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# Starchy Surveillance

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## ABSTRACT:

Students start learning about photosynthesis in early grade school, yet it is a topic they still struggle with in college. Misconceptions and lack of a deep understanding of photosynthesis may result from a paucity of quality science labs that address photosynthesis using inquiry. A quick internet search reveals that although a number of photosynthesis lessons are widely available, very few engage students in activities that allow them to actively construct an understanding of the principles of photosynthesis. Rather, most are cookbook style confirmation labs. The lesson presented here requires students to answer fundamental questions underlying photosynthesis using data they collected. This yields a deeper understanding and aligns with NGSS as students conduct an investigation and then use evidence to support their claims and make connections to other science topics.

## BACKGROUND:

There are a number of well-documented student misconceptions regarding photosynthesis. One of the most common is that plants get most of their food through their roots from the soil. Some students say this is the reason that plants need fertilizer (Barker 1995; Barman et al. 2006, Driver et al. 1994, Kose 2008, Russel, Netherwood, and Robinson 2004). Another misconception is that water is the primary growth material for plants because it is absorbed through the roots. Other studies show that students hold the misconception that minerals from the soil are food for plants and that they directly contribute to plant mass (Driver et al. 1994).

The activity described in this paper was designed to address each of these three common misconceptions. Students first look at six pictures of plants, some rooted in soil, others in water. They are asked to classify these plants based on how they grow. This activity helps provide evidence that soil cannot be a factor in contributing to a plant's growth or mass. Next, students perform a starch test on leaves from plants that helps them recognize that sugar production only happens when light is present, which would not be the case if plants got their food through the roots. However, light is a form of energy not matter, and therefore cannot directly increase plant mass. Therefore, the plant mass must come from someplace other than soil or the sun. We then discuss the reactions that involve water and carbon dioxide to produce glucose and how the sun provides the energy necessary to drive this reaction. After their investigation, students read about van Helmont's seminal willow experiment, reinforcing that plant mass does not come from soil.

In addition to addressing common misconceptions, this activity integrates all three dimensions of the Next Generation Science Standards (NGSS), in particular focusing on the Cross Cutting Concept: Energy and Matter, the Science and Engineering Practice: Constructing Explanations and Designing Solutions, and the Disciplinary Core Ideas: LS2. Cycles of Matter and Energy Transfer in Ecosystems and PS3.D energy in chemical processes (NGSS Lead States, 2013). This alignment is described in more detail in Table 1.

## TABLE 1: NGSS ALIGNMENT OF LESSON

| |
|---|
| **Standards**<br>**MS-LS1-6. Matter and Energy in Organisms and Ecosystems** |
| **Performance Expectation(s)**<br>*The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectations listed below.*<br>**MS-LS-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of mater and the flow of energy into and out of organisms.** |

| Dimension | Name and NGSS code/citation | Specific Connections to Classroom Activity |
|---|---|---|
| Science and Engineering Practices | **Analyzing and Interpreting Data**<br>• Analyze and interpret data to provide evidence for phenomena (MS-LS2-1)<br>**Constructing Explanations and Designing Solutions**<br>• Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (MS-LS1-6) | Students make observations and collect data to discover where the necessary energy to carry out photosynthesis comes from<br>Students interpret historical data to construct an explanation for where a plants' mass comes from.<br>Students explain what materials? are necessary for a plant to create its food, in addition to constructing an explanation regarding where a plant's mass comes from. |
| Disciplinary Core Ideas | **LS1.C: Organization for Matter and Energy Flow in Organisms**<br>• Plants, algae (including phytoplankton), and many microorganisms use the energy from the light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. (MS-LS1-6)<br>**PS3.D: Energy in Chemical Processes and Everyday Life**<br>• The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen. (secondary to MS-LS1-6) | Students are shown that plants need sunlight to create sugar.<br>Students investigate starch versus baking soda to discover the difference between the presence of starch and no starch.<br>Students conduct an experiment to explore the role of light in formation of starch. |
| Crosscutting Concept(s) | **Energy and Matter:**<br>• Within a natural system, the transfer of energy drives the motion and/or cycling of matter. (MS-LS1-6) | Students discover the light energy from the sun is turned into chemical energy for the plant by the process of photosynthesis. |

| | |
|---|---|
| Connections to Nature of Science (when appropriate):<br>**Science Knowledge is Based on Empirical Evidence**<br>Science knowledge is based upon logical connections between evidence and explanation. (MS-LS1-6). | During activity and post-activity discussions allow students to explicitly reflect on the data collected throughout the lab and its meaning. |

## ACTIVITY DESIGN:

After completing this lab, the student will be able to (1) identify the source of food for plants, (2) explain why light is important for plants, and (3) describe the importance of photosynthesis in plant growth. Materials required are found in Table 2 including Coleus plant (Figure 1 and 2).

### TABLE 2: MATERIALS AND QUANTITIES NEEDED FOR STARCHY SURVEILLANCE LAB

| Material Needed | Quantity |
|---|---|
| Coleus Plant (Figure 1 and 2)kept in dark | 1-2 per class |
| Coleus Plant (Figure 1 and 2) kept in light | 1-2 per class |
| Baking soda | 1 box for serves 6 sections of 30 kids |
| cornstarch | 1 box serves 6 sections of 30 kids |
| iodine | 1 bottle serves several sections |
| Plant pictures (found in teacher guide (see online supporting materials) | 1 set per group |
| 1000 mL beakers | 6-8 per class |
| Hot plates | 2 for the class (1 for ethanol, one for water) |
| Scoopulas | 3-5 for the class |
| Petri Dishes | Two per group |
| Forceps | One per group |

**FIGURE 1: COLEUS PLANT. COLEUS IS FOUND WITH MANY DIFFERENT VARIATIONS TO LEAF SHAPE AND COLOR**

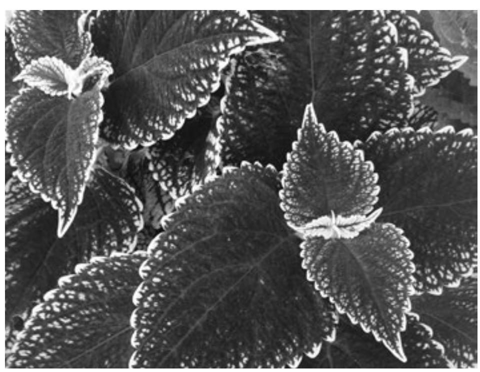


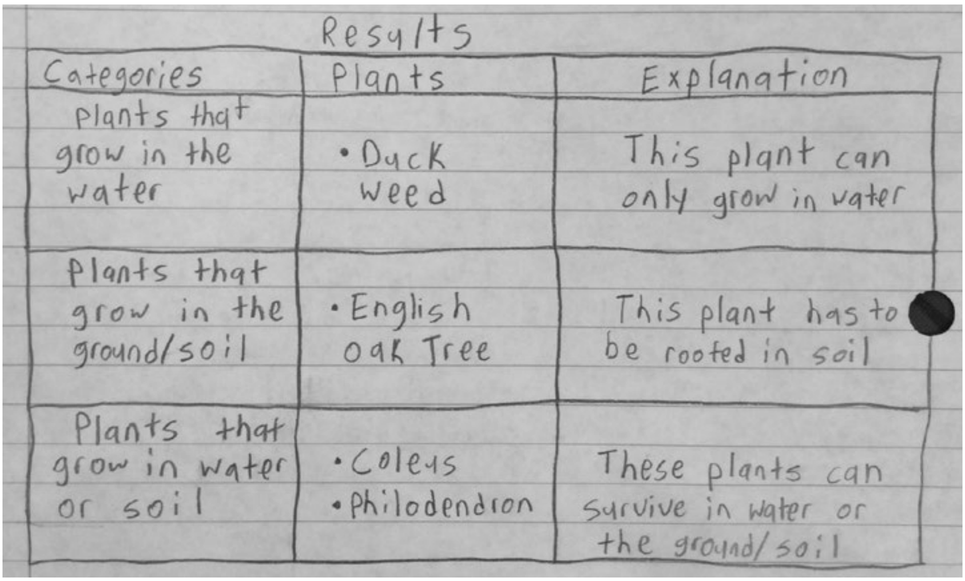
**FIGURE 2. COLEUS PLANTS COME IN MANY VARIETIES AND SOME HAVE MORE ANTHOCYANIN (PURPLE) PIGMENTATION THAN OTHERS. WHEN CHOOSING PLANTS TO USE IN THIS ACTIVITY, TRY TO SELECT ONES WITH A GOOD BALANCE OF CHLOROPHYLL AND ANTHOCYANIN.**

This lab can be completed in two, sixty minute class periods, with the activity portions happening day one, and the discussion, extension, and conclusion of the lab done on day two. Complete teacher and student guides are found online at: www.gvsu.edu/targetinquiry (users are required to obtain a password to access the materials but registration is free). The online guides contain details about set-up, useful facilitation tips, typical student data, and handouts with answer keys.

## WHAT IS THE FOOD SOURCE FOR PLANTS? PRE-LAB

Students are given several pictures of plants that are growing in different media (soil, water, vermiculite) and asked to classify the different plants based the pictures (see Figure 3). A class discussion at the conclusion of the pre-lab helps students recognize the

**FIGURE 3: A SAMPLE OF STUDENT WORK SHOWING CLASSIFICATION OF PLANT PICTURES BASED ON THE MEDIUM IN WHICH THEY GROW.**



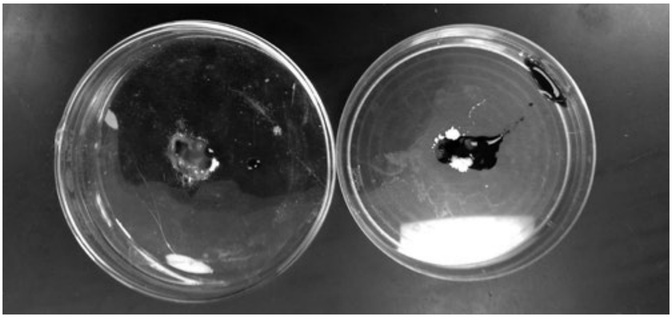
Results

| Categories | Plants | Explanation |
| --- | --- | --- |
| plants that grow in the water | • Duck weed | This plant can only grow in water |
| plants that grow in the ground/soil | • English oak Tree | This plant has to be rooted in soil |
| Plants that grow in water or soil | • Coleus<br>• Philodendron | These plants can survive in water or the ground/soil |

things that plants have in common that might be contributing to their growth, as well as key differences. Students realize that not all plants need soil to grow, thus beginning to address the misconceptions that plants obtain their food (matter) from soil.

**What is the food source for plants?:** This question is the heart of the lab activity. To try and answer this question, students do a series of activities. After completing the pre-lab classification of pictures, students conduct an investigation where they test for the presence of sugar in plants that have been kept in the light versus in the dark for 48 hours. However, students need to recognize that starch is made up of sugars and that we can test for the presence of starch using iodine. Students need to wear eye protection during this activity. When they add a drop of iodine to each of the two unknown white powders (cornstarch and baking soda) the cornstarch turns black, whereas the baking soda just takes on the brown color of the iodine as shown in Figure 4. This prepares students to be introduced to the idea that starch is a made up of sugars and we can test for the presence of starch by using iodine.

## FIGURE 4: BAKING SODA (LEFT) AND CORNSTARCH (RIGHT) WITH IODINE ADDED.



**Investigation-Starch test:** Students then use this starch test to examine the leaves from different Coleus plants (one kept in the light, and another in the dark). Students sketch the leaves before and after testing for starch to track changes. However, in order to clearly see the results of the starch test, student must first remove the red/pink pigment (anthocyanins, carotenoids, xanthophylls, and other accessory pigments that absorb light) by boiling in water (Figure 5) and then remove the green pigment (chlorophyll) by boiling in ethanol (Figure 6). This step requires the use of a fume hood in addition to safety glasses and heat-protective gloves (https://www.nsta.org/docs/SafetyInTheScienceClassroom.pdf). After the pigments are removed, students can place a drop of iodine on each leaf to see which leaf (light or dark) has starch (Figure 7). We have made a video of this portion of the lesson (https://www.youtube.com/watch?v=KKjZOG6YswY) so that students without access to the required safety equipment can still engage with these concepts.

## FIGURE 5: SHOWS A COLEUS LEAF WITH RED PIGMENT REMOVED AFTER BOILING IN WATER.

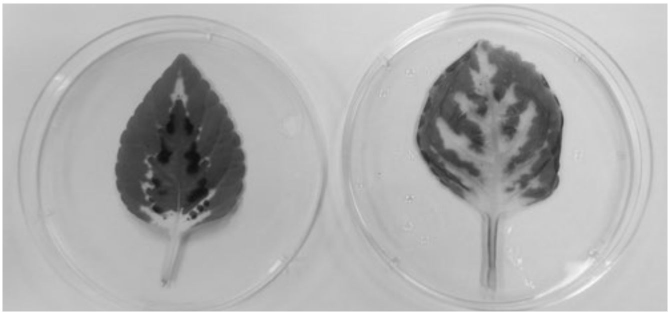


**FIGURE 6: SHOWS A COLEUS LEAVE WITH CHLOROPHYLL AND WITHOUT SHOWING THE DIFFERENCE BETWEEN A LEAVE THAT HAS BEEN BOILED IN ETHANOL VERSUS ONE THAT HAS NOT.**

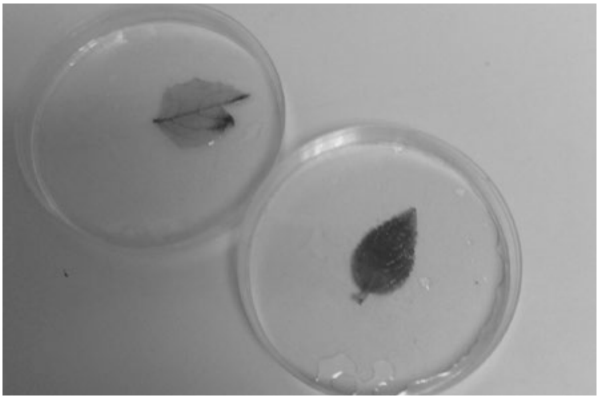


**FIGURE 7: COLEUS LEAF IN LIGHT (LEFT) AND LEAF KEPT IN DARK (RIGHT) AFTER REMOVING PIGMENTS AND ADDING IODINE.**

To analyze their data, students are asked to identify which plant showed the presence of starch and what the presence or absence of starch indicated (Table 4). From this, students could clearly see that only the leaf from the plant that was in the sunlight had starch. Thus, they were able to infer that plants need sunlight in order to produce sugar. This drives the point home that plant mass does not come from soil, but instead solar energy drives the reactions that form sugars (and therefore starches) that contribute to plant mass). A classroom discussion following data collection allows students the opportunity to reflect on what the presence and absence of starch meant and how it related to the data collected during the lab.

A relatively simple investigation like this really helps students to see that light is a key component to plants producing sugar. All of the students who completed this lab have been taught about photosynthesis before, yet after conducting this experiment we received numerous comments from students such as, "Wow, I really understand

## TABLE 4: SAMPLE STUDENT RESPONSES FROM DATA ANALYSIS QUESTIONS PRIOR TO CLASSROOM DISCUSSION OF LAB RESULTS

| Question | Student Answer |
|---|---|
| Which plant (if any) showed the presence of starch? | The plant that showed the presence of starch was the Coleus plant that was kept in the light. |
| What does the presence of starch mean? | The presence of starch means that the plant was photosynthesizing (making its own food) |
| What does the absence of starch mean? | The absence of starch means that the plant wasn't photosynthesizing because of no sunlight. |
| Why would a plant have starch present? | A plant would have starch present because starch is necessary for a plant to make food (its in the sun). |
| Why would a plant have a starch absence? | A plant would not have starch if it was kept in the dark (no sun) |
| Based on your results, where do you think these plants get their food? Use your data to justify your answer. | Plants get their food with sunlight because the plant kept in sunlight had starch, so that means it was making its own food |

photosynthesis now!", or "Why didn't we do this lab when we learned about photosynthesis last year?", or "I actually understand what the photosynthesis chemical equation means now!" This can be a great lab to run as an initial investigation into photosynthesis, or an introduction to a deeper discussion about photosynthesis to uncover and confront any naïve preconceptions students may have.

**Where does the mass come from?:** So far the activity has addressed the role of light, but not where the mass of a plant comes from. To complement the concepts that students discovered during the starch investigation, students are asked to analyze a scenario that describes Van Helmont's Willow Experiment where he determined the change in mass of a willow plant and the soil in which it was growing from a juvenile plant to an adult one. Students calculate the amount of soil from when Van Helmont planted the Willow compared to when it has grown significantly. In doing this, students determine that the amount of soil changed very little which leads them to the conclusion that the plant's mass cannot come from the soil because it has the same amount when it was a small plant and a large one (Table 5).

## WHAT DO STUDENTS GET OUT OF THIS?/DATA ANALYSIS

This activity was used in four different sections of 15-30 8th grade students. Before the activity, students took a pretest with seven questions from the AAAS Assessment website (Life Science/Matter and Energy in Living Systems: ME004012, ME013008, ME029006, ME095004, ME095005, ME109003, ME112005). After conducting the activity, students answered those same questions as well as questions about their likes/dislikes, and frustrations from the experience. The actual questions and student data are presented in Table 3.

Comparing pre and post test scores, we found that this activity addresses misconceptions about photosynthesis, especially where plants get their mass and ingredients needed for photosynthesis to occur. Using a paired-samples t-test the mean overall score was found to increase significantly from 3.33 on the pre-test to 5.29

## TABLE 5: GOING FURTHER: STUDENTS CALCULATIONS AND RESPONSES TO VAN HELMONT'S WILLOW EXPERIMENT

| Question | Sample Student Response |
|---|---|
| Write down the weights (in your lab notebook) that van Helmont measured:<br>Initial weight of soil =<br>Initial weight of plant =<br>Final weight of soil =<br>Final weight of plant =<br>Change in weight of plant = | Initial weight of soil=200lbs, Initial weight of plant=5lbs<br>Final weight of soil=200.2lbs, Final weight of plant=169.3lbs<br>Change in weight of plant=164lbs |
| What question was van Helmont trying to answer? | How much mass can a willow grow with photosynthesis after 5 years? |
| Based on the information given, what is the conclusion from van Halmont's Willow experiment? | The conclusion is: A willow can gain 164lbs over 5 years and the soil mass stays the same |
| In van Helmont's experiment, light energy was necessary for the willow to gain mass. What happened to the light energy after it reached the willow plant? Write down the specific equation for photosynthesis and relate the equation to this question. | H20 + CO2 + sunlight=glucose + O2 |
| Where did the new mass in the plant come from? | Sun gives the plant the ability to make food, and when you get food (or energy), you grow. |
| The Law of Conservation of energy states that energy can never be created or destroyed. Plants take light energy from the sun and uses it to produce sugar through the process of photosynthesis. Describe the specific of energy conversions that occur during this process. | Sunlight energy is converted to chemical energy for plants due to photosynthesis, and the plants save some of their energy for the winter |

on the post-test ($t = -8.64$, d.f. = 68, $p < 0.001$). The proportion of students answering each question on the post-test correctly was higher than the national data reported by AAAS (AAAS, 2015) for all questions (See Table 3). It is interesting to note that the scores were particularly high (65-90%) on questions that addressed the misconceptions we targeted: 1) plants get most of their food through their roots from the soil, 2) water is the primary growth material for plants, and 3) minerals from the soil are food for plants and directly contribute to plant mass.

Student comments regarding their likes and dislikes were analyzed by the authors for themes using "Grounded Theory" (Corbin and Strauss, 1990). One common theme that emerged was that students liked the hands-on nature of this activity; that they actually got to complete the process on their own rather than reading about it or doing a demo. They also liked how the leaves changed colors, and that they got to work in small groups. The most common dislikes included the amount of reading and writing required to answer the questions in the activity and data analysis, and that they felt like they were rushed to complete the questions. (Note: This activity was completed in two 47 minute class periods).

**TABLE 3. PRE-POST TEST INSTRUMENT WITH CORRECT RESPONSES IN BOLD, AS WELL AS THE PROPORTION OF OUR STUDENTS THAT ANSWERED CORRECTLY AND THE PROPORTION OF STUDENTS THAT ANSWERED CORRECTLY IN THE DATA AAAS PUBLISHED.**

| Question | Pre-test % correct | Post-test% correct | % correct from AAAS |
|---|---|---|---|
| Which of the following is food for a plant?<br>**(A) Sugars that a plant makes** (B) Minerals that a plant takes in from the soil (C ) Water that a plant takes in through its roots (D)Carbon Dioxide that a plant takes in through its leaves | 43% | 87% | 40% in grades 6-8; 39% in grades 9-12; 39% overall |
| Which organisms store some of the molecules from food in their bodies to use later as a source of chemical energy and building materials?<br>**(A) Both plants and animals**, (B) animals but not plants, (C ) Plants but not animals (D) neither animals nor plants | 52% | 57% | 51% in grades 6-8; 60% in grades 9-12, 54% overall |
| Where does the food that a plant needs from?<br>(A) the food comes in from the soil through the plant's roots (B) The food comes in from the air through the plant's leaves **(C ) The plant makes its food from carbon dioxide** (D) The plant makes its food from minerals and water | 48% | 87% | 33% in grades 6-8; 40% in grades 9-12; 37% overall |
| Which of the following is TRUE about the sugar molecules in plants?<br>(A) the sugar molecules are made by plants **(B) The sugar molecules come from the soil** (C ) The sugar molecules are one of many sources of food for plants (D) The sugar molecules are made from molecules of water and minerals | 46% | 88% | 38% in grades 6-8, 42% in grades 9-12 41% overall |
| Which of the following is TRUE about the sugar molecules in plants?<br>(A) The sugar molecules come from the soil **(B) The sugar molecules are the result of a chemical reaction** (C ) The sugar molecules are one of many sources of food for plants (D) The sugar molecules are made from molecules of water and minerals | 59% | 65% | 31% in grades 6-8; 41% in grades 9-12, 39% overall |
| What do plants use as food?<br>**(A) Plants use sugars that they make as food** (B) Plants use substances that they take in from the soil as food (C ) Plants use both sugars that they make and substances that they take in from the soil as food (D) Plants do not use sugars that they make or substances that they take in from the soil as food | 38% | 90% | 22% in grades 6-8, 27% in grades 9-12, 24% overall |
| Which of the following statements is TRUE about the carbon dioxide that is used by plants?<br>(A) It is combined with oxygen to make sugar molecules (B) it is absorbed through the roots of plants (**C ) It comes from air** (D) it is food for plants | 45% | 49% | 41% in grades 6-8, 44% in grades 9-12, 43% overall |

We want students to understand that science is a process and things do not always work out perfectly or cleanly every time. Yet, in the case of this activity, we found that when students do not get clear results it appears to negatively affect their understanding. The first time we tried this activity we used isopropanol because we did not have ethanol and our pilot trial with isopropanol worked fine. However, when the students used isopropanol, it gave mixed results and in some cases it did not remove the chlorophyll pigment from the leaves. While improvement in pre-test and post-test scores were observed regardless of the reagent used, there was greater improvement when the ethanol was used. We calculated mean relative gain (MRG) as [(pre-post)/pre] for students in the isopropanol sections (MRG= 0.58 ± 0.99) and ethanol sections (MRG= 1.31 ± 1.97), and found the difference between the two groups to be significant (t=-2.44, d.f.=61, p=0.02).

We also found that obtaining clear results led to less frustration for the students. In response to the question, "What was frustrating [about the lab]?" there were differences between isopropanol and ethanol sections. In the isopropanol sections, 16 of 33 (48%) respondents made comments that not getting the same/correct results was a problem while none of the respondents said this in the ethanol sections. These students said things like, "the results didn't come out like they were supposed to" or "It was frustrating that not all the groups got the result". Conversely, only 2 of 33 (6%) respondents in the isopropanol sections stated that "nothing was frustrating" compared to 12 of 36 (33%) in the ethanol sections. This suggests that while learning occurred regardless of the lab outcome, the students who obtained clear and interpretable results had a better experience.

## CONCLUSION/PERSONAL REFLECTION:

Photosynthesis is a challenging concept for students and is covered across many grade level standards. Yet, students are often uninterested and struggle with the fundamental concepts. We believe this is because photosynthesis is generally taught out of context or without connection to other science concepts. By doing this activity students demonstrated an understanding that plants use the sugar that it produces from photosynthesis to grow and produce more leaves, stems, and roots, and that sunlight is the driving force for photosynthesis that forms the mass of the plant. Scaffolding students' development of these concepts through a series of student-centered activities and investigations allows students to control their own learning and facilitates a deeper understanding of the basics of photosynthesis. This lab was taught to students as a science elective; however, some of these students also took 8th grade Earth Science with one of the authors. It was really rewarding to see students make connections between photosynthesis and concepts in Earth Science. For example, when we looked at regional buoy data and the Keeling Curve, students were able to explain daily and seasonal variations in data and correlate them to photosynthesis. They were able to look at annual $CO^2$ data from the atmosphere that had been collected by local buoys and correlate the drop in $CO^2$ during the summer to an increase in photosynthesis. While it was exciting to see that the pre and post data from this lab suggest that student growth occurs, seeing my students make these connections to other phenomena shows that a deeper understanding was gained from doing the Starchy Surveillance lab.

**Here are the links to the Teacher Guide and Student Guide referred to in the article "Starchy Surveillance, An Inquiry Lesson Photosynthesis." You can also go to *msta-mich.org* under Publications/Journal - *https://msta-mich.site-ym.com/?page=Journal***

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