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Where Have the Beans Been? Student-Driven Laboratory Learning Activities with Legumes for Conceptual Change

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Abstract

Accessible, familiar, relevant, effective and expansive teaching and learning resources is the dream of every teacher and educator throughout all types of educational systems. Furthermore, engaging students in meaningful scientific investigations using familiar objects inspire students to make the needed connection with the science concept being introduced. Actively engaging in solving problems, and arriving at empirically based conclusions, leads to a lasting effect on students' learning; what is more, a deep appreciation of science and the real understanding of the scientific process is fostered. In this paper, we provide a set of laboratory-based activities using a variety of edible legumes (beans, peas, lentils, etc.) to introduce students to various STEM concepts in integrated, empirical investigations. Legumes have been grown throughout the world, and have been cultivated since ancient times for more than 11,000 years. The seeds of legumes come in a wide variety of shapes, sizes, colors, and are known for their differing nutritional values based on their content. But most of all, they are accessible, familiar, real and relevant, and are limitless in terms of locales where they can be found. It is precisely these reason that make them an effective teaching and learning resource in the laboratory classroom settings. Throughout all these laboratory learning activities, students engage in hands-on experiments, conducting research, engage in productive discussion, write scientific papers, and present their findings within a scientific framework. Through these set of inquiry activities, teachers and students will never look at beans in the same way again. Perhaps in fact, teachers may even consider them as one of their best teaching and learning resources. Finally, the appendix section offers more ideas that support the teachers whom is introducing these scientific concepts with the use of legumes. We include additional ideas, information, activities, and questions (complete with answers) that we feel students may ask during the learning process. In doing so, we aim to save time and energy for those teachers who wish to use and/or adapt the suggested laboratory learning activities as a means of introducing conceptual changes.

Keywords: Legumes, Science Inquiry, Laboratory experiments, Learning science, Effective learning resources.

1. Introduction

So often teachers avoid engaging students, and/or student teachers, in simple experiments due to the fear that they might be perceived as silly and/or worthless. However, simple experiments with a clear focus have benefits. They are easy to conduct, and as well offer the students the opportunity to experience the scientific method as it is applied in their daily lives. In addition, they approach a problem solving and arriving at an empirically based conclusion. The approach with making observations that lead to questioning a phenomenon is the beginning. By developing hypotheses to be tested by experimentation, they move forward in the scientific process. Their results lead to acceptance or rejection of the formulated hypotheses. Such simple, yet meaningful experiments are powerful in conveying an understanding of the scientific method *and* the experimental processes. They often lead to a lasting effect on students' understanding as well as their appreciation for science, the scientific processes. After all, learning is about making connections (neurological, cognitive, social, and experiential) that result in raising new questions, expanding the construction of new ideas, leading to discovering new applications, and most of all hankering for more at all levels (Cross 1999).

In these laboratory-based activities, students work with variety of beans which are grown throughout the world and have been cultivated for their nutrient values since ancient time for more than 11, 000 years.

2. Legumes

Legumes are plants with double-seamed pods containing a single row of edible seeds. Legume is a common name for large seeds of several genera of the flowering plant family *Fabaceae* (also known as *Leguminosae*) which are used for human or animal food" (*Wikipedia 2017).* The word legume comes from "the Latin word *lego* which means 'to gather' the usual way legumes are harvested. However, in French, the word legume has a broader translation and means 'vegetable'" (Albert, 2017a). Beans, peas, lentils, and nuts (which contain high concentration of protein, fat, and carbohydrates) are legume foods.

Legumes are good sources of plant-based proteins (vegetable-based amino acids). They are also rich in the beneficial needed fiber and phytonutrients. For example, lentils (Figure 1) which often called a mighty legume, in addition to having a percentage of iron and minerals, they provide about 26 percent by weight (16 grams per cup) of essential proteins as well as 63 percent of a daily need of fiber per cup, Figure 1 (NG, 2015, p. 89). Furthermore, with the exception of plants belonging to the genus Styphnolonlum* (*Wikipedia 2917*), legumes have symbiotic bacteria living in their root nodules essential in the nitrogen-fixing process (Figure 2). Thus, legumes not only provide the most essential amino acids to the plants but also play an important role in the nitrogen cycle and in turn sustainable agricultural and environment.

Based on how we consume them, beans generally can be divided into two main groups, fresh beans (those picked and consumes at immature stage) and dry beans (Figure 3). Dry beans are beans left to mature and dry on the vine, and so often soaked in water before cooking. The seeds of dried beans are sometimes referred to as soup beans (Albert, 2017; Morgen, 1992). The fresh beans can be divided into board groups. The beans that are picked just as the inner seeds started to form. They are called Green or Snap Beans and can be eaten pod and all. They called snap beans because of their tender, crisp pods that snap when bent (the ends are snapped off before cooked)" (Morgen 1992, p. 67-58). The second type is called shell or dried beans. They are the beans that are picked as the inner seeds are almost half-way mature. Bean seeds are eaten either fresh or dried. Nutritionally speaking, "one major difference between the two stages is that immature pods contain good amounts of beta carotene and vitamin C, whereas the dried seeds are high in protein and carbohydrate in the form of starch" (Mogen, 1992, p. 57).

Figure 1: Among all the types of beans, lentils are ranked third highest in protein among beans and legumes after soybeans and hemp (e.g., NG, 2015; O'Connor, 2017)

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Figure 2: Field Beans growing near Burberry Lane.
http://www.geograph.org.uk/photo/3530289

Figure 2: Root nodules of Leguminous Plants
http://www.magma.ca/~pavel/science/n-fix-p.htm

Figure 3: Different types of Legumes

Beans generally can be divided into two main groups. The beans that can be eaten pod and all, called green or snap beans, and others that are shelled for their seeds and eaten either fresh or dried, called shell or dried beans. Dry beans are beans left to mature and dry on the vine. The seeds of dried beans are sometimes referred to as soup beans. Dry beans are shelled and usually soaked in water before cooking (Albert, 2017b, ¶. 2 &7).

Legumes contain high quantities of the essential amino acid, lysine and relatively low quantities of the essential amino acid, methionine. Therefore, it is often recommended to include beans with rice in the diet. This rice and beans combination constitutes a complete protein. These two foods do not have to be consumed at the same time, but eat them within the same day to recap the benefits of the complete protein (Figure 4). Appendix 9 shows examples of complementary food combination of low and high amino acids.

Figure 4: It is often recommended to include beans with rice in the diet.

Dry mixed beans and dry brown rise

Cooked mixed beans and cooked brown rise

3. Laboratory-Based Learning Activities

In this set of laboratory learning activities, students work both individually and in groups of 2-3 students with various types of familiar beans to:

1. Generate hypotheses to explain identified observations
2. Examine the hypotheses and eliminate those that do not provide a logical explanation for the observations.
2. Design and conduct lab experiments to test the hypotheses by:
   a. Determining the materials and/or equipment that is/are needed to conduct their designed experiments in order to test their own generated hypotheses.
   b. Designing the procedures that they would likely follow and employ in conducting their experiments.
   c. Conducting the experiments to test their hypotheses in order to accept or reject them.
3. Write a lab report/scientific paper, and communicate their findings with the scientific community-- in this case, their classmates. By writing this lab report/scientific paper, which they will give to others in their class to peruse, they will learn of the idea of a 'peer review process,' a typical practice in the scientific enterprise. With this comes the experience of generating a *sound* document; this involves logically presenting their hypothesis, and the experiments that proved or disproved their generated hypotheses. It as well introduces the idea of supporting their ideas, as they learn how to foster their own credibility. This is part of the processes that scientists go through when preparing and submitting papers for publication: this process, thus gives the opportunity for the students to 'be' scientists, and 'do' science. Then, as the publication process moves forward, these student papers may be: i) accepted with no changes, ii) accepted with changes and revisions, or iii) rejected for publication for a number of reasons. (Note, that this may be in of itself an additional learning experiences for the students).

4. Observational Scenario

The following is one of a few scenarios that we have used consistently to start the set of laboratory-based learning activities. Teachers are encouraged to adapt the scenario or create their own based on their students' need, environment and community.

Susan decided to change her eating habits by becoming a vegetarian, relying mainly on a daily plant-based diet. She researched what a healthy vegetarian die consisted of. By doing this, she discovered that many professionals highly recommend the consumption of leguminous plants as an alternative source of animal protein. They are also a good source of a daily needed fibers and some minerals (NG, 2015; Mogen, 1992)

She started her plant-based diet which included learning the proper ways to prepare her meals. One day, while soaking some beans in water to make a soup, she noticed that there always was foamy bubbles in the water from the beans. Susan made this same observation from the beginning of cooking the beans, and throughout the cooking processes (Figure 5a &5b).

Figure 5a: Soaked Uncooked Beans in a Pot Covered with Bubble Foam

Figure 5b: Cooking Beans in a Pot Covered with Bubble Foam

Furthermore, Susan made additional observations from reading and from watching cooking videos. For example, she realized that:

1. All beans need the pre-soaking beforehand--- except lentils and split peas.
2. Beans that float need to be discarded.
3. One must pour out the initial foamy water, and start cooking the beans with fresh water.
4. The foam (*scum*) that rises to the surface at the beginning of cooking the beans needs to be skimmed.

5. In addition, she learned that it is crucial to soak the beans as long as possible; the longer they soak, the greater assurance that the beans have eliminated most of the gas producing sugars.

Susan starting thinking about these observations and decided to bring them up to her science class in order to better understand the physiology of the leguminous plants. She was thinking about how important eating leguminous plants could be for human consumption. For those who either don't have enough access to meat, or don't eat meat and meat products, this could be a great alternative, Susan thought.

5.0. The Learning Challenges and Invitation to Inquiry

Susan discussed her observations with her science teacher, who decided to involve all the science students in Suzanna's class into this investigation. The teacher placed all Suzanna's questions and observations on the board. She then followed with asking the students to start generating hypotheses to explain all these observations. The teacher placed the students in teams. Each team was given the task to generate hypotheses and design a set of experiments. Their purpose was to reveal how the foamy bubbles occurred. With this notion, was the pertinent need to discover why this occurred when the beans where either soaked in water, cooked in soup, or stirred? The teams were also to suggest why the gaseous state of matter occurred, and to determine the chemical composition of the gases. After all, as one of the earliest and most cultivated crops by humans, "a bowl of beans is a more universal image of nurture than a loaf of bread" (Wool, 1999, p. 30), or a piece of red meat.

5.1. Goals and Objectives:

1. Confirm the main observation made by Suzanna.
2. Provide rational explanations for why there are foamy bubbles coming from the beans while soaked in water and/or cooked.
3. Generate a set of hypotheses to identify and determine the identity of the gas in the foam that is generated when beans are soaked and/or cooked.
4. Design and conduct a set of experiments to test the generated hypotheses (tentative explanation) and reach a valid and reliable conclusion.
5. Communicate the findings with the community (class) as a means to generate further questions; the goal here is to offer a means to generating more scientific investigations in the beans' production of gas. With more investigations, more data, information, and raised new questions can be generated, and as a result more knowledge is created.
6. Develop mathematical and analytical skills, as students plot/graph their data. This will encourage students to understand how the transfer of data to a graph will lead to the useful expression of meaningful knowledge.

5.2. Needed Materials:

The following materials and equipment are made available for the students. It is up to them to use them in part, and/or in whole, for their experiments. The students are made aware of the materials at hand, but are solely responsible for making the decision of what to use, how to use it and when. (Note that teachers do not need to provide all of the materials if they are not easily available).

- Various types of large sized beans (black-eye, fava, garbanzo, lima, red kidney, pinto beans, and others may be included)
- Small jars with tight lids or medium size flasks
- Rubber bands, rubber stoppers, and one-hole rubber stoppers
- Drinking straws
- Plastic cups
- Test tubes and test tube holders
- Limewater, Bromothymol blue and/or carbon dioxide sensor.
- Dissecting microscopes or stereomicroscopes
- Magnifying glasses or hand lens
- Dissecting lab kits, scalpel (dissecting knifes), or dissecting needles
- Hot plates or other heat source
- Forceps
- Litmus paper or pH measuring devise.
- Thermometers
- Tap water, salt and sugar

5.3. Confirmation of the Observation:

Confirmation of the observation is very important for two reasons. First, by their nature scientists are curious and skeptic. They also have an extreme desire to learn about the world around and within us. Thus, scientists are often intrigued by observations that capture their attention, those having unique patterns and/or those with causal and effect relationships. Second, by noticing for themselves the physical or morphological occurrences, students take ownership for discoveries, thus engaging even greater degrees of curiosity and desire to know. This makes the confirmation of the observation a prerequisite for each group of students to go forward and proceed with their task in this laboratory learning activity. Therefore, using Table 1, students are asked to:

1. Individually and independently confirm Susan's first observation: Do all beans form a foam when soaked and when boiled?
2. Individually submit evidence for confirmation of the observation to both the members of their groups, as well as to their teacher.

Table 1- Student Confirmation of Observation:

Do all beans form foamy bubbles when soaked and boiled?			
Selected Beans	Type of Bean	Soaked	Cooked Bean
First Bean			
Second Bean			
Third Bean			
Fourth Bean			
Fifth Bean			

However satisfying curiosity and the desire to know and discover the world around is not enough. Someone needs to go through the process of discovery. As Phelan (2009) suggests, "Explaining how something works or why something happens requires using agreed-upon methodological procedures that include objective observations, rational hypotheses, testable predictions, well designed experimentations, and rational analysis"; this supports, "interpretation and conclusions that are not clouded with emotions or preconceptions about what is being studied and observed" (p. 2-3).

5.4. Generating a Set of Hypotheses:

It is important for students to generate multiple tentative explanations for the observations they already made. A tentative explanation which we call a 'hypothesis' is an explanation that is relatively untested for a puzzling observation. Therefore, students are asked to provide well thought out tentative explanations or hypotheses. It is very important for students to understand the reason behind generating multiple hypothesis when dealing with scientific inquiry. This is simply because if one only generated one hypothesis for an observed phenomena, there could be inherent bias in their experiments and analysis. This is also the reason why we call a 'hypothesis' a tentative explanation; it is subject to change based on new findings and discoveries. In short, before starting to generate their hypotheses (tentative explanations to observed phenomena), students need to understand that a hypothesis is a tentative, testable explanation that can be accepted or rejected by a conducted experiment. Table 2 below shows examples of a set of hypotheses sixth grade students generated and tested in one of the classes.

Table 2
Examples of 6th Grade Students Generated Hypotheses to Answer the Question:
Why do beans produce foamy bubbles when soaked and cooked?

	Type	Examples of 6th Grade Students Generated Hypotheses
1	Beans as living beings	The beans are seeds and seeds are living things in sleepy mode. When put in water, they wake-up and start to breathe and produce the bubbles that we can see.
2	Beans' outer-skin cover	Beans have some special substance in their outer skin that react with the water to produce bubbles and foams
3	Beans' inner substance	Beans have some special substance inside that react with water and produce bubbles and foams
4	The way we soak and cook beans	It is not the beans, but the way we soak and cook the beans that makes beans produce bubbles and foams.
5	The type of water used in soaking and cooking beans	It depends in what type of water (salt, sweet, regular) you soak and cook the bean

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6.0. Laboratory Learning Experiments:

Figure 6 - Large-sized beans such as fava beans, Christmas lima beans, mark beans, and giant Peruvian lima beans (in B) are easier to dissect for studying interior anatomy.

6.1. Selection of the Beans:

In one of the pervious class activities, students decided to select the large-sized dry beans to use in their experiments. The beans dissect easily so as to see their interior anatomy, especially if magnifying glasses or dissecting microscopes are unavailable. Based on this justification, the students often selected the some of the following large beans Figure 6: mark beans, Christmas lima beans, giant Peruvian lima beans, black eyed beans, fava beans, garbanzo, lima, pinto beans, and red kidney. (Other large beans can be chosen based on availability, the age of the students, and/or if time allows.)

6.2. Studying the Structure of the Bean Seed

A) Using a hand lens, have the students study the features of dry and soaked bean seeds and identify all the labeled parts of Figure 7.

B) Utilize the following provided tools, measure the length, width, mass and volume of the beans.

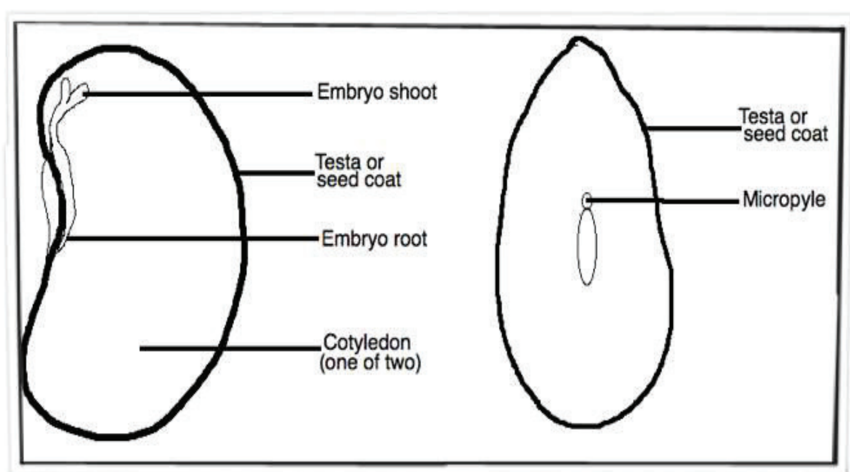

Figure 7: The external features of a bean seed
http://ibguides.com/biology/notes/reproduction-angiosperms-

6.2.1. Day 1: Know Your Beans

6.2.2. Length and Width

1. Obtain 10 beans from your teacher. Each person is responsible for taking all of the measurements for 5 of the beans.
2. Number the beans #1-10 with a pencil (NOT pen). Make your numbers dark and easy to read.
3. Measure the length and width of the beans as precisely as you can, in millimeters (mm), using the metric ruler. Look at the diagram below to see where to take measurements on your beans. Fill in Data

Table 3 with the measurements.

4. Calculate the average length and width of the beans in your sample. Fill in Data Table 3 with your averages.
5. Fill in the data chart on the board (for class data) with your averages.

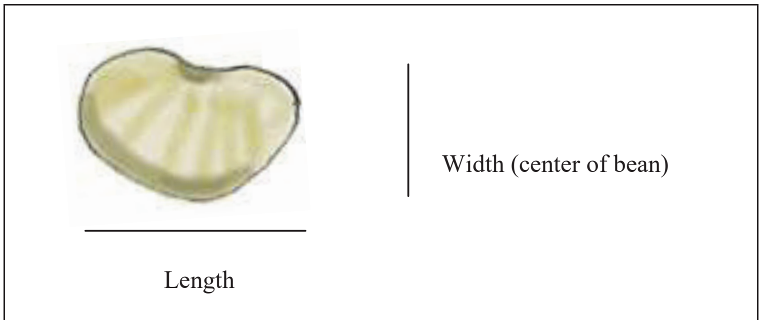

Figure 8: Measuring the length and width of the bean

6.2.3. Mass of a Given Object

On a daily basis, students, as well as many other people, are using the word 'mass' and 'weight' without really knowing the difference between them, and/or how science really defines them. Because of this, it is important for students to understand and be able to differentiate between the mass of an object and the weight of the same object; in this case, we are looking at the difference between mass and weight of a given bean. The mass of an object is the measure of the amount of matter the object is comprised of; this is a constant, regardless of space and time. For example, the mass of a seed of a given bean on the surface of Earth, Mars, and Venus is the same. Weight on the other hand is related, but quite different from the mass of that same object. In this case, "*the weight of an object is dependent on the force of gravity on the object and may be calculated as the mass times the acceleration of gravity* or W = mg." Unlike mass, weight is NOT constant, meaning it can vary depending on where a given object is in the universe. Therefore, ask students to:

1. Measure the mass of all your beans using the balance and record measurements in Data Table
2. Calculate the average mass of the beans in your sample. Fill in Data Table 3 with your average.
3. Fill in the data chart on the board (for class data) with your average.
4. Based on your understanding, what is the difference between mass and weight? Explain.
5. Can you think of alternative method to measure the length, width, and the mass of a given bean?

6.2.4. Volume of a 3-D Object

Volume is the amount of three-dimensional space occupied by an object or substance. It is one of the derived quantities defined by the International System of Units. The unit of volume is the cubic meter (m^3). (https://www.technologyuk.net/physics/measurement-and-units/measuring-volume.shtml). As in weight and mass, it is important for students to understand the conceptual meaning of volume and how to measure it. Ask students to:

1. Using graduated cylinder, measure exactly 50 mL of water and record this volume as your initial volume on Data Table 4.
2. Drop the 10 lima beans into the graduated cylinder and record the information as final volume.
3. Calculate the change in volume and record that number.
4. Calculate the average volume of one bean and record it.
5. Fill in the data chart on the board (for class data) with your average.
6. Based on your understanding, what is the difference and the relationship between volume and density? Explain.
7. Can you think of alternative method to measure the volume of a given bean?

Data Table 3: Length, Width and Mass of Dry Beans (Day 1)

	Length (mm)	Width (mm)	Mass (g)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Average			

Data Table 4: Volume of Dry Beans (Day 1)

Initial Volume of Water (mL)	Final Volume of Water (mL)	Change in Volume (mL)
Inference and Conclusion:		

6.2.5. Surface Area of 3-D Irregular Solid Object

Measuring the surface area of 3-D object is a challenge for many students, and the 3-D irregular solid object is even more of a challenge for most students, at all educational levels. In simple terms, the surface area of a given solid object is a measure of the total area that the exterior of the solid surface of that specific object occupies. Challenge the students to individually measure the surface areas of five different types of beans. First they must write how they are planning to do this. This must be done before they actually do the calculation. Upon completion, ask the students to openly share their method of calculating the surface areas of five different beans; make sure they note as well the difficulties they encountered in completing this task, as well as their means on how they overcome them. Student can be advised to utilize the following website to learn the means to calculate the surface areas of a solid object. Student will discover that while it is easy to measure and calculate the surface area of a cube, it is more difficult to do so for a cylinder, and even more difficult to measure and calculate the surface area of 3-D irregular objects such as beans. (http://www.mathguide.com/lessons/SurfaceArea.html). Finally, inform the students that surface area is very important in many branches of science and mathematics. Then ask them to conduct Internet research to find out why and how the surface area is important in, for example, both chemistry and biology.

6.3. Storage and Soaking of the Beans

1. Write your group number (assigned by your teacher) on the small cup.
2. Measure out 50 mL of water with the graduated cylinder and pour it into the cup.
3. Drop all of the beans into the water in the cup and let them sit until the next class period.
4. Write a hypothesis describing how the beans will change after soaking.
    a. Tell how much of a % change you think there will be.
    b. Tell whether you think the beans will be larger, smaller, or no change.
    c. Write your hypothesis in you science journal.
5. Clean up your lab station. The lab will conclude the next class period.

6.3.1. Day 2: Observing Changes

6.3.1.1. Re-measuring

1. Get your labeled cup with the soaking beans. Pour off any extra water.
2. VERY CAREFULLY pat your beans dry, trying to leave skins on the beans. If the skins came off while soaking, try to figure out which skin goes with which bean.
3. Re-measure the length and width of each bean, and fill in Data Table 5 and the class data chart.
4. Re-measure the mass of each bean and fill in Data Table 6 and the class data chart.
5. Re-measure the volume of the beans and fill in Data Table 6 and the class data chart.

Data Table 5- Length, Width and Mass of Soaked Beans (Day 2)

Beans	Length (mm)	Width (mm)	Mass (g)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Average			

6.3.1.2. Data Analysis

1. Using the class average data table, complete Data Table 7 by filling in the appropriate information.
2. Using the Calculations section, calculate the % of change for each bean (for length, width, mass, and volume) by using the following formula:

% of change = (final – initial / initial) X 100

Figure 9 below shows the relative sizes of various soaked beans in comparison to their dry version beans.

Figure 9: Relative Sizes of Soaked vs. Dry Beans

The process of soaking beans in the laboratory

Relative sizes of Soaked vs. Dry Beans

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Data Table 6- Class Averages & Percent Changes for Length, Width, Mass and Volume

Type of Bean (Condition)		Class Average Length (mm)	Class Average Width (mm)	Class Average Mass (g)	Class Average Volume (mL or cm^3)
Black-Eyed Beans 	Dry				
	Soaked				
% Change					
Fava Beans 	Dry				
	Soaked				
% Change					
Garbanzo Beans 	Dry				
	Soaked				
% Change					
Lima Beans 	Dry				
	Soaked				
% Change					
Red Kidney 	Dry				
	Soaked				
% Change					
Pinto Bean 	Dry				
	Soaked				
% Change					

6.4. Dissection of a Bean Seed

Understanding the anatomical structure of the seed of a given bean is essential for understanding the physiological processes behind how the seed germinates, grows, and produces. The dissecting and studying the anatomy of a bean seed is a skill students need to learn, practice and perfect; through this process, students learn how to pay attention to details, be patient, and be careful when dealing with delicate objects. It is also important in helping students develop a better sense of observational skills, etc. Divide students into groups of 2-3 students and ask the members of each group to:

1. **Split one of the soaked bean in half.** There is a line that runs down the middle of most beans (e.g., Giant Peruvian lima bean, kidney bean, or Christmas lima bean is a good example to work with). Use this line to guide the opening of the bean. The bean should be evenly split. Use a dissection knife if you need to split the bean in half along this line.

Safety Precaution: An adult should cut or supervise the cutting of any bean for younger students

2. **Examine and observe the inside of the bean.** Use a magnifying glass to see all of the details of the bean. Some structures may not be easily recognizable to the naked eye. Make notes and sketch what

you see. See Figure 10 and 1 for an example.

3. **Identify the parts of the bean seed.** You will find the embryo, cotyledon, and the seed coat. Sketch the structures out in your notebook. See Figure 10 for an example.

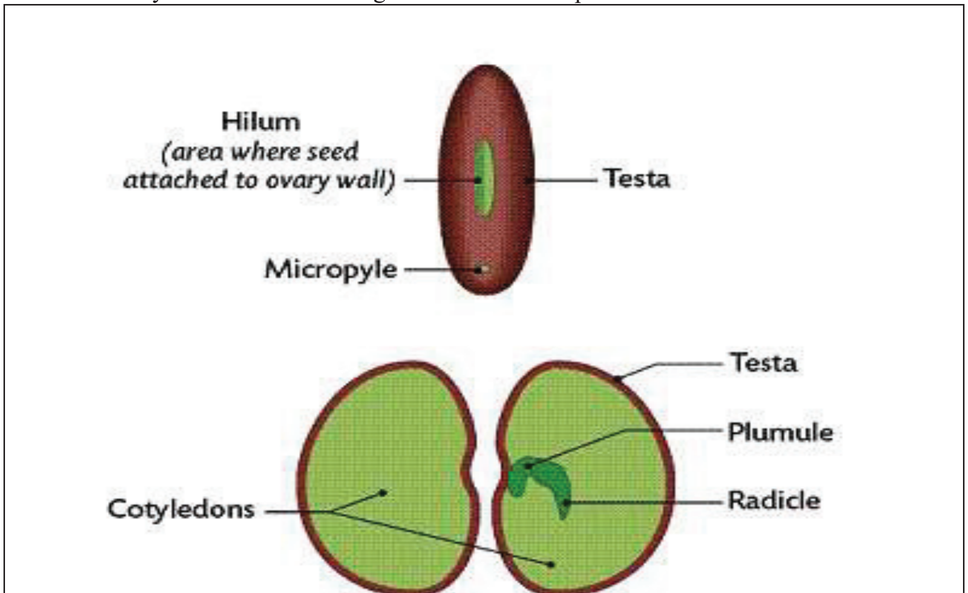

Figure 10: One example of the Structure of the Bean Seed

Figure 11: Soaking the beans in water with red or blue food coloring help to identify the parts of a given bean seed

7. Testing of Hypotheses

In this phase of the laboratory activity, each group conducts their designed and approved experiment to test their generated hypotheses. The teacher has already prepared two sets of 50 beans that have been soaked in water for at least 24 hours. Each set of 50 beans is in a closed jar as shown in the diagram below (see Figure 12).

Figure 12: 50 Seeds soaked in a jar

7.1. Gas Production – Testing for Carbon Dioxide

7.1.1. Background information

Germination occurs when a dormant seed begins to sprout and grow into a seedling. Some steps of the germination process are:

- The seed coat softens and allows for absorption of water.
- The seed swells and the coat cracks and opens, allowing oxygen to become available to cells.
- Enzymes break down starch stored within the seed into glucose molecules that move into the cells.
- Cellular respiration begins as glucose molecules react with oxygen and provide energy to the cells for seed growth and development.

Cellular respiration converts glucose ($C_6H_{12}O_6$), and oxygen (O_2) into carbon dioxide (CO_2) and water (H_2O), with the concomitant release of energy. The equation for cellular respiration, where "energy" refers to ATP and heat, is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Since carbon dioxide is a product of this reaction, carbon dioxide gas can be collected, tested for and measured, so as to determine the rate of cellular respiration.

7.2. Testing for Carbon Dioxide Using Lime Water

To conduct this task, first help each group of students to assemble the apparatus shown in Figure 13 at their working lab-station. Then have each group of students to:

1. Place in Tube "A", 10 ml of Potassium hydroxide (KOH) solution. This solution helps absorb all CO_2 in the air.
2. Place in Tube "B", 10 mL of lime water to test that the air passing into the flask containing the seeds is free of carbon dioxide.
3. Flask containing the soaked seeds
4. Place in Tube "C", 10 ml of lime water and connect it to a suction pump.
5. Observe and write down what happened.
6. Repeat the experiment by replacing the seeds in the flask with dry seeds, and then with boiled seeds.

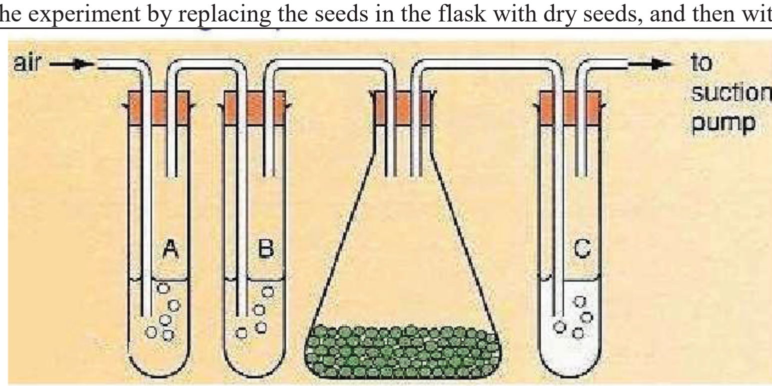

Figure 13: Apparatus for Using Lime Water To Test for Carbon Dioxide

7. Upon completion, answer the following questions
   a. What color was the limewater solution in tube B and C at the beginning of the experiment?
   b. What color was the limewater solution in test tube C after mixing it with gas coming from the flask containing the soaked beans?
   c. Where did the gas come from in the flask with beans?
   d. What type of gas does this experiment show beans excrete?
   e. Does this experiment show that beans are living entities? Explain.
   f. What have you learned from this experiment?
   g. If you have to re-do this lab experiment all over again, how would you do it and why?

7.3. Testing for carbon dioxide using Bromothymol blue

In this experiment, students will determine if germinating beans produce carbon dioxide. Each group of students:

1. Obtain two jars "A" and "B"; add 15 ml of tap water and 3-5 drops of bromothymol into two small beakers and place each one in the two jars.
2. In jar "A" place 20 dry beans. In jar "B" place 20 soaked seeds.
3. Cover jars with lids, put in a rack, and let sit for 24 hours.
4. Record any color changes and results. (As seen in Figure 14, Jar "A" will remain blue while Jar "B" will be green).
5. Repeat the experiment with boiled seeds.
6. What have you learned from this experiment?
7. If you have to re-do this lab experiment all over again, how would you do it and why?

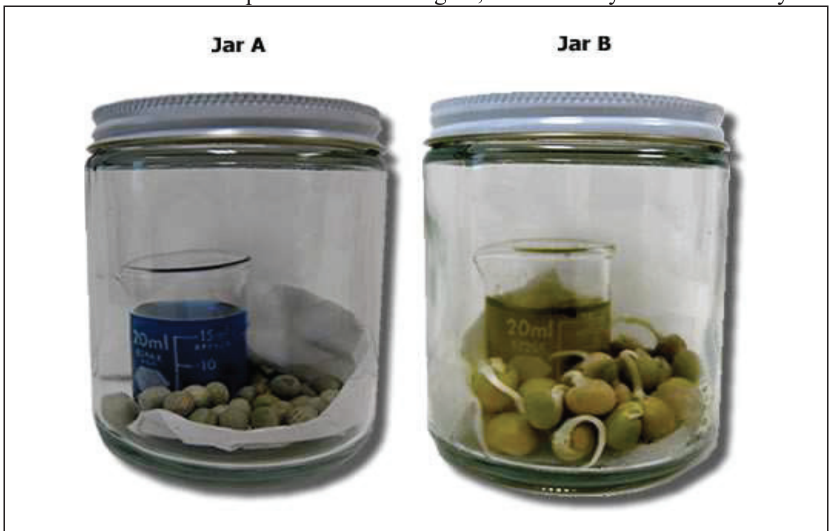

Figure 14: Dry seeds and soaked seeds with bromothymol blue

7.4. Testing and measuring carbon dioxide using a Carbon Dioxide Sensor

For the following experiment your students need to have the carbon dioxide sensor instrument shown in the Figure 15 below which is easily available and to obtain from various educational companies such as *PASCO Scientific, Vernier, etc.* If possible, provide one for each group of 4-5 students working together.

1. Start a new experiment on the data collection system.
2. Connect the carbon dioxide sensor to the data collection system using the extension cable. Calibrate the carbon dioxide gas sensor.
3. Create a graph display of Carbon dioxide concentration (ppm) versus Time. Place 20 dry seeds into an empty sampling bottle.
4. Predict what will happen to the amount of carbon dioxide in the sampling bottle containing dormant seeds. Explain your prediction.

Answers will vary. Based on the pre-lab discussion, students may correctly predict that the seeds are not growing so they won't be using their food source. Therefore, little to no cellular respiration will occur and the carbon dioxide level should remain the same.

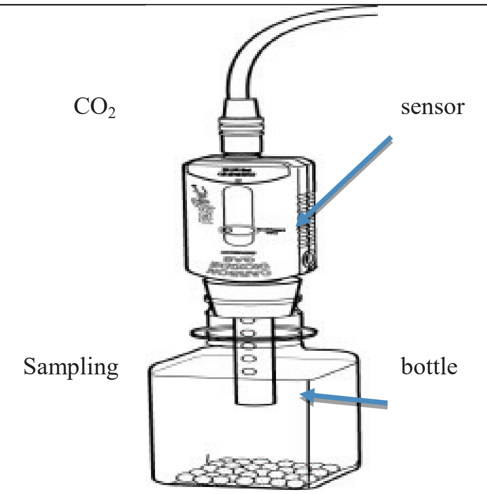

Figure 15: Carbon Dioxide Sensor
Source: PASCO's Biology through Inquiry Teacher Guide (PS-2870C).
https://www.pasco.com/products/experiments/biology-through-inquiry/germinating-seed-respiration.cfm

8. Collect Data

1. Gently push the stopper of the carbon dioxide gas sensor into the sampling bottle.
   Note: Do not allow the sampling bottle and sensor to fall over during the experiment.
2. Start data recording. Adjust the scale of the graph to show all data.
3. After 3 minutes (180 seconds) stop data recording.
4. Name the data run "dormant seeds".
5. Remove the carbon dioxide gas sensor from the sampling bottle.
6. Remove the dry seeds from the sampling bottle. Dispose of them according to your teacher's directions.
7. Fill the empty sampling bottle with water and then pour the water out. (This will flush excess carbon dioxide from the bottle.)
8. Record any additional interesting observation that you might see.

8.1. Repeat steps # 1-7 by replacing the dormant dry seeds with soaked germinating seeds.

Predict what will happen to the amount of carbon dioxide in the sampling bottle containing germinating seeds at room temperature. Explain your prediction.

Note for Teachers: Answers will vary. From the pre-lab discussion, students may correctly predict that since a germinating seed is growing, it will be carrying out cellular respiration as it consumes its food source. Therefore, the amount of carbon dioxide in the bottle should increase.

8.2. Collect Data

1. Place 20 germinating seeds into the empty sampling bottle.
2. Gently push the stopper of the carbon dioxide gas sensor into the sampling bottle.
3. Wait 10 seconds and then start data recording.
4. Adjust the scale of the graph to show all data. After 3 minutes (180 seconds) stop data recording.
5. Name the data run "germinating seeds".
6. Remove the carbon dioxide gas sensor from the sampling bottle.
7. Remove the germinating seeds from the sampling bottle. Dispose of them according to your teacher's directions.
8. Fill the empty sampling bottle with water and then pour the water out. (This will flush excess carbon dioxide from the bottle.)
9. Record any additional interesting observation that you might see.

8.3. Data Analysis:

1. Use available tools on your data collection system to find the values for Initial and Final CO_2 concentrations (ppm). Record these in Table 7. Then calculate the change in CO_2 concentrations.
2. Divide the CO_2 concentration (in ppm) by Time (in seconds) to calculate the rate of change for each run

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of data or use graph tools on your data collection system to calculate the slope of the line. Record these values in Table 7.

Table 7:
Comparison of the rate of carbon dioxide production in germinating and non-germinating seeds

Sample	**Initial** CO_2 **Concentration (ppm)**	**Final** CO_2 **Concentration (ppm)**	**Change in** CO_2 **Concentration (ppm)**	**Time (s)**	**Rate of** CO_2 **Production (ppm/s)**
Dry, dormant seeds	490	492	2[1]	180	0.01
Germinating seeds	564	1108	544	180	3.02
Source: *PASCO's **Biology through Inquiry Teacher Guide*** (PS-2870C**)**. https://www.pasco.com/products/experiments/biology-through-inquiry/germinating-seed-respiration.cfm					

Graph your data for CO_2 concentration (in ppm) versus Time. Label the overall graph and the x-axis and y-axis. Label each axis with appropriate units.

9.0. Analysis and Synthesis Questions

9.1. Analysis Questions

Upon successful completion of the laboratory work, ask students to answer the following questions. Use the data in Table 7 to answer the following questions.

1. How does the rate of CO_2 production for germinating seeds compare with the rate of CO_2 production for the dry, dormant seeds?
   From this example, the rate of gas production for germinating seeds was 3.02 ppm/s versus virtually no change for the non-germinating seeds.
2. Keeping in mind the visual differences between non-germinating and germinating seeds, what difference would these seed types have in their energy requirements? Explain.
   The dormant seeds have very little cellular activity, mainly cellular respiration. They are not growing, so they do not need much energy (ATP). Germinating seeds are growing and developing and need a large amount of energy (ATP) for these activities. The evidence for their cellular activity is the production of carbon dioxide.
3. There can be a small change in the amount of CO_2 present in the sampling bottle containing dormant seeds. Is this change significant? Explain.
   The change is not significant. It is expected that CO_2 concentrations fluctuate in a closed container.

9.2. Synthesis Questions:

Upon successful completion of their work in the lab, ask students to answer the following synthesis questions using available resources to help you answer the following questions.

1. On Day #1 of a 3-day experiment, 50 dry seeds are placed in a sampling bottle and a small amount of water is added to the bottle. A carbon dioxide gas sensor is used to seal the bottle and record carbon dioxide levels once every hour for three days. Predict what will happen to the carbon dioxide level over the 3 days, and sketch a graph to show your prediction. Explain your graph. Students should draw a graph showing a line with a positive slope; carbon dioxide levels will increase in the bottle over the three days. Students should explain that the seeds will begin to germinate and as they start using their food source, respiration will occur, producing CO_2.
2. The pH level of soils can vary significantly. Soils can either be acidic, neutral, or alkaline (basic). Describe an experiment you could carry out to test whether the pH of water affects the rate of carbon dioxide production of germinating seeds.
   Students should describe an experiment in which they soak seeds (of the same type, such as black beans) in water solutions of different pH. Students should indicate that they would change only the pH (the independent variable) using different buffers and would hold other variables constant (such as the number and kind of beans, the temperature and the length of time the beans are soaked).
3. What other factors might affect the rate of production of carbon dioxide gas by germinating seeds?
   Other factors that might affect the rate of production of CO_2 gas by the germinating seeds include temperature, size and type of seeds, the number of days soaked in water, and the age of the seeds.

10.0. Gas Production – Beans Free of Embryos:

Living organisms metabolically generate usable energy in the form of ATP from the oxidative breakdown of food molecules. During the biochemical processes, they use oxygen to breakdown the food molecules and release the energy stored in the chemical bonds of food into energy that cells can use. Gas in the form of carbon dioxide, as a by-product, is released. In the following learning activity students empirically test whether or not beans free of embryos can still be able to generate energy and gas.

Students are divided into groups and asked to:

1. Select #10 soaked beans.
2. using the dissecting knife and the twister, carefully remove the embryo from each bean including the epicotyls and hypocotyls – radical axis; use Figure 16 as an example.
3. Predict what will happen if you place the beans free of embryos in a small flask for a few days? Write down your predication.
4. Place the beans without their embryo (epicotyls and hypocotyls – radical axis) in a small flask.
5. Repeat all steps of Experiment V, Gas Production, at least 3-times to ensure accurate outcomes. Record you observations and final findings.
6. Upon complexation, each group of students are asked to answer the following questions:
    - Does your predication agree or disagree with your final finding? Explain why or why not?
    - If you have to re-design and re-do this experiment all over again, what and how would you do it, and why?
    - It has been said that sometimes we 'get gas' from eating beans, but not from eating peas. Do you agree or disagree? Explain why.
    - It has been said that sometimes we 'get gas' from eating beans, but not from eating seeds. Do you agree or disagree? Explain why.
    - How does your involvement in this activity provide evidence that you are already scientists?
    - Do you think scientific experimentation can give us insights into the generation of value judgments, and non-quantifiable information? Explain.
    - If you had to re-do this lab activity all over again, how would you do it differently and why?
    - What have you learned from actively engaged in this learning experiment?

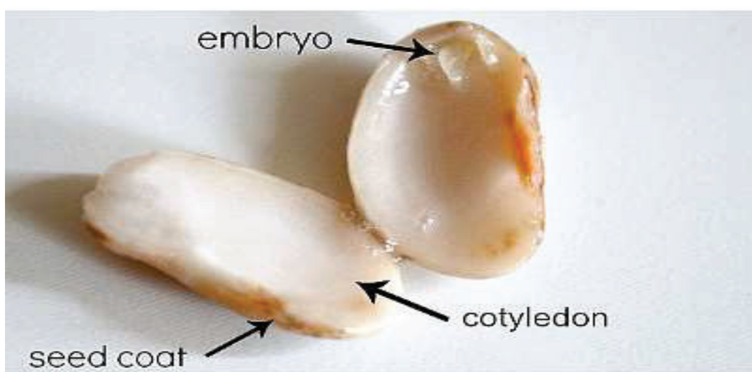

Figure 16: An embryo including the epicotyls and hypocotyls from a given bean

11. Acidity of Gas Production:

In simple terms, acids dissociate into H^+ and lower the pH value, while bases dissociate into OH^- and raise the pH value. With this in mind, acid gas is any product that contains a mixture of significant amount of gas or gases such as quantities of hydrogen sulfide (H_2S), carbon dioxide (CO_2), or similar acidic gases. However, many people confuse the use of acid gas and sour gas, and thus end using them incorrectly as a synonyms.

> *Strictly speaking, a sour gas is any gas that specifically contains hydrogen sulfide in significant amounts; an acid gas is any gas that contains significant amounts of acidic gases such as carbon dioxide (CO_2) or hydrogen sulfide. Thus, carbon dioxide by itself is an acid gas, but not a sour gas.* (https://en.wikipedia.org/wiki/Acid_gas)

In this learning activity students investigate the acidity and the alkalinity of the boiling bean solution. Divide the class into groups of 2-3 students, and ask the members of each group to:

1. As you are cooking a type of bean, and see gaseous bubbles begin, place a lid on the pot, and turn off the heat.
2. As the pot cools down, prepare to take the pH of the bean solution by obtaining pH strips and having them ready for use, sitting alongside the pot.
3. Carefully open the lid of the cooled down pot, and insert the pH strip. Write down the pH of this solution, as depicted by its color coordination to the proper pH value on the pH chart.

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4. Complete Steps #1-3 for each bean variety.
5. Lastly, boil water alone, let it cool down with the lid on, and check its pH using the following chart in Figure 17.
6. Before draining, divide the soaked bean in to equal portions.
7. Cooke one portion of the soaked beans for one hour in the same water in which they were soaked. Then measure the pH.
8. Drain the second portion of the soaked beans, add a fresh water and cook for one hour. Then measure the pH.
9. If time allows, to make a fair comparison, measure the pH of:
    a. Tap water at room temperature.
    b. Water after it is added to the beans at room temperature.
    c. Water after the beans soaked for 48 hours at room temperature.
    d. Boiled tap water after being cooled down.
10. Upon Successful Completion ask students to answer the following questions:
    a. Is there a significant change in the pH as a result of:
        i. Beans soaked in water?
        ii. Soaked beans cooked in the same water?
        iii. Soaked beans cooked in fresh water?
    b. Why do you think that it is important to put a lid on the pot, as you turn off the heat on the boiling beans in water?
    c. Did you notice any changes in pH between the different bean varieties?
    d. If you did not notice a change, can you suggest anything about the acidic or basic nature of the bean solution? Can you suggest that there is a common gas released by all beans?
    e. What was the purpose of boiling water alone, void of beans, and taking its pH as you had done for the cooking of the beans in water?
    f. If you have to re-design and re-do the experiment all over again, what, and how would you do it and why?
    g. What have you learned from actively engaged in this learning experiment and activity?

Figure 17: pH Chart.

Table -8- The pH In Various Stages of the Experiment

	Experiment Stage	pH	Additional Observation
1	pH of tap water.	7.0	
2	pH of boiled and cooled down tap water.	7.0	
3	pH of tap water after immediately adding it to the beans.	7.0	
4	pH after the beans soaked in the tap water for 24 hours.	6.5	
5	pH of the solution of the beans cooked for one hour in the same water in which they were soaked.	6.5	
6	pH of the solution of the beans which was drained and cooked in fresh water.	6.5	

Note: To determine pH measurement at a very precise level, one could use a pH meter that minimally goes out to the first decimal place. Otherwise, with use of traditional pH strips, the change in pH will be subtle, as viewed by the color change; thus, one would get a pH variation, but it may be slight, which could frustrate learners. But, if a spectrophotometer is available (such as the long standing, Spec 20©, one could determine the color intensity difference if the shades are two close for the eye to discern). In this case, a few drops of a universal indicator solution can be added to the solution to be tested. Shades of blue, for example, could be differentiated and a more accurate determination of the pH can be determined. Students can then draw a correlation between the increase in color intensity and the acidity or basicity of the solution (s).

12. Extended Inquiry Suggestions

Students who always like to have additional challenges and/or additional homework for extra credit, can be asked to undertake one or more of the following extended inquiry investigations.

1. Try to put the beans directly in the limewater (soaking them in the limewater) and see what happen. Make notes concerning this occurrence, and share with your teacher and classmates.
2. Design and perform an experiment to test ideas such as:
    a) Certain bean types taking in more water than others.
    b) Temperature variations and the possible effect on the taking in of water by one bean type, or all bean types.
    c) Adding salt to the water to see if there is any decrease or increase in water uptake of one bean type, or all bean types.
    d) Differentiation in water uptake with beans that are void of their seed coat (leaving just the embryo and the cotyledon intact) versus those with their seed coat. This again, can be done with beans of one type, or all types.

13. Critical Thinking and End-of-Session Discussion Questions:

1. Why do you think beans and peas are grown everywhere that people are able to farm?
2. Why do you think beans are technically a fruit?
3. Why some legumes such as peanut, soy nuts, and carb nuts are called legumes? What differentiates between, for example, peanut, walnuts and almonds?
4. Why do you think beans are a good source of protein?
5. Finally, upon completion of your experiments, answer the following questions:
    a. Were you able to generate a number of hypotheses?
    b. Were you able to eliminate most of your generated hypotheses using logic and reasoning before you selected the final hypothesis that needed to be tested empirically?
    c. Were you able to repeat the experiments for each hypothesis?
    d. Were you happy or disappointed that you were: (i) Able to disapprove your hypotheses? Explain. (ii) Not able to disapprove your hypotheses? Explain.
    e. What does "peer reviewed" mean? Why do you think the process of peer review is important in a scientific endeavor?
    f. Did you submit your scientific paper to your classmates and teacher? And, did you successfully communicate your findings to the scientific community consisting of your teacher and classmates?
    g. If your answer in question "f" is yes, was your paper:
        i. Accepted without revision? Explain why, in your opinion.
        ii. Accepted with revision? Explain why.
        iii. Rejected for publication? Explain why.
6. Why do scientists try to disprove, rather than prove, a given scientific discovery, hypothesis and/or theory?
7. What have you learned from engaging in this learning activity, both via conducting the laboratory experiment(s) and in writing the paper?
8. Distinguish between hypothesis and theory.
9. Explain how the design of an experiment can affect the quality of the outcome of testing a given hypothesis.
10. Explain how the repeatability of experiments in science can decrease our skepticism in, and increase our acceptance of, the outcomes and conclusions of science experiments and discoveries.
11. Seed dormancy is defined as a state in which seeds are prevented from germinating even under normal favorable environmental conditions for germination.
    a. What is the cause of seed dormancy?
    b. What role does dormancy play in plant seeds and germination?
    c. How does the phenomenon of seed dormancy have contribute to the development of humanity and civilization throughout the human history?

14. After Session Homework Questions

Protein in most legumes is incomplete when it comes to the number of the types of the amino acids contains except one. Conduct internet research to find out which legume this is. Then find out what, if any, is the disadvantage and the advantage of this bean in comparison to the other types of beans.

- What should you look for when you buy packaged legumes?
- In addition to beans, what are the other gas-producing foods that should be avoided when eating beans?

- Compare and contrast various types of canned backed beans in terms of calories that comes from fat: vegetarian backed beans, backed beans with franks, and backed beans with pork.
- When soaked, dried legumes expand, on the average, to two to three times of their size?
  Conduct internet research to find out what type of potentially toxic substances various types of beans might have and how to deal with them?
- Beans are rich in proteins and other nutrients which make them desirable items for food and human consumption. Proteins are "essential to health and normal body function because they are part of body structure, regularity enzymes, and hormones. Research however has indicated that eating too much of high-protein diet or to low-protein diet can be unhealthy and leads to serious health consequences. Conduct internet research to find out the consequences of consuming too much of high-protein diet and low-protein diet on human health.
- Conduct internet research to find out the relationship between legumes, grain, and nitrogen.

15. After Session Research Inquiry Questions and Investigation:

Conduct Internet research to find out:

1. Why beans have been neglected by many people as a good source of food and diet?
2. Why been is considered good for lowering cholesterol, and good for combat heart disease, stabilizing blood sugar, reducing obesity, relieving constipation, diverticular disease, hypertension, and type II diabetes, and lessening the risk for cancer.
3. Why it has been advised that to introduce beans to someone a new as a source of food, is to use low-self-canned beans instead of cooked dry beans?
4. Why it has been advised that in using canned beans, it must be put in strainer and rinsed with cool water for several times before eating.
5. Why it has been advised to consume beans not only with meat but even with plants that contain proteins? (hint: Lysine).

16. Final Remarks:

Our experience with conducting this laboratory exercise has shown that students really enjoy the challenges of performing lab experiments with a purpose in mind. In addition, students find the process of preparing and writing scientific papers, and the experience of submitting scientific papers for publication, to be a worthwhile educational experience. As one student put it, "it makes me a better student in terms of organizing my thoughts, solving problems, writing my term papers, and appreciating science, what scientists do and endure in the realm of doing science and achieving scientific discoveries." In short, students understand what characterizes scientists from nonscientists, as well as gaining knowledge to distinguish scientific from non-scientific claims or proposals. They also learn that "the objectivity of science lies in its willingness to subject every aspect of the hypothesis to rigorous testing, [and] if the predictions derived from the hypothesis are not confirmed by experiment, the hypothesis is rejected and a new model sought" (Bowler, 1993, p. 17). This is because, using Margulis' and Sagan's words (2001), students understand that "science is an intensely social activity, a group enterprise based on observation and consensus, methodical checking and rechecking, it compensates for limited individual perception and cultural superstition. [And as well], science admits occasional flashes of insight with which a new, more fruitful way of looking at the world is transmitted first to scientist and eventually to their public" (p. xii).

17. Acknowledgment:

We would like to acknowledge the help of those teachers who reviewed our activities, tried them in their classrooms, and provided us with the valuable feedback. It is their recommendations which made this set of proposed activities pedagogically more useful and effective, in order to help students learn, master, and apply the intended learned concepts and principles. For all of you Thank You.

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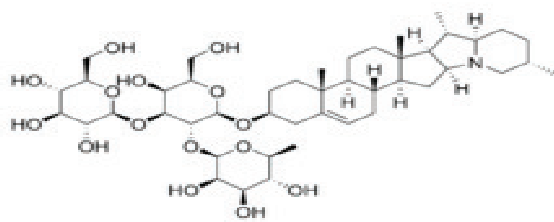
19. Appendixes

This section of appendixes is more for teachers than the students. We included additional ideas, information, activities, and questions and answers of those most likely students might ask during the process. In doing so, we aim to save time and energy for those teachers who wish to use and or adapt the suggested laboratory learning activities with beans for conceptual changes.

Appendix 1: Foams in Beans

Legumes are rich in substance called 'saponins'. Saponins are "a class of chemical compounds found in particular abundance in various plant species such as legumes, soapwort and soapbark which produce a soapy solution when shaken in water (Gemede, and Ratta, 2014; Lawrence, 2011). More specifically, they are amphipathic glycosides grouped phenomenologically by the soap-like foaming they produce when shaken in aqueous solutions, and structurally by having one or more hydrophilic glycoside moieties combined with a lipophilic triterpene derivatives" (Wikipedia, 2017, ¶.1). With this in mind, we can infer that the foam is water that happens to trap air bubbles because of its physical properties.

Chemical structure of the saponin solanine



Saponin has bitter tasting and produces foam when shaken in water. It also believed to have medical benefits

https://en.wikipedia.org/wiki/Saponin

Saponins are structurally complex, and have particular physical, chemical and biological properties. They are known for foaming and in addition for their sweetness; for these reasons, you see their use in beverages and sweets. As well, they are antimicrobial, insectidal and molluscicdal; for these reasons, saponins are used highly in the cosmetic and pharmaceutical industry. And it is their lipid-soluble aglycome and water soluble sugar chains that allow for their ideal use in the detergent industry. They act as transitory chemical molecules due to their nonpolar and polar end which helps with wetting, emulsifying and foaming. (Gemede, and Ratta, 2014, p. 286).

Appendix 2: Acid Gas, Sour Gas, Bases, and Salts

Any product that contains a mixture of significant amount of gas or gases such as quantities of hydrogen sulfide (CO_2), carbon dioxide (H_2S), or similar acidic gases. However, many people confuse the use of acid gas and sour gas and thus end using them incorrectly as a synonyms.

Strictly speaking, a sour gas is any gas that specifically contains hydrogen sulfide in significant amounts; an acid gas is any gas that contains significant amounts of acidic gases such as carbon dioxide (CO_2) or hydrogen sulfide. Thus, carbon dioxide by itself is an acid gas but not a sour gas. (https://en.wikipedia.org/wiki/Acid_gas)

1	Acids	Substances which produce hydrogen ions in solution	Dissociate into H^+ and lower pH
2	Bases	Substances which produce hydroxide ions in solution	Dissociate into OH^- and raise pH.
3	Neutralization	Hydrogen ions and hydroxide ions react to produce water	$H^+_{(aq)} + OH^-_{(aq)} \longrightarrow H_2O_{(l)}$
4	Buffers	Absorb the excess ions to maintain pH.	$CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}$
5	Salts	Ionic compounds	$Na^+ + Cl^-$

Appendix 3: Statistical Testing

Statics is the science that uses mathematics to evaluate and compare data. It is these statistical methods that allow for summarizing data and finding averages, means, or medians. With the many tests in this field, one can generate greater ideas, more akin to the truths in reality. One uses these to generate the most logical truth for a certain population or idea (Belk and Maier, 2016, p. 17).

	
A little variability, but high probability of reflecting average of all beans in each given sample.	A high variability but low probability of reflecting average of all beans in the sample.

Looking at sample "A", "B", and "C" individually in the Figure 16 below, we can see that the size of various beans in sample "A" is closed enough to each other. This is the same for sample "B" which contains small size of beans. However, the size of various beans in sample "C" is significantly varied from each other. Therefore we can infer that in both sample "A" and sample "B" individually, each has a little variability, but high probability of reflecting average of all beans in the sample. On the other hand, sample "C" has a high variability but low probability of reflecting average of all beans in the sample. In short, statistical tests calculate the variability within samples to determine the probability that two samples differ only by chance (Belk and Maier, 2016).

Appendix 4: Anatomy of a Seed

It is safe to conclude that beans have been growing and cultivated everywhere that people farm. Indeed, they are one of the earlier and most cultivated crops world-wild (Wood 1999). Today, in the United States,

> *Michigan is the leader in the United States for the production of the most dried beans whereas California is the leader in dried lima beans production. And it is Palous, near eastern Washington and northeastern Idaho, that many dried peas and lentils are grown. The US sends many of the beans produced to India, South America, and Europe.* (Margen 1992, p. 347)

Beans are seeds, and seeds are dormant living entities that can remain dormant for years until the right conditions are available for them to germinate, including receiving enough water and oxygen to grow. A given seed contains an embryo that is surrounded by a food store for nourishment during germination, with an outer hard seed coat. The embryo plant in the seed "has either one or two leaves called cotyledons. A dicot has two embryo leaves, and a monocot has one embryo leaf. The cotyledons are used as a food supply while the roots and foliage develop. (Margen 1992, p. 156). For most seeds, including beans, "germination involves imbibitions, or soaking in enough water to make the seed swell and break its coat. This rehydration stimulates the production of enzymes that 'wake up' the embryo" (Margen 1992, p. 157).

Appendix 5: Gas and Flatulence Caused By Eating Beans

There is no doubt that eating beans can cause gas (flatulence) at least for some people, especially those who don't have enough experience in how to cook beams. There is however a good reason for that. Beans are high in fiber, which is beneficial for our digestive tract, but it can also cause gas. In addition, most beans contain raffinose, a trisaccharide sugar that requires specific enzyme to digest, and unfortunately, we lack the needed enzyme to digest raffinose. Thus it passes easily through to our large intestine. Our digestive system doesn't really digest fully everything we eat and thus so often indigestible matter remains in the intestine. Bacteria which inhibits our large intestine attack and break down indigestible matter causing the flatulence in some people.

The sugar "Raffinose" can be broken down by enzyme called alpha-galactosidase (α-GAL), which is the active ingredient in Beans which many people buy and use to prevent flatulence and Stomach cramps that might result from the movement of the gas (Branch, 2014; Cherif, Jedlicka, Hornick, Verma, and Aron, 2010). However. Pratt and Matthews (2005) have good tips for beans lovers for reducing any discomfort associated with eating beans:

- *Some people find that canned beans as well as massed beans are less gas producing.*
- *If you eat beans frequently in small amounts, your body will become accustomed to them and you'll reduce any digestive problems.*
- *Soak the beans before cooking: rinse and pick over the beans, then boil them for two or three minutes. Turn off the heat and let them soak for a few hours. Pour off the liquid, add fresh water, and continue cooking. This boiling and soaking releases a large percentage of the indigestible carbohydrate in the beans, making them easier to digest. Even though some vitamins are lost to this method, if it allows you to enjoy beans, it's to your benefit.*
- *Some people find that pressure-cooking beans reduced their gas-producing qualities. It also considerably speeds the cooking process.*
- *Try using Beano, an enzyme product that helps reduce the gas associated with foods like beans. Put a few drops of the product on the first bites of the food. It goes to work digesting the carbohydrates that would have fed the gas-producing bacteria."*

(Pratt and Matthews 2005, p. 38-39)

Furthermore, other studies "show that soaking beans for 12 hours or germinating them on damp paper towels for 24 hours can significantly reduce the amount of gas-producing compounds. In fact, soaking followed by 30 minutes of pressure cooking at 15 pounds per square inch reduced the compounds by up to 90 percent in one study" (Home Remedies, 2002, p. 312).

Appendix 6: Why Beans Are Good for Lowering Cholesterol?

Beans in general are among the best foods to eat for lowering cholesterol because they contain very high level of soluble fiber. This is important because soluble fibers have the ability to trap cholesterol in the intestine and helps keep it out of the bloodstream.

	Beans	Grams of fiber in a half-cup serving
1	Lentils	8 grams
1	Black beans	7 ½ grams.
3	Pinto beans	7 ½ grams.
4	Lima beans	6 ½ grams
5	Kidney beans	6 ½ grams.
6	Black-eyed peas	5 ½ grams
7	Chickpeas	4 grams

*(Home Remedies, 2002, 415; Pratt and Matthews 2005, p. 44)

Appendix 7: Example of Data Gathered in One of the Laboratory Experiment

The table blow shows an example of data gathered in one of the laboratory experiment by students in a college nutrition class investigation beans.

Bean Type	DATA: Bean Experiment					Bean Name
	Number of Beans	Length (mm)	Width (mm)	Volume (mL)	Weight (g)	
Bean #1						Mark Beans
Dry	20	24.28	14.29	23.2	26.3475	
Soaked	20	28.37	16.10	76.0	63.5630	
Bean #2						Chickpea
Dry	20	10.95	8.72	8.0	8.6467	
Soaked	20	13.62	10.38	14.0	16.7445	
Bean #3						Fava Beans
Dry	20	21.29	15.81	28.0	29.0478	
Soaked	20	24.26	18.06	38.0	32.9741	
Bean #4						Christmas Lima Beans
Dry	20	22.94	13.71	22.0	24.5986	
Soaked	20	31.00	18.22	56.0	27.4722	
Bean #5						Giant Peruvian Lima Bean
Dry	20	26.00	16.04	32.0	38.5230	
Soaked	20	33.70	20.24	68.0	38.6909	
Bean #6						Red Kidney Beans
Dry	19	17.62	6.69	8.36	11.9025	
Soaked	19	21.28	10.36	20.9	24.7493	

- A count of 20 beans were weighted before and after soaking. The balance types used was OHaus (d. 0.0001g)
- A count of 5 beans were used to determine volumes in each case - dry beans and soaked beans. Depending on the size of the bean type I used a 50 or 100 ml graduated cylinder. Students multiplied 5x results and recorded that as result for 20 beans. For example: Bean#6 (20 count) used 5 to determine volume. Multiplied result by 5 to get value for 20 beans. There was one case where only 19 beans were in total. The students made math adjustment to get results for 19 beans.
- A count of three beans in each case was used to obtain measurements - width & length of beans. Students made effort to select representative samples in each case - dry and soaked. They recorded the average in each case here to be good estimate. They used 0-6" (150mm) Digital Caliper for taking measurements.

Appendix 8: Complementary Food Combination

Students are given a copies of the following table but with only the first column is filled with the needed information (Food with limited amino acid). Students are asked to search for and complete the other three columns with the needed information (Foods high in limiting amino acid, Complementary food combinations, and Pictorial food combinations).

Table -11-
Complementary Food Combination (Cherif, et.al, 2010, p. 219)

Food with limiting amino acid	+	Foods high in limiting amino acid	→	Complementary food combinations	Pictorial food combinations
Legumes: *Limited in methionine and cysteine*	+	***Grains,*** ***Nuts and seeds***	→	• *Rice and lentils* • *Red beans and rice* • *Rice and black-eyed peas* • *Hummus (garbanzo beans and sesame seeds)*	
Grains: *Limited in lysine*	+	***Legumes:***	→	• *Peanut butter and bread* • *Barley and lentil soup* • *Corn tortilla and beans*	
Vegetables: *Limited in lysine, methionine, and cysteine*	+	***Legumes*** *(lysine)* ***Grains, Nuts and seeds*** *(methionine and cysteine)*	→	• *Tofu and broccoli with almonds* • *Spinach salad with pine nuts and kidney beans*	
Nuts and seeds: *Limited in lysine and isoleucine*	+	***Legumes:***	→	• *Sesame seeds with mixed bean salad* • *Lentil soup with slivered almonds*	

Appendix 9: Various Types of Graphs and Charts and Their Better Use
Appendix 9 lists the graph / chart types. The second column shows examples of uses for each respective graph that the students should discover with their research and then select which one they want to use and why. The third column is for students notes for the discussion of appropriate applications for each type (Cherif, Harris, and Murphy 2018, p. 48)

	Graph /Chart Type	Use This Type to:	Applicable example:
1	Line	Show tends over time (years, moths, and days, or categories)	
2	Bar	Visually compare value cross a few categories when the chart shows duration on the category text is long. It is an ideal way to analyze distributions and measurements of central tendency such as mean, median, and mode.	
3	Pie	Show populations of a whole by illustrating percentages of a whole or to numerically represent a category of facts with distribution of values within one field of a database. Use it when the total number is 100%.	
4	Bubble	Show the relationship between sets of values.	
5	Column	Visually compare values a cross a few categories	
6	Area	Show trends over time (years, months, days) or categories. Use it to highlight the magnitude of change over time.	
7	Combo	Highlight different types of information. Use when the range of values in the chart varies widely or there are mixed type of data.	
8	Pivot	Graphically summarize data and explore complicated data.	
9	Venn	Show relationships between mathematical sets by identifying and showing the commonalities and differences between things, people, places, historical events, ideas or physical attributes based on their characteristics.	
10	Axis or Scatter	Investigate correlations and examine relationships between the variable.	
11	Stack or sorting bins	Show the distribution of values within one field of a database by representing a range of data for one variable.	

Appendix 10: Few Selected Questions and Answers
Questions and Answers that teachers could use in class discussion (Note that a few question are purposely left without answer to elicit room for teacher self-discovery).

1. It has been stated that “it is better to overcook beans than to undercook them” (Berry and Fabricant 1999), Why do you think so?
2. Why we have been advised of not using a pressure cooker in cooking beans?
   If one uses a pressure cooker in the cooking of beans, it is likely that foam and debris accumulation will hurt the apparatus. In addition, one cannot really gauge if the cooking of the beans is complete, for it is difficult to get to the needed pressure to cook the beans, and then just turn it off. You will not be certain the beans are tender to eat. (Berry and Fabricant, 1999, p. 25)
3. Why we have been advised of not adding salt and or acidic matter while we are cooking the beans?
   Always add salt and acid at the end of the cooking process. Otherwise, you may end up with beans that are cooked, but lacking in tenderness unless you cook them for a very long time. (Berry and Fabricant, 1999, p. 25)
4. Why we have been advised that, if we have the time, and it is possible, we should cook beans without soaking?
   It is a greater benefit nutritionally to NOT soak the beans. Certain beans, such as lentils, adzuki beans, flageolets, rice beans and split peas will have their amino acids degraded if soaked for prolonged periods of time. (Berry and Fabricant, 1999, p. 24)
5. What is the best way to cook beans?
   According to Elizabeth Berry’s Great Bean Book, there are two basic methods for cooking beans. One involves a more extensive cooking method, whereas the other is considered a ‘quick soak method’.
   The more extensive method consists of the following procedure:
   - *Covering the beans with water (about 2 inches in height) for a minimum of 4 hours.*
   - *Follow with the draining of the beans, placing them in a pot, and bringing them to a boil.*
   - *Once boiling has been reached, reduce the heat and allow for continuous simmering. The purpose here is to tenderize the skins of the beans, and may require 30 minutes to 3*

hours of time. As a side note, always be watchful of your beans cooking. Because of the simmering over such a long amount of time, one may need to consistently add water.

The quick-soaked method involves bringing the beans to a boil, followed by two minutes of cooking. After this, let them soak for one hour. Follow with removal of the water, addition of new water, and subsequent cooking once again as in the extensive cooking method noted above. (Berry and Fabricant, 1999, p. 24)

6. Throughout human history, the ancient farmers and modern ones have been planting and eating beans and gains. They found a way to combine beans and grain in their diet, such as rice and lentils, succotash of corn and limes, and couscous with chickpeas, to name a few. Today, we know that this combinations of grains and beans are very healthy and essential for healthy diets. What type of explanation can you provide to justify this essentiality?

   Grains and beans each provide the needed components for what is called a 'complete protein'. Amino acids, specifically tryptophan and lysine, are found in beans, but not grains. Thus, when bringing both grains and beans together in a standard diet, one is certain of generating the very crucial 'complete protein'. It is this 'complete protein' that supports life and growth for a human being. (Berry and Fabricant, 1999, p. 8-9)

7. It has been said that those farmers who, for example, plant beans, corn, and squash intermingling in the same plot of land, are practicing sound agriculture. Did you agree or disagree with this claim and why?
8. It has been advised to not soak or cook beans in salt and acid rich water. Conduct internet research to find out the reasoning that could be used to support or refute this culinary advice?

   When one uses salt and any type of acidic product, there is most certainly a toughening of the beans' skin. Because of this, the beans do not reach a state of tenderness. That is the main reason why these should not be added at the end of the cooking process. (Fabricant, 1999, p. 25).

9. What is the purpose of soaking beans before cooking?

   The mean purpose for soaking beans before cooking is to rebuild the moisture balance that is lost during the processes of drying and maturing. However, you can cooking dry beans without soaking them first, but it will take longer time and more energy. Some dry beans such as lentils which contain high amount of protein, fiber, and folate, do need to be soaked before cooking.

10. Why do you think it has been stated over and over again that "without beans, a vegetarian diet, like the regimens required by Jainism and Buddhism, would be impossible to maintain"?
11. Why do you think, it has been advised that when you eat meal made from legumes, it is better to also include bread or other food made from grains in the meal? Explain

    Answer for Q. 10 & 11:

    Of all the vegetables known, beans have the highest consistency of protein. It is the breakdown of the proteins into its component parts, the amino acids that human beings need in their diet. Nine amino acids are considered essential, and the only means of supporting their attainment is in one's diet. Soybeans provide all the nine amino acids, whereas legumes only provide eight, missing methionine. But if one ingests grains in their diet, though lacking tryptophan and lysine, they will obtain the needed nine essential amino acids. Fabricant suggests this is the main reason one sees the 'age-old partnership of grains and legumes (*Fabricant,* 1999, 25-26).

12. Why do we soak beans before cooking them?

    The soaking of the beans is a necessary occurrence in that it prepares and aids in efficient cooking of the beans. They are composed of oligosaccharides, carbohydrates that rarely were looked at in biochemistry, until it was noted that these particular substituents were crucial in cell recognition and binding, especially in immune responses. These need to be broken down into their monosaccharide component parts. By soaking them, we are fostering this break down into the component parts. We need to discard the water, for some of the oligosaccharides leach out of the beans. This is not healthy for consumption Wikipedia 2017)

13. What are the many ways people have been using to reduce the gas generated as the result of eating beans or diets with beans?

    According to Fabricant, the Beano product contains the necessary enzymes to support the processing of beans and generate reduction in the formation of gas. As well, there are other effective means of reducing gas occurrences. These include, using the herb epazote and Kombu, which is a type of kelp. Also, fennel seeds is a method used in India to reduce gas elicitation (1999, 27).

You may wish to direct your students to Michael Sweeney (2016) book "*Complete Guide to Brain Health*", David Perlmutter's (2015) book "Brain Making", and or "National Geographic" magazine, February 2014 issue, or any of the references in the appendix 2, to read as part of your class discussion.

14. Why do most of not all Legumes have high content of proteins?

    The high protein content of many legume is due to their endosymbiotic association with nitrogen-fixing *bacteria (Rhizobium spp.) in their root nodules. These bacteria are able to convert free atmospheric nitrogen into a form that can be used by plants in making of protein and other nitrogen-containing compounds. Specifically, nitrogen fixation converts the unusable N2 gas into ammonium (NH4+), which the plants can incorporate in the synthesizing of proteins" Because of this, Legumes are also used as green manure to enhance soil fertility. (Levetin and McMahon, 1996, p. 195 & 203)*

15. Why when talking about beans, especially peanuts (groundnuts), the African American professor George Washington Carver (1864-1943) stands out historically, academically, commercially, and agriculturally?

    George Washington Carver has been credited for being single-handedly responsible for developing the peanut as a major crop and crop product in the United Stated in the post-Civil War in the south of the U.S.A. Because of him, peanuts have gained especial place in the American diet and opened the door to many more potential uses of peanuts.

16. What is Quinoa and why many vegetarians love to eat?

    Quinoa is neither a gain nor legume. It is simply a mild herbaceous (gluten-free) plant that is rich in protein content (8 grams per cup). It is also cooks quickly and easily adopts other flavors. These are a few of the reasons that attack vegetarians and others to adding quinoa to their diet.

17. What is Tofu and how is made?

    Tofu is a white, cheese-like food made from soybean milk that is curdled with nigari or calcium sulfate and shaped into blocks. Since it is made from soybean, it is rich in protein and believed to help keeping weight off better than any other fruits or leafy green vegetable. It is also believed to have healthy benefits that could support the colon and lung system (Wood 2005; Pratt and Mathews,2005)