fungi as an example of how real science experiments can be used in an elementary classroom.
Bridging the Gaps in Elementary Life Science Lessons

**Importance**

Education in STEM fields has been linked to continued scientific leadership and economic growth. That being said, the United States is falling behind other international school systems in math and science (Epstein et. al 2011). With a rise in STEM-based jobs, a focus needs to be placed on improving STEM lessons for elementary students to enhance student interest in the field and to properly prepare them.

**The Need for Change**

The National Research Council (2011) found that roughly 75% of United States 8th graders are not proficient in math following the completion of the school year. The study also found that in the United States, only 10% of 8th graders met the Trends in International Mathematics and Science Study (TIMSS) advanced international benchmark in science. TIMSS compares one country’s achievements to that of another country by using average assessment scores. The average assessment scores show the country’s achievement level. Countries are ordered based on these assessment averages. TIMSS reported the change in average achievement in fourth grade science in the US. The report found that the 10th percentile score increased by 20 points while the 90th percentile decreased by 10 points. These data indicate that the gap between the lowest and highest scores decreased. The lowest scores were 20 points higher in 2015 than in 1995. With that said, the highest scores were 10 points lower in 2015 than in 1995. The United States only increased 4 points from 1995 to 2015 compared to higher increases from countries like Slovenia (+78 points) and Singapore (+67 points).
Table 1: A comparison of TIMSS average achievement of fourth grade science from different countries. The figure shows the change in the 10th percentile and the 90th percentile (Mullis, I. et al. 2015).

Research shows that proficiency in STEM related topics is dropping in the US in comparison to other countries, and yet instructional time allocated for STEM education in the classroom is continuously reduced. The Center on Education Policy (2008) found that since the enactment of No Child Left Behind (NCLB) in 2002, 44% of all districts have reduced instructional time for social studies, science, art and music, and physical education to increase instructional time for English language arts and/or math. Griffith (2008) found that more than half of the teachers within selected Midwestern states cut time from science instruction to increase the length of math and reading instructional time. Teachers felt that the importance of
meeting their state assessment goals in math and reading led to the decrease in science class time (Griffith 2008). Funding and professional development for science education was cut in these Midwestern states. 70% of teachers received less time for professional development in science compared to the amount they were provided for math and reading (Griffith 2008). 50.7% of the states said that their school provided a quarter or less funding for science instruction than the funding they provided for math and reading instruction. Professional development for science education is an important tool necessary to teach educators how to integrate science into math and reading instruction (Griffith 2008). Keeley (2009) found that in school districts that have not attained adequate yearly progress (AYP) status, science is often not taught at all. The US government defines AYP as the “amount of yearly improvement each Title 1 school and district is expected to make in order to enable low-achieving children to meet high performance levels expected of all children” (US Department of Education 2002).

The 2018 National Survey of Science and Mathematics Education reported how often self-contained elementary teachers taught science (Fig. 1).

**Figure 1:** Time allocated for teaching science within elementary classrooms (Plumely 2019).
Plumley (2019) found that 18% of primary grades and 26% of intermediate grades teach science all or most days every week. The survey found that 42% of primary grades and 36% of intermediate grades taught science some weeks but not every week. With that said, only 17% of primary grade instructors and 25% of intermediate grade instructors felt that they had control over the amount of instructional time to spend of each topic.

The National Survey quantified the number of daily minutes spent on teaching subjects in self-contained classes (Fig. 2).

![Average Number of Minutes Per Day Spent Teaching Each Subject in Self-Contained Classes](image)

**Figure 2:** A breakdown of the average number of minutes spent per day in each core subject: language arts, mathematics, science, and social studies. Science and social studies receive fewer hours in all elementary grades than math and language arts (Plumley 2019).

Time spent on science and social studies is much less than time spent on reading/language arts and math education. Primary grades are taught an average of 17 minutes a day of science while intermediate grades are taught science an average of 23 minutes a day.

**Misconceptions of STEM Education**

A common misconception about STEM education is that it is only for older students. In actuality, STEM education is ideal for younger students as it harnesses their natural creativity,
resourcefulness, and ability to explore technology (Clayton 2019). Additionally, Inagaki et al. (2006) found that young children have a natural ability to understand the biological world. Young children have the basic ability to identify biological entities and phenomena. Children as early as preschool can differentiate between plants and nonliving things through growth and regrowth in plants. Another misunderstanding in STEM education is that the lesson should include all four disciplines equally: science, technology, engineering, and math. A more natural approach develops an interdisciplinary connection in STEM through investigation and problem-solving (Ansberry et al. 2019). Clayton (2019) addresses a misconception that STEM overwhelms elementary school teachers. There is plenty of support for educators in STEM-related education. Annie Corley-Hand, the principle of Mary Kay McMillin Early Childhood Center, a K-2 school in New Jersey found that a gradual introduction of STEM material to educators allowed them to more confidently take on the subject (Clayton 2019). Ready-made STEM kits help increase elementary teacher comfort even further. Another concern with STEM education is the lack of time available for it (Clayton 2019). Cross-subject integration of STEM can increase time spent on STEM subjects without decreasing time allocated for other focal subjects like math and language arts. Corley-Hand explains that in her school, children learn about fairytales, such as The Three Little Pigs, and use the storylines to design and build houses to withstand the “big, bad wolf” (Clayton 2019).

STEM education can often require large expenses. There are, however, inexpensive options for school districts. For example, donated recyclables, like paper, cups, string, and cardboard, can be used for engineering and modelling projects. There are many free or low-cost STEM resources online that educators can access (Ansberry et. al 2019). Life science lessons can take place outdoors and educators can use nature to enhance their lessons. The National Science
Teachers Association (nstaa.org) has many free and low-cost science-related materials for teachers to use. PlantingScience (plantingscience.org) is a website designed by botanists to engage students in hands-on plant investigations (Hemingway et al. 2011). Websites such as this are designed to allow students to work with peers and science mentors to improve their understanding of science. The emphasis in STEM education should focus less on high-tech gadgets and more on positive experiences to increase enthusiasm in the sciences.

These misconceptions about teaching STEM may occur due to a lack of science education in preservice teacher training. The 2018 National Survey of Science and Mathematics found that only 24% of elementary teachers surveyed felt very well prepared to teach life science lessons (Plumley 2019). Teacher-readiness for science education can influence student perception and later impact their interest in the sciences and STEM-related careers (Pratt 2007). Future teachers often take science courses in college; however, the quality and quantity of these courses are sometimes lacking. It was suggested that preservice teachers show high-level proficiency in math and sciences prior to licensure (Plumley 2019). Not all states require preservice teachers to pass the mathematics and science portions of the licensure tests. One study of 77 educational schools found only 13% of them provided adequate mathematics preparation (Epstein 2011). It can be inferred that if only 13% of the studied schools provided adequate math preparation in a society that places a high value on mathematics education, science preparation is likely not much higher.

Case Study

Tessier (2010) suggests teaching preservice educators through the use of inquiry-based science to model effective science education and to increase confidence in the subject. Preservice teachers had to complete the following during their normal biology course:

1. pick from one of four examples
a. measuring rates of carbon dioxide release from yeasts in sugar water under various conditions
b. assessing the abundance of myriad human traits among students on campus
c. assessing phenotypic traits of a species growing in different locations near campus
d. measuring species richness in locations along a gradient of human influence

2. design an experiment and write question, hypotheses, and predictions

3. conduct experiment and collect data

Preservice teachers who completed the inquiry-based instruction had an improved attitude about biology and about their ability to teach science. The future teachers were better able to appreciate the experimental nature of the sciences and were excited to take the new information into their classrooms (Tessier 2010). A better understanding of the sciences may help mitigate some of the previously discussed misconceptions about STEM education among current and future teachers.

**From Student to Scientist**

Inquiry-based scientific instruction is a form of instruction that focuses on active student learning and the importance of understanding (Chiappetta 1997). It can leave students feeling more confident in their scientific ability (Clayton 2019) and could lead to improved interpretative skills, problem-solving skills, and scientific writing and reasoning (Tessier 2010).

Outdoor classrooms are an engaging solution that provides real-world experience for children learning life sciences. Eick (2012) reported a case study of a third-grade classroom that used an outdoor classroom and nature-study to support science and literacy learning. The teachers and students went outside and found something of interest: insects, trees, acorns, streams, etc. When the students came back inside, they checked out books related to those topics. The students wrote stories during designated writing times about those topics. Pre-determined
poetry and stories from language arts kits were replaced with pieces that dealt with the science topics. Wigfield et al. (2008) found a significant benefit to concept-oriented reading instruction, similar to what Eick (2012) witnessed in the third-grade classroom. Student engagement has shown to be an important contributing factor to reading comprehension (Wigfield 2008). Highly engaged readers are more likely to use questioning and summarizing to gain meaning from texts. Outdoor classrooms, real science topics, and associated concept-oriented reading instruction will improve student engagement and thus improve student reading comprehension (Wigfield 2008).

Real-world science experiences not only increase student engagement but can also be used to make connections between school and surrounding communities. Bouillion et al. (2001) defines connected science as the use of real-world issues and school-community relationships to bridge their culturally and historically built knowledge. Alternatively, direct instruction is a teaching philosophy that involves carefully planned lessons that include clear teaching instruction (Cox 2015). The connection between school science activities and children’s lived experiences benefit students both cognitively and emotionally. Bouillion et al. (2001) followed a team of fifth-grade teachers who used a student-identified problem of pollution along a nearby river as an interdisciplinary anchor for teaching science, math, language arts, and civics. The students were motivated to participate in their learning because they could genuinely improve their community. They saw the relevance in their learning and were therefore more interested in participating. Bouillion et al. (2001) interviewed a few students about their experience with connected science pedagogy and overall, they seemed excited to play a primary role in designing solutions for the pollution problem in their community. The case study with the fifth-grade teachers found that the increased interest and relevance of the science lessons helped increase engagement (Bouillion et al. 2001). The students gained a sense of confidence in their own
abilities and were excited to discuss issues and solutions related to the riverbank project. Hammond (2001) found that when a science curriculum was designed based on students’ lived experiences, parental and student participation in school science activities increased.

Connected science instruction was found to improve long-term knowledge retention. Upadhyay and DeFranco (2008) compared connected science instruction to direct instruction by looking at the gain and retention of science vocabulary over time. Long-term retention was higher for the students who participated in the connected science instruction classroom than for those who participated in direct instruction. Although long-term student retention was higher with connected science instruction, students preferred direct instruction as they felt the expectations of what to know was clearer. A careful balance of direct instruction and connected science instruction could help lower the rate of loss of science knowledge while keeping expectations clear for students.

STEM problem-based activities cultivate critical scientific thinking and promote engagement in the sciences. Often these types of activities are only used in middle and high school classrooms, but elementary students benefit as well. Elementary students have the cognitive development to participate in STEM activities, likely increasing their interest in STEM-based education. STEM lessons can also build confidence and self-efficacy in a student’s own abilities to be successful in more advanced math and science courses later in their schooling (DeJarnette 2012).

Case Studies

In her book STEM-Infusing the Elementary Classroom, Miranda Talley Reagan (2016) looks at how to make instructional activities meaningful for students. She gives an example from her own classroom that deal with the following concepts: inferencing, environmental effects,
defending with evidence, addition and subtraction with money, division, economic impact, and persuasive writing. Reagan (2016) designed a lesson plan that provides students with a real-world unpredictable situation. The third-grade students were told that they were packaging engineers in charge of designing a new package for shipping candy canes. The following steps were taken throughout the lesson:

1. Students watch a video on packaging engineers and what must be considered during the design of packaging including visual appearance, environmental concerns, cost of production, cost to consumer, and effectively protecting the product. The students then design a rubric to score their packaging design.

2. Students read an article on candy cane manufacturing and are asked to use what they learn to defend their packaging design.

3. The students calculate the cost of producing their package design and how it translates into consumer costs.

4. Finally, students had to pitch their packaging solution to a candy cane company using a movie making app or a voice recording app.

Reagan (2016) found that her students were excited to execute their projects and discover the outcome. She had the students design their own original solution to a real-world problem and defend their solution while also utilizing other cross-content areas.

Another lesson called Native Plants and Seeds, Oh My! had fifth grade students explore native plant species such as whorl milkweed to learn plant basics (Pauley et al. 2016). The unit was broken into four different lessons that each lasted the span of a day.

1. The first lesson involved the students reading an article from National Geographic Explorer called “Staying Alive”. The article has facts about extreme plants in extreme conditions. The students had to fill out a graphic organizer to identify main idea, key excerpts and details from the article. The students filled out a KWL chart with what they know, what they want to know, and
what they learned and had a group post-discussion once everyone had completed filling out the graphic organizer.

2. The second lesson discussed what it means to be a botanist and added that term to their vocabulary list. They started a hands-on experiment where students could use their senses to observe and explore the whorled milkweed, a native plant in Minnesota. The lesson began with identifying the following vocabulary words: roots, stem, leaves, seeds, xylem, and phloem. Each vocabulary word (except xylem and phloem) had a station that also included a whorled milkweed sample, rulers, hand lenses, and a “discovery” poster with writing utensils for students to record their observations. The students also had to put the same information into their science notebooks. The lesson ended with a group discussion.

3. Lesson three had the students use dissecting microscopes to look at prepared plant part slides. The students had to fill out a graphic organizer. They had to write the name of the plant part and draw detailed pictures that they were observing. The students filled out another KWL chart and wrote what they had learned about plants.

4. The final lesson was a scientific inquiry about the germination of milkweed seeds in varied number of weeks in cold stratification. The students generated questions following the template: How does_____ affect____? They came up with three different hypotheses and then the students developed a plan to conduct their research investigations.

The native plants unit is a good example of one that uses a combination of direct instruction and connected science instruction. As Upadhyay and DeFranco (2008) suggest, a balance of direct and connected science instruction is the optimal teaching method. It gives students a direction of focus, while allowing them to engage in their learning. The native plants lesson allowed the students to connect with plants around their community. The students also discussed interactions within the ecosystem.
Hemingway and Packard (2011) share a two-week long project involving inquiry-based learning in middle and high school settings. The lesson is called Wonder of Seeds and is part of Bruce Alberts’ (then-president of the National Academy of Sciences) challenge to incorporate inquiry into laboratories and fosters reflection on the process and nature of science. The lesson includes resources like PlantingScience (plantingscience.org), a website designed by the Botanical Society of America that provides students with first-hand experience of how science works and how scientists think. During the two-week lesson, students:

1. work in small groups to investigate a research question while being guided by their teacher and the science mentors;
2. brainstorm and decide their research question, experimental design, predictions, and interpretations;
3. keep research journals and discuss their observations and evidence as well as their data;
4. communicate with science mentors and peers about research ideas and progress; and
5. learn what scientists know and how they think when working with authentic science experiments.

PlantingScience provides seeds to classrooms free of cost and offers other materials for a low cost. The hands-on interaction with living plants helps capture student interest while the online interactions with a mentor can guide student thinking and science collaboration (Hemingway et al. 2011). Although this program is great for fostering interest in older students, PlantingScience does not support the younger students who need that initial engagement in the sciences. Elementary students, as previously mentioned, are just as cognitively capable of complex, inquiry-based thinking (Hemingway et al. 2011).

Another lesson is called “Mysterious Mycorrhizae? A Field Trip and Classroom Experiment to Demystify the Symbioses Formed between Plants and Fungi” (Johnson et al. 2009). The goal of these lessons is to help students gain an appreciation for the influence of
invisible soil organisms on plant growth, learn about symbioses and how they influence nature, and conduct an experiment and collect long-term data while also learning about the scientific method. In this lesson, students

1. follow instructions to prepare planting pots and plant four or five seeds in each pot;
2. design and write an experimental treatment (plant species or type of soil) and fertilize the plants;
3. record data weekly in a science journal including drawings or photographs;
4. after 8 to 12 weeks, observe and draw root structures;
5. weigh plants after drying them in a warm oven for 48 hours if possible

This lesson lets the students individually design their experiment as they get to choose what variable they want to manipulate. The lesson does not lay out step-by-step how to execute this experiment with students. For teachers who are not scientifically trained, creating a lesson plan for this project may be daunting. The National Survey of Science and Mathematics Education in 2018 found that only 31% of elementary science teachers felt very well prepared to teach a science lesson (Plumley 2019). A well-designed science lesson should help even the not-scientifically-trained educators feel comfortable teaching elementary students about science. My goal is to help bridge the gap between scientists and elementary teachers by providing an easy to follow lesson plan that allows students to develop into science citizens.
References


Symbiotic Relationships Unit Plan

**Essential/Inquiry Question:** What is a beneficial relationship? How does adding mycorrhizae to milkweed affect growth?

**Standard(s) to be addressed in this lesson:**
5.LS.1.1 Ask testable questions about the process by which plants use air, water, and energy from sunlight to produce sugars and plant materials needed for growth and reproduction. State Assessment Boundary: The chemical formula or molecular details about the process of photosynthesis are not expected in state assessment.

5.LS.2.1 Develop a model to describe the movement of matter among producers, consumers, decomposers, and the air, water, and soil in the environment to (a) show that plants produce sugars and plant materials, (b) show that animals can eat plants and/or other animals for food, and (c) show that some organisms, including fungi and bacteria, break down dead organisms and recycle some materials back to the air and soil. Clarification Statement: Emphasis is on matter moving throughout the ecosystem. State Assessment Boundary: Molecular explanations, or distinctions among primary, secondary, and tertiary consumers, are not expected in state assessment.

RL.5.1 Quote or paraphrase a text accurately when explaining what the text states explicitly and when drawing inferences from the text.

RI.5.2 Determine one or more main ideas of a text and explain how they are supported by key details; summarize a text.

RI.5.9 Integrate information from several texts on the same topic in order to write or speak knowledgeably about the subject.

RI.5.10 Independently and proficiently read and comprehend informational texts, including history/social studies, science, mathematical, and technical texts exhibiting complexity appropriate for at least grade 5.

5.MD.A.1 Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.

5.G.A.2 Represent real world and mathematical problems by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation.

W.5.1 Write opinion pieces on topics or texts, supporting a point of view with reasons and information.

W.5.2 Write informative/explanatory texts to examine a topic and convey ideas and information clearly.
W.5.7 Conduct short research projects that use several sources to build knowledge through investigation of different aspects of a topic.

W.5.8 Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources.

Background for Teacher:
Mycorrhizae are a group of fungi that form beneficial symbiotic relationships with plants. A symbiotic relationship is when two or more organisms form a relationship, which could be beneficial, harmful, or neutral. A beneficial symbiotic relationship is called mutualism. In the case of mycorrhizae and plants, the fungus provides the plant with nutrients and the plant provides the fungus with sugars from photosynthesis. Mycorrhizae have also been shown to provide plants with stress resistance and tolerance. The fungi improve soil structure. It forms a matrix in the soil particles that holds the soil together without compacting it. This could help reduce erosion. Mycorrhizae produce proteins that are important for soil quality and storing carbon. Mycorrhizae can form on the outside of plants roots, or they can enter the cell wall and form structures called arbuscules.

In the wild, milkweed seeds undergo a dormancy period in the winter to keep young plants from sprouting (germinating) in freezing temperatures. Enzymes, or proteins, in the seed coat keep the seed from germinating right away. Throughout the winter, the enzyme breaks down. The rise in temperature during the spring indicates to the seed that it is time to grow.

Scientist:
A botanist and a mycologist would use this type of science. Mycologists are biologists who study fungi. The fungus in question is not well understood and mycologists are interested in understanding more about it. Mycorrhizae contribute to plant health but much of how the fungi function is a mystery. Botanists are biologists who study plants and are equally interested in this topic because of the mutualistic (both species benefit) relationship between the fungi and plants.

Student Background Knowledge:
Student Misconceptions

- All fungi are bad
- Fungi are plants

Accurate Conception

- Fungi are used in medicine; penicillin comes from a fungus. Fungi are used to make food and drinks. Bread rises because of the use of yeast, a fungus. The making of some cheeses like brie or gorgonzola, also require fungi. Fungi help bring nutrients to plants and trees. They assist in plant-to-plant communication. Fungi are essential in decomposition. Without them, decomposition would be slowed; and humans would be inundated with trash.
- Fungi belong to their own kingdom. They are more closely related to animals than they are to plants.
### Instructional Items:

#### Materials for Students and Teacher:

| Books | • Notable Notebooks: Scientists and their Writings by Jessica Fries-Gaither  
• Monarch and the Milkweed by Helen Frost |
| --- | --- |
| For Data | • Composition notebook or graphing notebook (preference left to student, but graphing notebook may make data recording easier)  
• Colored pencils (specifically blue and green)  
• Writing utensil  
• Electronic stainless-steel 0-6in. calipers (e.g., Neiko 01407A Electronic Digital Caliper Stainless Steel Body with Large LCD Screen)  
• Ruler or tape measure  
*if you don’t have access to calipers: *  
• Flexible tape measure |
| For Growing | • Milkweed Seeds  
• Rootattainer  
• Low nutrient, sterilized soil (Metro-Mix 360)  
• Ziploc bag of sand  
• Refrigerator  
• Endo-Mycorrhizal powder (e.g., Root Naturally Endo Mycorrhizae -4oz)  
• Tape for Labelling  
• Permanent markers  
• Grow light  
• Sand  
• Spray container with water |
| For Activities | Each small group gets:  
• 3-5 seeds (preferably lima beans)  
• Plastic bag  
• Paper towel  
• Spray bottle (this can be shared) |
| For Staining | • Scale  
• Weigh boats (sm. or med.) |
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**Engage:**

The students will start the lesson by going over how to write in a science notebook. As a class, read *Notable Notebooks: Scientists and their Writings* to teach the students about the importance of keeping a proper science notebook. With that, the students will get their science notebook (any notebook of their choosing). They will make the first page a title page with essential questions and the second page will be labeled a table of contents. Each journal page should be numbered at the bottom corner until 35, leaving room for additional pages.

1) Either print out the table that depicts each plant space label, or have the students draw a similar table to keep track of where each plant is for future recording purposes. The table is designed as a bird’s eye view of the roottainer spaces (Fig. 1).
Explore:
THE GROWING PROCESS:
1. Obtain milkweed seeds either locally or from a provider
2. Have students place milkweed seeds in a Ziploc bag of sand, moisten it, and place in a refrigerator or cooler for 2 weeks
   - Discuss how milkweeds are a native weed. A process called stratification is used when seeds are placed in a simulation of their natural conditions. Prompt the students think about what time of year milkweed pods burst open. Fall. [https://seed-balls.com/life-cycle-of-milkweed](https://seed-balls.com/life-cycle-of-milkweed) Ask them: When do the milkweed plants grow? What happens to the seeds that burst from the pods? They are dormant until the Spring to prevent early growth and freezing. Ask the students if there is a way to replicate this experience without waiting for winter? Place seeds in the refrigerator
   - Read a short story “Monarch and the Milkweed” by Helen Frost. Discuss the life cycle of the monarch butterfly and why the milkweed is important for this life cycle. *Monarch caterpillars only grow on the milkweed plant. The toxins in the milkweed provide the Monarch butterflies with their toxins.*
- Print out the above diagram for the students to paste into their science notebooks (Fig. 2). Have the students fill out each stage of the monarch butterfly life cycle and have them draw or briefly describe the stage.
- Have students watch a video about milkweeds and the decline of monarch butterflies due to habitat degradation https://www.youtube.com/watch?v=6JpLR2hpfSk and have them answer the following questions:

**Monarch Butterfly Video Follow-Up Questions:**

1. What are two reasons the milkweed plant is important to monarch butterflies?
   - chemical defense
   - it is where monarchs lay their eggs
2. Why has the monarch butterfly population size decreased?
   - habitat destruction because of development and agriculture
3. What can we do to help grow the monarch population?
   - plant milkweed gardens and maintain diversity

3. Prepare roottainer with a low nutrient, sterilized soil like Metro-Mix 360 filled to the top of the container
   - (a) the roottainer is used because it comes apart easily and gives easy access to the milkweed roots without damage
4. Remove the milkweed seeds from the sand using tweezers, make an inch deep hole in the soil using a finger, place the seeds into the soil, water the seeds until soil is damp, cover the roottainer with the plastic top (or saran wrap), then place the entire roottainer set up under a grow light and leave: water the plants (soil wet to touch) once a week
For Step 4: The students should also use this time to practice measuring plant materials. Take the students to an outdoor garden (if your school has one) or take a trip to a local forest/field. Students should use the following procedure to practice measuring:

- Pick 3 or 4 different plant objects (leaf, stem, plant height, flowers, etc.) to measure
- Draw the plant object in the science journal
- Use a ruler or tape measure to measure their chosen plant material
  - if calipers are available have the students practice taking stem diameter using the calipers. Calipers are sharp and can cut the stem when closed too abruptly. Practicing use can minimize this from occurring with their grown milkweed
- Record the measurements in the scientific journal

Take this opportunity to learn about seeds and their growth. Teacher prepares the seeds germination experiment a week before planting milkweeds. The teacher should begin the lesson by following the introduction on the biggreen.org germination lesson plan. The students should take the following steps in their journals:

- Define germination by finishing the statement “Germination is…”
- Make a hypothesis about what the seed will look like when it germinates. The students can use drawings and words to describe their hypothesis.
- Observe seeds and draw what they see. Describe observations in words.
- Determine whether their hypothesis was supported or refuted

Soak seeds overnight to break seed coat. The students should be able to split the seed open into two separate sections. The picture below depicts the three different seed parts (Fig. 3).

![Image of labeled seed parts](https://mamapapabubba.com/2013/09/21/lima-bean-dissection/)

Figure 3: Labeled example of the seed parts

- Draw and label the parts of a seed (Fig. 4).
5. Once the milkweed plants have started to grow, have the students measure stem height (from soil to top leaf), leaf size (the newest leaf), leaf count, and stem width (if possible) once a week.

6. Have students record the data in their science notebooks in a table format.

*For Step 6:* The students should have one data table for each piece of data. Have them draw it by hand or have them paste the template in their journals (Fig. 5 and 7). These data tables should be completed for each week and either labeled with the date or the week # (Fig. 6). See example:
Each spot on the table represents the plant depicted in the bird’s eye view figure. The skipped boxes indicate the spaces where plants did not grow.

Figure 6: Example of data collection without the printout

Figure 7: Example printout for data collection

WHILE THE MILKWEED GROWS:
This is a good time to discover fungi and how they contribute to our lives.

1. Ask students what they know about fungi. Use the question: Where do you come across fungus? Record and categorize their responses on the board. The categories may include medicine, food and drink, decomposition, disease, etc (Fig. 8).
2. Students should read the following articles:
3. Students should write a paragraph summary of each reading in their science journal
4. Using their summaries, students will write a three-paragraph paper discussing the benefits of fungus

THE INOCULATION:
1. After two weeks of growth, dig a roughly ¾ inch hole next to the plant and put mycorrhizal fungus in the soil of half of the plants; for the other half of the milkweed plants, put sand in the soil (explain the importance of having a control): label containers with tape and permanent marker
   - students should write a hypothesis about what the fungus will do to the plants when added. This hypothesis should go in their science notebooks.
   - plants stop growing when they are touched so by adding the sand to the milkweed plants without fungus, all the plants are kept in the same condition
2. Let the plants grow with the fungus for at least 2 months, taking measurements once a week
3. At the one-month point the class will collectively use the data that have been collected to find averages. The averages should be used from each week. At this point, there will be four numbers (averages) to graph for each item of measurement (e.g. stem width, leaf length, leaf width, leaf count, and height). Each item of measurement should have its own line graph (Fig. 9).
Average: 3.953cm

Average: 3.953cm

Average: 4cm

Figure 9: Example data tables, averages, and line graph show how the data are to be used. Averages are taken from each table, and those averages are graphed on the line graph. The x-axis is time (number of weeks) and the y-axis is item of measurement, in this case, average height (cm).

STAINING
1. The students should use their data averages to make a line graph that depicts weekly growth in their science notebooks. Each point on the graph will show the weekly average for the plant measurement. Students should have four different graphs and two lines on each graph (one for with mycorrhizae and one for without) (Fig. 10).
2. Open the roottainer, remove the milkweed plant, and rinse the dirt off with water.

3. Test for successful mycorrhizal fungus colonization with the following staining technique (the teacher should handle all the chemical processes)

   Prepare the following before staining:
   
   a) make 10% KOH by measuring out 5g of potassium hydroxide pellets using the spatula, weigh boats, and scale and putting them in 500mL of distilled water. Store the KOH solution in a glass jar
   
   b) pour enough KOH solution into a glass graduated cylinder or other glass container to cover the roots and soak the root in 10% KOH for 10 minutes. This clears the root tissue to make viewing the inside of the root easier

   c) rebalance the pH of the root by soaking them in vinegar
   
   d) make 150mL of a 1:1:1 water/glycerol/lactic acid mixture by measuring out 50mL of water, 50mL of glycerol, and 50mL of lactic acid and mixing them together in a glass storage container
   
   e) make a 0.05% trypan blue stain by adding 0.075g of trypan blue powder to the 150mL of the water/glycerol/lactic acid mixture

Once ready to stain have each small group do the following:

a) receive a roottainer unit with four milkweed plants
b) remove the milkweed from the roottainer and rinse off the roots with water

c) the students should observe the milkweed roots and record what they see in their scientific notebooks prior to staining
d) the teacher will soak the roots into the KOH solution for 10 minutes and distribute the roots back out to each small group
e) with gloves on and using the tweezers, the students will then put the roots in the vinegar for another 10 minutes.
f) place the roots in the trypan blue stain overnight*

*if there is concern of the stain falling over, the plant stems can be cut off and a screw cap can be placed on the storage container

4. Once the roots have been stained, the students can use a dissecting microscope to look for mycorrhizal inoculation
   a) using tweezers, students grab the milkweed and cut off the stem
   b) the cut root is placed on a petri dish with distilled water
   c) the petri dish is placed under the dissecting microscope

*Teachers Note:
The mycorrhizal fungus should look like dark blue structures within the root structure
The left picture is with mycorrhizae present and right is without the fungus present.

5. Have the students draw what they see in their notebooks.
6. Ask the students what they noticed about their plants with the mycorrhizae compared to their plants without it. Was there a difference in the weekly averages?
7. Students should look back on their hypothesis. Have them answer the following questions in their journals: Do your data support or refute your hypothesis? Did the fungus help or hurt the plant?

**Explain:**
Have the students write the answers to the essential questions in their notebooks. Give a definition of a symbiotic relationship and ask the students for other examples.

*For Teacher: A symbiotic relationship is a special type of interaction between species. These interactions can be beneficial, harmful, or have no effect. Headlice that live on the human scalp are an example of a harmful symbiotic relationship (parasitism). Clownfish and sea anemones are an example of a beneficial symbiotic relationship (mutualism). If the students are struggling to think of examples, show them a few pictures of species relationships and see if they can determine if the relationships are harmful, beneficial, or neutral. You could also show them pictures with relationships and ask them if they can determine what the relationships are.*

Example: Lichen growing on a Northern Red Oak
Record their answers on the board. Mention that mycorrhizae and plants form a mutualistic symbiotic relationship. Ask the students to answer the following questions: How do the fungi benefit from the plant? What can the plant provide the mycorrhizae? If the students don’t know how to answer this, ask them what plants make to eat. Could the fungi use this as well? Next, ask the students how the plant might benefit from the fungus. Ask them to think about what plants might need to grow. How could the fungus help provide the plant with these materials?

On the whiteboard, project the picture with the mycorrhizae on the pine tree roots. Have the students come up and circle what they think is the fungus. As a class, go over what is the fungus...
and what is the root. Print out the following picture and have them circle the mycorrhizae with a colored pencil and paste it into their notebooks. The following is an example of what the mycorrhizae and root structure look like:


Ask the students: By looking at this diagram, how might the mycorrhizae help the plant acquire nutrients in nutrient poor environments? Explain that mycorrhizae help bring in nutrients because the fungi reach out further than the plant roots. In doing so, the fungi are able to draw in nutrients from a larger area and may find nutrient rich soil that is not directly near the plant roots.

**Elaborate:**
Connect the milkweed and fungus relationship to other plants. Have your students think about and respond to the following scenario:

One of your neighbors wants to grow a garden but every time they try, the plants are small and rather underwhelming. Your neighbor lives in an area with very few nutrients in the soil. They’ve heard about our growing project in the classroom and ask for your gardening expertise. What would you tell your neighbor about how to help his garden veggies grow better? Write a how-to guide explaining how to add mycorrhizae to the garden and how the fungus would contribute to plant growth.

You want to build a butterfly garden using milkweed for our school but the principal needs convincing still. Make a PowerPoint presentation explaining the importance of making a butterfly garden on the school grounds and explain how you would make the garden.
Resources:


Department of Biology Utah State University (n.d.) Decomposition. Retrieved from http://herbarium.usu.edu/fungi/decomposition


| Week One* | • read Notable Notebooks and put together scientific journals  
• place milkweed seeds in bags of wet sand and put in refrigerator |
| Week Two | • discuss milkweeds, when they germinate, and why we put them in cold  
• read “Monarch and the Milkweed” by Helen Frost  
• discuss the life cycle of the monarch butterfly and how milkweed plays a role  
• watch the monarch video and answer follow-up questions |
| Week Three | • plant the milkweed |
| Week Four | • practice measuring plant material  
• record data in journals |
| Week Five | • define germination and hypothesize what seeds look like when they germinate  
• observe lima bean seeds and record in journal |
| Week Six | *a day before class: soak seed overnight  
• seed dissection  
• draw and label parts of the seed |
| Week Seven | • introduce fungus  
• read articles and summarize  
• using summaries, write a three-paragraph response |
| Week Eight* | • inoculate the milkweed with fungus  
• discuss the importance of having controls in an experiment |
| Weeks Nine-11* | • take measurements once per week |
| Week 12* | • do math lesson with collected data  
• review how to get averages and how to make line graphs |
| Weeks 13-14* | • take measurements once per week |
| Week 15* | • take last measurements of plants  
• tell students that next week we will be staining the milkweed roots to see if our inoculation was successful  
• use data to make line graph |
| Week 16 | • stain the roots following the staining protocol  
• discuss symbiotic relationships |
| Week 17 | • writing assignment that connects the milkweed and fungus relationship to that of other plants  
• persuasive milkweed PowerPoint presentation for principal |
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• persuasive milkweed PowerPoint presentation for principal |

*regular classroom lessons will occur during these occasions
The Life Cycle of:

Stage:

Stage:

Stage:

Stage:

Stage:
### WITH MYCORRHIZAE (A)

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### WITHOUT MYCORRHIZAE (B)

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### Parts of a Seed:

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<th>Cotyledon</th>
<th>Seed Coat</th>
<th>Embryo</th>
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<tbody>
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<td>Provides food for the baby plant, or seedling</td>
<td>Protects the seed from insects, disease, and damage</td>
<td>This will germinate into a baby plant, or seedling</td>
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Label the parts of the seed with your work station group.