Identify the area of biology you know is frequently difficult for students:

“Science is a way of thinking much more than it is a body of facts”
Carl Sagon, PHD

Science education is not only teaching content, but also the process of scientific work. Students have difficulty doing experiments involving control of variables. Instruction to help students understand their own learning process will allow them to demonstrate their understanding in a way that would enhance transfer of learning. To establish the connection between science and design, students need to see how building and testing their design is related to scientific method (Holbrook & Kolodner, 2000).

Rationale:
A study done by David Klahr, a psychology professor at Carnegie Mellon and Milena Nigam from University of Pittsburgh showed that students who were taught how to design experiments and control variables learn better (77%) than students who were asked to conduct open-ended inquiries (23%) without teacher guidance. The evidence showed that when the teachers provided “direct instruction” to teach students experimental design process, students were able to control variables more successfully than students who were asked to do it on their own. The Control Variables Strategy, according to findings from Klahr's research, is "the skill that allows scientists to design unconfounded experiments and to draw valid conclusions from experimental outcomes." Good experiment design is a skill essential to all forms of scientific inquiry and one that, according to Klahr, is not effectively learned through exploration. Direct instruction is necessary to the teaching of this concept. According to Gerry Wheeler, a former nuclear physicist and currently the executive director of the National Science Teachers Association, when dealing with misconceptions, direct learning sometimes has little or no effect in overcoming the misconception. "When you directly tell the learner something that contradicts their misconception, it has no impact," says Wheeler. "If you try to do straight explanatory when talking density with a fifth grader, odds are they won't get the concept. If you don't let them explore, they don't get it." But if you don't explain the concept and the formula (mass divided by volume, and the fact that mass isn't weight) then all their exploring may or may not lead to comprehension, especially when dealing with students below sixth grade. "Some topics are rich in misconceptions," Wheeler says. A good science teacher has to again range up and down that spectrum of techniques, using both direct instruction and exploratory learning to get the concept across.
Audience:
Fifth grade students at the Penn Alexander School. Penn Alexander is a neighborhood public school in West Philadelphia. The school’s site is a city block with a park-like setting and serves as a center for community activity. The student body reflects the rich diversity of the school’s neighborhood. Representing more than 19 countries and speaking many languages. The small class size is optimal for teaching and learning with a student-to-teacher ratio 23:1 in 5th grade. This activity builds upon a third grade unit these students encountered in third grade, Plant Growth and Development in which students build upon their understanding of plant life cycle as a vehicle for experimentation. The main objective is to teach students how to design and conduct controlled investigative experiments. From here they will be studying ecosystems and using what learn from controlling variables to develop observational skills in a bigger system.

Enduring Understanding:

Students will develop an appreciation of the need for careful and precise design of experiments and the scientific method is an iterative process, with refinement of hypothesis.

Students will develop an interest in investigating plant growth and understand all living things have to solve the same basic problems, but they solve them in different ways.

Standards:

3.2 Inquiry and Design
C. Recognize, identify, and use the elements of scientific inquiry to solve problems.
   • Design an investigation with limited variables to investigate a question.

3.3 Biological Sciences
B. Know that living things are made up of parts that have specific function.
   • Determine how different parts of living things work together to make the organism function

Background Information:
Scientists use an experiment to look for cause and effect relationships in nature. To do this they design an experiment so that changes to one item cause something else to change in a predictable way. These changing quantities are called variables. There are three kinds of experimental variables; independent, dependent, and controlled. The independent variable is the one changed. The dependent variable changes in response to the change or is caused by and depends on the value of the independent variable. Controlled variables are quantities that remain constant, most experiments have more than one controlled variable. A testable question can often be written in the form, “How does __________ affect __________?” The blanks represent the independent and dependent variables. A testable question can lead to experimentation that can be done in the time provided with available resources, and in a safe manner. A testable question can be generated from a non-testable question by scanning the question for possible variables.
that can be tested. A student may ask, “Why do some plant live and some die in my house?” By listing the variables involved with plant growth like light, fertilizer, water, etc, the non-testable question can be changed to, “What is the effect of light on plant growth?” Frequently, changing the question words “why” or “How” into “what” is necessary to turn a question into a testable one.

To help students develop an interest in investigating plant growth Dr. Paul Williams a plant pathologist at the University of Wisconsin spent about 15 years developing the Wisconsin Fast Plant (Brassica rapa) through selective breeding. He was able to speed up the development process. The plant goes thru a cycle of seed to seed in about 36 days. What also makes these plants special is the seeds are small, grow in crowded conditions, grow well under constant light, and produce a large number of pollen legs and fertile seeds. The plant cycle germination, plant growth, flowering, pollination, fertilization and seed pod development then seed maturation and dispersal. Germination is the starting point, where the plant seed is placed under conditions that will start the seed, which is the reproductive structure of a plant that includes outer seed coat, an embryo, and nutritional tissue for the embryo. After the seed is planted the encasement around the embryo separates and makes its way thru the soil this is the beginning of plant growth. The parts of the plant that grow are the roots, stem, branches, leaves, flowers and fruit. Roots hold plants up and suck up water. Stems hold plant towards the sun. Branches hold leaves outward to get more sunlight. Leaves receive suns energy and light to make food. Flowers attract bees to get pollen and make seeds to make new plants. Fruit is the part of the flower that protects seeds and gives them food until they grow. The flower is the reproductive part of the plant. Flowers are made up of four parts, sepal, petals, stamen, and a carpel. The sepals are the structure that protects the flower before it opens. The petals are the colorful structures that attract pollinating animals. The stamen has a long slender filament topped by the anther these contain sperm bearing pollen grains. A carpel structure is composed of the stigma, the tip, the style, a slender tube that holds stigma up, and the ovary, the area where fertilization of female eggs and the beginning of plant embryo take place. Pollination is the transfer of pollen by wind, animals, or other means to a plant’s female reproductive structure. Fertilization is the fusion of two gametes to form a zygote. In seed development the female gametophyte, the embryo sac, is surrounded by ovule tissue called integuments. These will now develop into a seed coat that will protect the embryonic plant until it germinates into the ground. The cycle then continues with seed dispersal.

**Structure of the Lesson:**

**Big Ideas:**

1. Plant growth and number of seeds produced by a single plant is affected by such variables as nutrients, light, water, and extent of pollination.
2. Controlling variables enables the effect of each variable to be identified and studied.

Prior Lesson
Students brainstormed the day before on: What are the variables that determine how well Wisconsin Fast Plants grow? What are the criteria of a fair test? They read an article about the best conditions for growing Wisconsin Fast Plants. Students mentioned some of following for good experiment:
* The researcher develops a good plan.
* The topic chosen is interesting and worth doing.
* The researcher gathers information on topic.
* The researcher makes careful observations.
* The researcher keeps good records.
* After collecting data, researcher draws conclusions based on results.
* The findings of experiments are communicated.

Objectives:
1. Students learn more about variables that affect plant growth.
2. Students learn how to conduct experiments using these variables.
3. Students understand what constitutes a fair test by understanding the differences between independent variables, dependent variables, and controlled variables.
4. Students use planning outlines to design their experiments.

Materials:
For each student:
1 student notebook
1 Planning Outline worksheet

For each four-member team:
1 Outlining the Team’s Experiment worksheet
Scissors
Paper

For the class:
1 large sheet of newsprint
Set of markers
Overhead projector, screen, transparencies of student activity sheets, and markers
Blank index cards for variables

Procedures:
1. Start with asking the class, “Why do some plants live and other plants die?” and record students’ ideas.
2. Explain to students that the things your houseplant needs are called variables.
3. “What are all the variables that the Wisconsin Fast plants need to grow?” (The day before students read an article about the variables of Wisconsin Fast Plants.) Record each of the variables. The list should include light, water, fertilizer, space, soil, and temperature.

4. Discuss how each of these variables meet the needs of the plants’ growth and the experiments they will be designing demonstrate that changing one of these variables causes an effect on plant growth.

5. Experiments must be organized in a testable way. To do this setting up a plan and understanding the cause and effect part of the plan helps scientists learn more about plant needs.

6. Using the overhead transparency of the planning outline, demonstrate what each student’s Planning worksheet will look like. First, set up the board in a way it would look like for a control plant.

7. Then set up the Planning board to illustrate how it would look for an experiment testing the variable of light.

8. Have the students break up into their teams. Each team will have 16 plants with which to work. Half the plants are the control plants, and half will be the experimental plants. Groups will follow the directions on group worksheet.

9. As the groups are working to design experiment circulate around the room and ask: Which variable would you like to change? What is that called? Why do you think that would make an interesting experiment? What might happen to the plant if you changed that variable?

10. Bring class back together to share out their experimental designs. Students need to emphasize independent, dependent, and controlled variables in their plans.

Teacher Notes:
Plants need four things to grow healthy: water, sunlight, carbon dioxide, and nutrients. There are many different nutrients plants need, but nitrogen, phosphorous, and potassium are the main kind needed to enhance plant growth. These nutrients are found in the fertilizer pellets used in the fast plant kit. For successful growth these plants need to follow the planting procedures recommended by the company that developed them.

Concerning effects of:
Light: The cycle of the Fast plants depend on continuous lighting, changing that system will cause the plants die.

Water: The cycle of the Fast plants depend on continuous watering, changing that system will cause the plants to dry out and die.

Soil: The soil used in the fast plant kit is especially formed to enhance growth of this particular seed using different soil will change results from no growth to smaller plants depending on the soil content.
Fertilizer: Growth of plants are enhanced by fertilizer pellets, not enough effect growth size, and too much will cause death.

What comes next?

For the next two days students will reflect about the topic the decided to test. The will begin to do research and learn more information on their topic so they can begin to create a hypothesis. Lessons on the importance of repeating experiments and how to average findings will be taught during this time. The group self evaluation sheet will be used the next day for students to start reflecting about their project and access their understanding of variables before they start researching. The scientific method quiz and Bill’s Pills scenario is the end of the unit assessment.

Resources:
http://www.sciencebuddies.org/mentoring/project-variables.shtml
http://www.acesesxcellence.org/LC/TL/filson/lab.html
http://www.nabt.org/sub/position_statements/laboratory.asp


Planning Work Sheet

Name: ______________
Date: ______________

What we think will happen (hypothesis):

The variable we will test:
Independent Variable (cause)

How we will test the variable (procedures):

The variables we will not change:
Controlled Variables:

The Dependent Variable:
What will be measured as the change? (Effect)
Directions for using the Planning Work Sheet

Group Name: __________________________
Date: _________________________________

Directions: Do each of the following activities as a cooperative team.

1. Cut out pieces of paper that measure 1” x 3”. Using a separate piece of paper for each variable, write out each of the requirements that the Wisconsin Fast plants need to grow well.

2. Place pieces of paper with the variables written on them one under the other under controlled variables.

3. As a team, select one variable you plan to change. Discuss it with your teammates. Place under the heading independent variable. What are the ways this variable might be changed to make a good experiment? Talk about this, and share your ideas about these questions:
   a.) Would changing this variable make an interesting experiment? Why?
   b.) Would changing this variable make a doable project? Would we have any special problems with materials or equipment? Could we handle these problems?
   c.) What might happen to the plant if we change this variable?
      If we change ________________ then ________________ (dependent variable) will be the result.

4. Use the questionnaire checklist to see if you set your project with independent variable, dependent variable and controlled variable.

5. Fill in your Planning Work Sheet and pick a person to share out your experimental idea.
Group Self Evaluation:
Reflection Activity for research day 1

<table>
<thead>
<tr>
<th>Questions</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>How will the independent variable be measured?</td>
<td></td>
</tr>
<tr>
<td>How will your dependent variable be measured?</td>
<td></td>
</tr>
<tr>
<td>How will all controlled variables be held constant?</td>
<td></td>
</tr>
<tr>
<td>What questions do you foresee happening? What could you do to prevent?</td>
<td></td>
</tr>
</tbody>
</table>
**Scientific Method Quiz**

**Directions:** Choose the correct term, from the word bank, for the statements below. Some may be used more than once; others will not be used at all.

<table>
<thead>
<tr>
<th>Constant</th>
<th>Experimental group</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Hypothesis</td>
<td>Scientific method</td>
</tr>
<tr>
<td>Dependent variable</td>
<td>Independent Variable</td>
<td>variables</td>
</tr>
</tbody>
</table>

1. A test group in which a single variable has been changed.
2. A tentative explanation used as a basis for investigation.
3. The condition that results from changing the independent variable.
4. A series of steps used to solve a problem in a logical manner.
5. A standard used for comparison to show the effect of an experimental factor.
6. The variable that is changed during the experiment.
7. All variables that are kept the same in both the experimental and control groups.
8. An educated guess.
9. Test group that is used for comparison with other test groups.
10. A factor that is changed.

**Directions:** Place the following steps of the scientific method in order from 1 to 10.

1. Perform the experiment
2. Organize and analyze the results
3. Identify the problem
4. State the conclusion
5. Ask a new question relating to the original problem
6. Write a project report
7. Gather information about the problem
8. Form a hypothesis
9. Make and record observations about the experiment
10. Design an experiment to test the hypothesis
Bill's Pills (Bugs, That Is)

Since he was a little boy Bill was fascinated by little organisms he called Pill Bugs. Bill. They were easy to find under old logs or under a flat stone in the woods. When the bugs were picked up, they would roll into a perfectly round ball the size of a pill. Just by observing their behavior, Bill came to believe that pill bugs liked dark and moist habitats. When his biology teacher assigned a research project, Bill decided he would study pill bugs.

Bill was surprised to find out from his reading that pill bugs were not insects. They belonged to another group of arthropods called Isopods. Many kinds of Isopods live in the ocean, but not very many kinds lived on land. Pill bugs were land Isopods. Because they were similar to their ocean cousins, pill bugs had a special system for obtaining oxygen. Bill assumed that pill bugs needed a moist environment for the breathing system to work. He also assumed that was why pill bugs lived under things- under a rock or rotten log was moister than out in the open.

The places in which pill bugs lived were dark as well as moist. Could it be that both darkness and moisture caused pill bugs to live under things, Bill wondered? He decided to answer this question for his research project. He believed that if pill bugs were given a choice between a moist and dark or a moist and light habitat, then the pill bugs' preference would be moist dark. Said another way, the number of pill bugs preferring moist and dark would be higher than those preferring moist and light.

Bill prepared a small experimental chamber. Inside, the chamber was 40 cm square. The bottom was covered with sponge. Bill created a moist habitat by pouring 150 ml of water onto the sponge. He had glued a small ledge around the inside of the chamber, 1 cm above the sponge. The ledge supported a 40 cm piece of glass. One half of the glass was covered with heavy cardboard; the other half was left clear. This meant one half of the sponge would be dark and the other half-light.

To conduct the experiment Bill collected 100 pill bugs. He moistened the sponge and placed the pill bugs into the center of the chamber. He covered the pill bugs with the glass cover and waited 15 minutes. When the time was up, he counted the number of pill bugs he could see under the clear glass. He calculated the number of pill bugs under the dark side by subtracting the number of light-side pill bugs from 100. Bill repeated this experiment 5 more times, and then averaged his results.
Directions: Read the scenario and fill in the information about the described experiment.

Problem:
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Materials: (Make a list)

Procedure: Highlight the sentences describing the experimental procedure.
Independent Variable: ________________________________
Dependent Variable: ________________________________
Variables that were kept constant:

Describe the control group if one was used, if one was not, and then describe how it should have been set up.

Are the results from this experiment valid? Why or why not?