Forming a research project using the scientific method: a research experiment on maple syrup production

By Sarah Lehnen
National Science Foundation Graduate STEM Fellow in K-12 Education
Sugar Creek Watershed K-12 Education Program
The Ohio State University-Ohio Agricultural Research and Development Center

Abstract: The purpose of this activity is to introduce high school freshmen to the scientific method and report writing through the design, implementation, and analysis of a-semester-long experiment. The students were responsible for designing a research project on sap production in maple trees beginning with the formation of a research question and ending with a full research report written in standard scientific format.

Grade level: 9th (Botany)

Objectives: 1) Introduce students to the scientific method, 2) give student real-life experience designing and analyzing a research project, 3) use a local resource (woodlot) for place-based learning, and 4) provide students with practice writing a scientific report.

National Standards: Understanding of:

* Scientific inquiry
* Natural resources

Ohio Benchmark and Academic Content Standards – Grade 10:
Life Science: D.10
Describe how cells and organisms acquire and release energy (photosynthesis, chemosynthesis, cellular respiration and fermentation).
Life Science: D:11
Explain that living organisms use matter and energy to synthesis a variety of organic molecules (e.g., proteins, carbohydrates, lipids and nucleic acids) and to drive life processes (e.g. growth, reacting to the environment, reproduction and movement).
Scientific Inquiry: A.2
Present scientific findings using clear language, accurate data, appropriate graphs, tables, maps and available technology.
Scientific Inquiry: A.4
Draw conclusions from inquiries based on scientific knowledge and principles, the use of logic and evidence (data) from investigators.

Materials:

Woodlot with Maple trees (Sugar and Red)
5-gallon buckets for sap collection
Spiels
Storage drums for sap (55 gallon)
Scale for measuring sap mass
Cordless drill w/ 7/16 in drill bit

Background: The focus of this exercise was for students to learn to follow the scientific method from start to finish by forming a research project on sap production in maple trees. The students were responsible for forming a research question, thinking of a hypothesis, designing a study, collecting the data, analyzing the results, and writing a full research paper describing their findings.

Methods Day 1: The students were given background information on maple syrup production – what time of year sap is collected, (Feb. to April) why the trees are moving sap between the branches and the roots during this period, the sugar content of sap during this period (~1-3%), and the process of boiling sap down into maple syrup. The students are also asked to remember what they learned in earlier botany units about how the tree produces and stores sugar. The students were given information about the trees available to them for this experiment and taken to the woodlot to view the trees up close.

Methods Day 2: The students were introduced to the scientific method (see handouts). The instructor discussed each of the six steps in the method and had the students write notes under the first section of the handouts. The students were then asked to come up with two possible research questions in pairs and these questions were written on the board. The instructor vetoed only those questions that were not considered either feasible or scientifically sound and told the students why these questions could not be used for this experiment. The students then voted for their top two questions and the two questions receiving the most votes were chosen for the project. The students were divided into two self-selected groups based on the research question they wanted to research. The students were told to come up with a study design as homework.

Methods Day 3: The students were broken up by their research question and told to combine their study design into one standardized procedure. The instructor guided the students in their thinking by coming up with possible problems (e.g., if the sap is frozen, how will it be measured? How will trees be selected for the study? How will the students control for other variables that may affect their results?). Each student was responsible for taking notes on the all of the research methods and for making a sheet to record the data colleted.

Methods Day 4: The students chose a partner to work with and were taken out to the woodlot to select the trees used for their experiment. The instructor made sure the trees were appropriate for the study and helped students measure the variables being tested (e.g tree diameter, number of limbs on tree, tree elevation).

Methods Day 5: The trees were tapped using a cordless drill and spiels were inserted into the drilled holes. Buckets were hung on the spiels to collect the sap. After their trees were tapped, students could return to the classroom to work on a lab assignment.

Methods Day 6-30 (1/3 class period): Every day, students were responsible for collecting and measuring the sap produced. After weighing the sap and recording the mass of sap produced, they poured the sap into a drum for storage, and then returned the empty

buckets to the trees (the sap was processed into maple syrup by the instructor). On cold days when the no sap was produced, the students did not collect sap although they still recorded weather variables on their data sheets.

Methods Day 6: The instructor discussed the elements of well-written introduction and methods sections (see handouts). The students were assigned the introduction and methods sections as homework (due the following week). Students could collaborate with their partners but each student was responsible for turning in his or her own work.

Methods Day 16: The instructor handed back the introduction and methods sections and provided feedback on what should be changed for the final draft.

Methods Day 30: The instructor described the purpose of using statistics to evaluate data. The students were introduced to such concepts as calculating a mean and the meaning of a standard deviation. The students were told to calculate the mean sap produced per day for their tree.

Methods Day 31: Students used the handout to record all of the data for their research question. Each student wrote the mean sap produced per day for his or her tree on the chalkboard and calculated a mean for each treatment. The instructor calculated the standard deviation and p-value of the t-test comparing the treatments. The instructor wrote the SD and p-value on the board and reminded the students what these values meant for interpreting their results.

Methods Day 32: Students were taken to the computer lab in order to use excel to make a graph of their results. The instructor guided the students through the handout provided. The instructor told students what to include in the results section and the results section including a graph was given as homework.

Methods Day 34: The instructor passed back the results section and provided feedback about common mistakes. The instructor than discussed elements to include in the discussion section of the paper and asked students to break into groups to brainstorm their main findings, variables that may have affected the results, and ways to improve the experiment in the future. After the group brainstorm session, the instructor listed the main points the groups came up with on the board. The students were told to incorporate these points into their discussion sections. The instructor told the students the due date for the final draft of the research paper and reminded students that they needed to include corrections from earlier drafts of the paper.

Optional (Day 40): The students were asked to prepare a brief presentation of their findings and present these findings to 5^{th} grade students. Students were told to include visual aids in their presentation such as photos, equipment used, and graphs of their results. Students worked in pairs and each 9^{th} grade pair was matched with a pair of 5^{th} grade students.

GK-12 Module Student Handout

The Scientific Method

STEP #1: Observing and asking a question

Components of a "good" scientific questions:

Something observable

Something measurable

Example of a good question

STEP #2: Do background research

What is the purpose of background research?

Has anyone else already answered this question?

Has a similar study been done that may help you make a hypothesis?

STEP#3: Construct a hypothesis

Components of a good hypothesis

Comes out of background research

Predicts answer to question- usually a cause and effect statement

Must be measurable

Variable:

A variable is any factor, trait, or condition that can exist in differing amounts or types. An experiment usually has three kinds of variables: independent, dependent, and controlled.

Independent variable: *the variable changed by the scientist*

Dependent variable: *The variable observed one the independent variable is changed. Depends on the changes made to the independent variable.*

Controlled variable *does not change but must be observed to ensure the changes in the dependent variable are caused by the independent variable.*

What are your variables?

Example: Does tree cover affect temperature ?

Independent variable= Tree cover

Dependent variable= temperature

Background research shows that if you stand in the shade you are cooler.

Hypothesis: More tree cover will lead to a decrease in temperature.

STEP #4: Test your hypothesis by conducting an experiment and collect data

Experimental Procedure:

A detailed recipe of how you will conduct your experiment.

Must be clear, detailed and complete so that other scientist could repeat your experiment without you present.

What materials will you need for your experiment?

STEP #5: Analyze your data and draw conclusions

Clearly label all graphs and tables

Independent variable- x-axis

Dependent variable- y-axis

Be sure to note all units of measurement

How will you record your data?

Draw conclusions

Do your results support or contradict your hypothesis?

Did you find a relationship between your independent and dependent variables?

Were there any problems with your experimental procedure that might have influenced your results?

STEP #6: Communicate results

GK-12 Module Student Handout

The Scientific Method

STEP #1: Observation and forming a question

Components of a "good" scientific questions:

_____

_____

What is your research question?

_____

_____

STEP #2: Background research

What is the purpose of background research?

_____

_____

How will you research your question?

_____

_____

_____

STEP#3: Construct a hypothesis

Components of a good hypothesis

_____

_____

Variable:_____

_____

Independent Variable:_____

_____

Dependent Variable:_____

_____

Control Variable:_____

_____

Example: Does tree cover affect temperature?
Independent variable= Tree cover
Dependent variable= temperature
Background research shows that if you stand in the shade you are cooler.
Hypothesis: More tree cover will lead to a decrease in temperature.

What are your variables?

_____

_____

STEP #4: Test you hypothesis by conducting an experiment
Experimental procedure:

_____

_____

Must be _____, _____ and _____ so that other scientists could repeat your experiment without you present.

What materials will you need for your experiment?

_____

_____

STEP #5: Analyze data
Clearly label all graphs and tables
Independent variable- x-axis
Dependent variable- y-axis
***Be sure to note all units of measurement
How will you record your data?

_____

_____

Draw conclusions
Do your results support or contradict your hypothesis? Did you find a relationship between your independent and dependent variables? Were there any problems with your experimental procedure that might have influenced your results?

STEP # 6: Communicate results

Research report: Intro and Methods check sheet (20 pts total)

Format (4 pts)

__ Double spaced

__ 12 pt font

__ Written in third person

__Spelling

Title (2 pts) - 8-12 words

__ Title should clearly describe the experiment

Introduction (6 pts) - 1-2 paragraphs

__ Provide relevant background in 3-4 sentences (see sugar maple handout)

__ State the **research question** you are investigating

__ State your prediction for your results (**hypothesis**)

Methods (8 pts) - 1-2 paragraphs

__ Written in paragraph form – **Not as a list**

__Describe in enough detail that a reader could replicate the experiment. How did you determine which trees to use in your experiment? Where did you tap the tree (side of tree, height from ground)? What were the dimensions of the hole you drilled? How often and for how long did you collect sap?

__ Include in your description the materials you used: 7/16 in drill bit, 5-gallon bucket, spile, 55 gallon drum, scale, ect.

__State how you will compare your results (you will use a two-sample t-test)

Example Intro and Methods

Course name
Teacher
Date
Your name

The effect of duration of light exposure on plant health

Introduction: The rate of growth and length of time a plant remains active is dependent on the amount of light it receives. Light energy is used in photosynthesis, the plant's most basic metabolic process. Increased light duration allows the plant to make sufficient food to survive and grow. However, plants require some period of darkness to properly develop. When a plant gets too much direct light, the leaves become pale, sometimes burn, turn brown and die. The research question for this study was to determine the length of exposure that would be harmful to a plant. The hypothesis was that plants exposed to light for more than 20 hours a day would have more brown leaves than plants exposed to only 10 hours of light.

Methods: Forty soybean plants were used in this study. The plants were about 8 in tall at the start of the experiment and had an average of 10 leaves each. The plants were randomly assigned to either the 10-hour or 20-hour treatment group. Then, the plants were placed in separate trays and set 16 inches below an indoor florescent grow light bulb (24-inch, 20 watt) for either 10 hours per day or 20 hours per day. Every two days for two weeks, the number of brown leaves on each plant was counted. At the end of the experiment, the treatment groups were compared using a two-sample t-test.

Research report: Results and figure check sheet (20 pts total)

Format (4 pts)

__ Double spaced

__ 12 pt font

__ Written in third person

__Spelling

Results (6 pts) – about 1 paragraph – this section is short!

__ State only your results – **no interpretation!**

__State the results you and your partner collected (example: The mean sap produced per day was 2.4 lbs for the large tree and 1.7 lbs for the small tree.)

__State class results (example: For the class overall, the mean sap produced per day was 2.9 lbs for the large trees and 2.1 lbs for the small trees.)

__ State the p-value of your t-test to the $1/1000^{th}$ place. (example: The difference between the sap produced by the large and small trees was statistically significant (p=0.004).)

Figure (8 pts)

__ Label both axes (x and y) with units!

__ Give your figure a title

__ Label the figure with a description below the figure

__ Display the mean value of both groups

__ Include **Standard Error** bars for both groups

Excel instructions for making a figure:

1. Open a new excel workbook.
2. Save your workbook.
3. Type the group names into columns B and C in row 1.
4. Enter the mean value for both groups in row 2.
5. Enter the standard error for both groups in row 3.

	Large tree	Small tree
Mean	6.6	7.6
SE	2	2.5

6. Click on “chart wizard”
7. Select “column” under chart type, click next
8. Select the mean values in “data range”, click next
9. Enter your figure title and label your x and y axes. Include units in your axes, example: Mass of sugar maple sap (lbs).
10. Click “finish”.
11. Double click on your display bars, click on the “Y Error Bars” tab, click on “custom” and select the data range for “SE” in your workbook. Click “OK”.
12. Select your figure, go to “Edit” on the menu, select “copy”
13. Open your maple sugar report, put the cursor underneath the “Results” section and select “paste”
14. Save your workbook and your report.

Example Results and Discussion

Results: The mean number of brown leaves per plant was higher in the 20-hour group (7.6 brown leaves/plant) than in the 10-hour group (6.6 brown leaves/plant; Figure 1). However, this difference was not statistically significant (p=0.084).

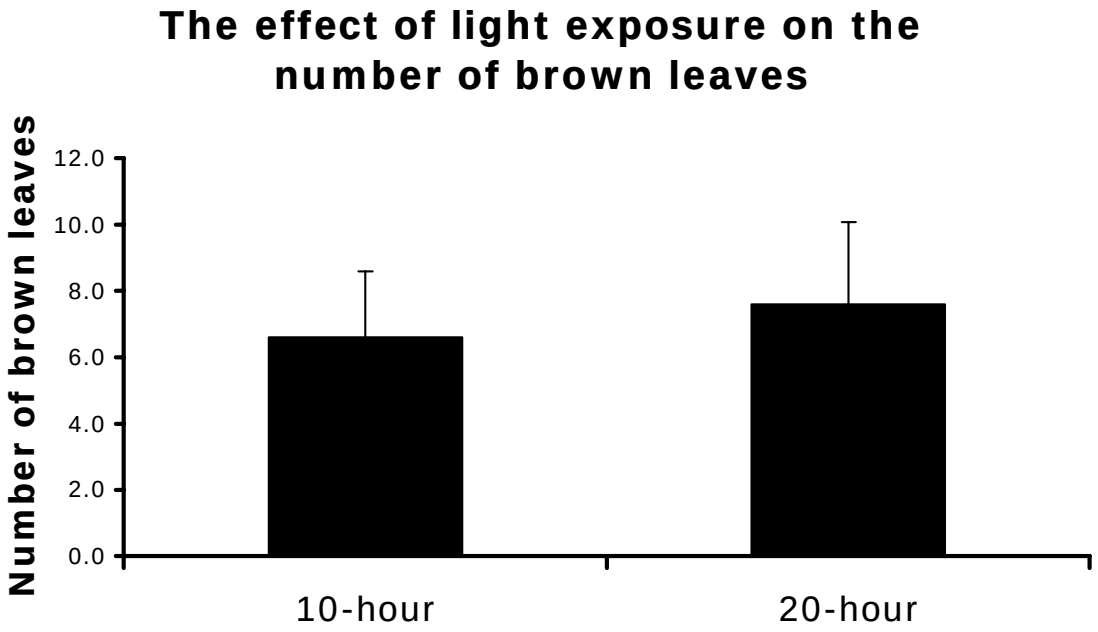

Figure 1. The effect of light exposure on the number of brown leaves in a soyplant.

Discussion: Consistent with our prediction, the number of brown leaves was higher in the 20 hour group than in the 10 hour group. However, our results were not significant. This may have been due to too small a sample size or too short a study duration. It may also be that the species of plant we used, soybean, is especially resistant to excessive amounts of light. Future experiments should be conducted using larger sample sizes, longer study durations, and different plant species.

Sugar Maple Results Worksheet

Part A.

Group members initials	Name:	Name:
Mean (Average)		
Standard Error (SE)		

The **Standard Error** (SE) is a measure of the **variability** of your data. For example, here are the quiz scores from two sections of a botany class:

	Class 1	Class 2
	8	6
	9	7
	9	10
	9	10
	9	10
	9	10
	10	10
Mean (Average)	9	9
SE	0.22	0.65

The mean (average) for the both classes is the same but the second class has a higher standard error meaning there is more variability in the scores of the second class.

Part B.

Two-sample T-test results: p-value =_____

A two-sample t-test determines if two samples are significantly different from each other.

A p-value less than or equal to 0.05 is statistically significant (groups are significantly different)
A p-value greater than 0.05 is not statistically significant (groups are not significantly different)

Sugar Maple Experiment – Final Research paper – 50 points

1. Make sure you include all corrections from your Introduction, Methods, and Results. Follow the format of the example.

2. The Discussion section is arguably the most important part of the report – many times it's the only section people will read! Put some thought into it. Make sure you include:

1) Your main finding – was your hypothesis correct?

2) State at least 3 problems with the study. What variables could you not control? What else may have affected your results? Hint: think of the issues we discussed during the study design phase

3) State at least 2 future studies that would 1) address the problems you identified, or 2) build upon your findings.

Format (5 pts)

___ double spaced
___12 pt font
___Spelling is correct

Introduction (10 pts)

___contains relevant info
___Provides background on sugar production and storage in maple trees
___States your hypothesis and the reasons for your hypothesis

Methods (10 pts)

___detailed and complete

Results (10 pts)

___States the results
___Includes the sample size (number of trees). Ex: If there were five large trees in the experiment you would write "the mean sap produced per day was 3.4 lbs (n=5) for the large trees".
___States the p-value for your results
___Includes a figure – cite the figure in your text. Ex: "the mean sap produced per day was 3.4 lbs (n=5) for the large trees and 2.7 lbs for the small trees (n=5; Figure 1)."

Discussion (15 pts)

___Main finding
__At least 3 problems with the study
__At least 2 future studies