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Using Student Developed Research Projects to Stimulate Student Inquiry

Grades 7-12

Student designed and implemented scientific research promotes scientific literacy. When students develop their own projects, they become more actively involved in the learning process. As students become more actively involved in the scientific process their retention of concepts and their desire to learn increases.

Using classroom available resources and possibly outside lab facilities, if available, students can develop, implement, and report on a question of research that is of interest to them. If students are actively engaged in the learning process and establish ownership of knowledge through scientific inquiry then they will develop into more motivated learners. This can make things easier for the teacher as well as the student and parents. Also, many Maryland Core Learning Goals may be achieved simultaneously as a result of student-developed projects. The following are guidelines for developing projects in the classroom. A sample project is included. These projects can be started any time during the year or semester. The only limiting factor is to make sure the students have several weeks to carry out the procedure. Once started, provide students with some time daily in class for project work.

Maryland Core Learning Goals

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Introduction to the Scientific Process

Before students can start a scientific inquiry they must have some background knowledge of the process. For middle school (7-9) students this can be accomplished by simulating an investigation as a class.

1. Provide an investigation topic
   example; How can we make a paper airplane fly far?
   - Give each student a blank sheet of paper.
   - Ask them to make a paper airplane.
   - Ask them how they could measure (quantify data) which paper airplane is the best and list on board
   - Ask them what are some conditions that should remain the same for testing the airplanes (constants)-list on board
   Ask what are we going to compare our results to? (control = teachers plane that is not changed between the first and second flight)

2. Run Investigation. Record data in a developed data table.

3. Ask students...How can you improve your airplane if I provide you with tape and paper clips? They should reply... If I do this, then my airplane should improve. (hypothesis)
   Have them write down their hypothesis and make modifications to their plane.
   Ask them what is it that they are changing (independent variable) and list on the board.
   Ask them what should happen as a result of that change (dependent variable = better flying plane).
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4.  *Experiment* = Test Hypothesis. Using parameters determined in step one, test their airplanes again. Record data. In the interest of time fly the planes only one, but discuss the importance of repeated measures in science.

5.  *Analyze data.* Was their hypothesis supported or not? Which flew better and why….. What other modifications and tests could be used to make a better plane (further research)?

For *high school students (10-12)* this can be accomplished by reading and analyzing a research article. Have the students identify the following:

1. Title
2. Author and/or scientist presenting the research
3. What is the hypothesis?
4. What are the independent and dependent variables?
5. What is the control?
6. List the constants
7. How was data quantified?
8. What conclusions were drawn from the data?
9. What follow up research could be carried out?
10. How could they modify this research to do a comparable study in our class?

After this introduction, students can then consider a research topic of their own. They should also decide (or you should decide) if they will be working independently or in teams of 2-3.

**Sequencing using 5E Model**

**Engage:**
- Brainstorm ideas for student research project
- Experimental design and setup

**Explore:**
- Monitor and collect data from designed experiment

**Explain:**
- Using data analysis techniques (i.e. graphing) the students will explain the results of their experiment
- Students will draw conclusions based on evaluation of data.

**Extend:**
- Students will develop a powerpoint presentation and trifold display board to present the results of their research.

**Evaluate:**
- Formative Assessment:: Brainstorm ideas
  Student Proposal
  Literature Review
  Experimental Design
- Summative Assessment: Research Paper, Tri-fold Board, Powerpoint Presentation
Brainstorm Ideas- Day 1
Using in class resources: textbooks, scientific journals, scientific supply catalogs, previous labs, and on-line real time data (see attached), have students brainstorm a minimum of 4 possible ideas for research topic.
Have students answer the following questions:

a. What materials are available for my use based on what we have done in lab?
b. What could I vary about the materials to suit my research?
c. What kinds of results do I expect?
d. How could I measure/quantify my results?

This can take as little as 30 minutes or a full class period.
Students hand in ideas for a score (10 pts) and feedback.

Submission of Proposal-Day 6
Students should provide; Title for research
Material needed
General Procedure

Students should be given at least a week and then turn in for a score (15pts) and feedback.

Submission of Formal Literature Review-Day 14
Students should follow Literature Review guidelines provided.

Students should provide; 1-4 pages in length
Must describe past research and procedures related to topic
Bibliography: Minimum guidelines depending on class

Example; AP Biology; Two books
One scientific journal
One internet site

Students should be given at least a week and then turn in for a score (20pts) and feedback.

Submission of Title, Experimental Design and Brief Abstract (without conclusions)-Day 21
Students should follow How to Write a Scientific Paper guidelines provided.

Students should provide; Title; A phrase that states purpose of project and contain the
Independent and Dependent variables.

Abstract; Paragraph about design of project
Experimental Design;
a. One page introduction that explains how you will set up, run, and analyze the data
b. Second page that includes;
- Independent variable
- Dependent variable
-Hypothesis
-Constants
- Materials List
-Procedure
-Data collection and analysis plan

Students should turn in for a score (20 pts) and feedback.

Students should set up and carry out research in class for several weeks and collect data.
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**EXPLAIN**

**Submission and Presentation of Final Project**

Students should provide: Research Paper with details of research following guidelines provided. (130pts)

**EXTEND**

Tri-fold presentation board with all components of experimental design  
Oral Presentation with PowerPoint (200pts)

**EVALUATE**

See rubric for guidelines

**SAMPLE RESEARCH PROJECT:**

Title: The Effect of particulate organic material on the growth of *Potamogeton perfoliatus*

Abstract:

An experimental procedure has been designed to test the effect of particulate organic material, POM on the growth of the submerged plant, *P. perfoliatus*. POM, in the form of heat killed algae is added to four experimental units of plants, while four other units serve as the control. Students will monitor plant growth by measuring stem length, shoot number, and leaf number over a 6 week time period. Data are analyzed and reported to the class.

Introduction:

Submerged aquatic vegetation (SAV) beds are critical habitat for esturine species (Dennison, et.al. 1993). The restoration of SAV beds in the Chesapeake Bay is now one of many initiatives launched to improve the health of the bay. Determining the effect of various conditions on SAV growth will provide valuable data for future restoration efforts.

SAV provide food and habitat for waterfowl, finfish, and shellfish. SAV also affect nutrient cycling, sediment stability, and water clarity. One possible factor affecting SAV growth is the rapid life cycle of phytoplankton; microscopic plants that thrive in coastal and esturine systems. These small plants can absorb nutrients from the water column faster than SAV which afford phytoplankton the advantage of nutrient utilization. Due to an influx of excess nutrients (nitrogen & phosphorus) from fertilizer runoff, water treatment plant effluent, groundwater, and atmospheric deposition, rapid phytoplankton growth may lead to “blooms”. These “algal blooms” have many detrimental affects on organisms in the water column. One of the results is the rapid decompositon of dead algae by decomposing bacteria. This process consumes oxygen which leads to critically low levels of oxygen in the water column. SAV beds trap suspended particles, such as phytoplankton, from the water column, which are in turn deposited in the sediment. The hypothesis of the research example is that these trapped particles (POM) add nutrients to the grass bed sediments, thereby stimulating SAV growth. The purpose of this research project is to determine what if any effect this particulate organic material (POM) will have on the growth of *Potamogeton perfoliatus* (red-head grass).
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**Experimental Design:**  
Independent Variable- POM (heat killed algae)  
Dependent Variable- length and number of shoots  
Hypothesis:  
If excess POM is added to the sediment, then it will stimulate the growth of  
*P. perfoliatus* in terms of shoot length and shoot number.  
Constants: Type & number of plants, salinity, light, water quality

**Materials:**  
Algae: Can be purchased from Carolina Biological Supply or Wards Science.  
Order 30 dehydrated pellets of *Chlorella spp.* These keep nicely in the refrigerator.  
*P. perfoliatus* cuttings  
Equipment to grow SAV:

**Total List for 2 Growth Chambers**  
(Note: All materials will be provided by Horn Point Lab: Contact John Rhodenhausen or Chesapeake Bay Foundation unless otherwise noted.)

- 2 - shallow plastic tubs  
- 2 - water filters  
- 2 - powerheads  
- 4 - incandescent light bulbs (65 or 75 watt)  
- 4 - light shrouds (swing arm desk lamp)  
- 2 - powerstrips with surge protectors  
- 2 - ground fault interrupters (GFI)  
- 2 - thermometers  
- 2 - submersible aquarium heaters (Second Nature Acura 1000 - 150 watt)  
- 1 - pH test kit  
- 1 - carbonate hardness test kit  
- 1 - nitrate test kit  
- 8 - small plastic growth trays  
- 1 - foam sheet  
- 2 - bags of sand (50 pounds each)  
- 1 - bag of topsoil B (40 pounds, lower organic content than potting soil)  
- 1 – Bag Instant Ocean  
- 1 - quart size freezer Ziploc® bag  
- 1 - *ruler*  
- 1 - *cup measure*  
- 1 - *5 gallon bucket*  
- 1 - *6 feet of 1” rubber hose (for siphon)*  
- 1 - *about 100 feet of string (depending on the height of your ceilings) - optional*

*Not provided*
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Procedure:

Part 1 - Assembling growth chambers

Step 1 - Assembling growth chamber (one hour):
Materials
2 - plastic tubs
4 - desk lamps
4 - incandescent light bulbs
2 - power strips
2 - ground fault interrupters (GFI)
2 - submersible aquarium heaters (Second Nature Acura 1000- 150 watt)
1 - 6 feet of 1” rubber hose for siphon (Not provided)
1 - about 100 feet of string (Not provided) – optional

Once you have all the parts for your bay grass growth chamber, you will need to assemble them in your classroom. If split into two groups, a class of 15 students or more should be able to prepare the Growth Chamber in one hour. The Growth Chambers will be very heavy and difficult to move once filled, so choose your location carefully.

1. Place tubs on table. Label the outside of each tub clearly with an “A” or a “B”.

2. Set the unplugged heater to 75 degrees and attach it to the inside to the bottom of the growth chamber. Wait ten minutes, then plug it in (leave it on, and begin recording water temperatures from this day until the end of the experiment).

3. Assemble the lights and attach them to the table so they can sit about 10” above the water surface. Plug the lights into the powerstrip. Turn the lights on. Connect all plugs to the Ground Fault Interrupter. Make sure drip loops are set up to prevent water from accidentally dripping into the powerstrip socket.

4. Optional: Attach a string from each lamp to the ceiling as an added safety precaution, if wanted. This will prevent the lamps from falling into the water.

Teachers Note: It is up to the individual teacher to determine safety precautions to be taken with the lights. If accidentally submerged into the water, the light bulbs will burst and an electric shock of standard household current (120 volts) could result. Anything plugged into an outlet or powerstrip should have a drip loop@ to prevent water from accidentally dripping into the socket. See diagram.

5. Prepare the powerhead pump by attaching the cylindrical plug of the powerhead to the water intake of the powerhead. Then attach the sponge filter by stretching it over the adapter. The sponge filter will prevent particles from clogging up the powerhead. It will also provide a place for beneficial bacteria to grow.

(Expect to have many extra parts in the box that will not be needed.)

6. Place the powerhead on the bottom of one end of the tank on its side and direct the flow of water down the long side of the chamber. If you decide to use the foot with the suction cups, be aware that the suction cups slip off the side of the chamber once algae grow. This may cause the powerhead
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nozzle to be aimed into the tray of sediment, causing a “blow out”. We suggest not using the foot and suction cups at all.

Step 2 - Assembling growth chamber (continued) (one hour):

Materials
2 - bay grass growth chambers (from Part 1)  
2 - thermometers  
1 - water quality test kits (Nitrate, pH, Carbonate Hardness)  
1 – hydrometer (optional)  
1 – Bag of Instant Ocean  
Data sheets

Procedure:

1. Fill the Growth Chamber with tap water to about 4 inches deep. Add 1 cup of Instant Ocean to each Chamber. Salinity should range from 5 ppt to 12 ppt.

2. Set up drip loops on all cords so that water can not run into the outlet.

3. If it is not already done, plug the powerstrip into the GFI and then into the outlet as in the diagram below.

4. Plug in the powerhead/filter (and leave it on). It should immediately begin circulating water in your Growth Chamber. Remember to set-up the drip loops!

5. Put the thermometer into the water. It can be attached to the side of the growth chamber with the suction cup, or it can float free.

6. Test the water quality of your school’s tap water using the nitrate, pH, and Carbonate Hardness test kits. Record this data .

7. The assembled growth chamber will look like this:
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**Step 3 - Planting Bay grass cuttings (one hour)**

**Materials**
1 - container of bay grass cuttings  
2 - bags of sand  
1 - bag of topsoil  
8 - planting trays (13 2@ x 9 2@ x 3@)  
1 - quart size freezer Ziploc® bag  
1 - 5 gallon bucket (Not provided)  
1 - Ruler (Not provided)  
1 - Cup measure (Not provided)

*Teachers Note: It is extremely important to keep the cuttings in water until planting.*

**Procedure:**
1. From one of the bags of sand, set aside 10 cups of sand for use later.

2. Thoroughly mix the bag of topsoil and one full bag of sand in a container, a bucket or black tub is suggested.

3. Use a permanent marker to label the lip of each of the eight planting trays so that you can tell them apart. (Example: A1, A2, A3 A4, B1, B2, B3, B4)

4. Fill the 8 planting trays with the sediment mixture until all 8 are equally full. Pack the sediment in each tray firmly with your fingertips.

5. Sprinkle remaining sand evenly over the sediment mixture that is in the planting tray. This should be a very thin layer (about 1/8 of an inch).

6. Lay the foam sheet on top of the sediment surface. Remember: once the foam is in the water, it will float, so hold it in place tightly. (Any material can be used that will hold sediment in place until it is on the bottom of the growth chamber)

7. Two people should gently lower the trays into a Growth Chamber. Tip one end of the tray when lowering, slowly. Hold the foam in place on top of the sediment surface until all bubbling has stopped. This may take quite a while. This will minimize disturbance of the sediment.

8. Remove the foam sheet carefully by lifting one end slowly. Repeat procedures 4 through 7 until each growth chamber has 4 trays in it.

9. Divide the cuttings into 8 equal parts.

10. Plant cuttings in each of the planting trays by using your index finger to push the base end (leaves should be pointing up) of the cutting into the sediment mixture. Continue this for all trays until all cuttings have been planted.

11. Fill black tubs with more water until water depth is 6 ½ inches. Check this level weekly and add water when necessary. Be careful not to disturb the sediment. Turn on the lights if you haven’t done so already.

12. You are now ready to monitor your bay grasses.
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Your set up should look like this:
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Procedure: 

1. Now that grasses are planted, allow them 1-2 week to equilibrate in the tanks. 

2. After a week for each planting tray in the experimental chamber add 1 pellet of heat killed *Chlorella spp.*  
   Record the day the algae is added and begin measurements on the SAV. 

   **Procedure for heat killing Algae**  
   a. Place pellet in clean test tube.  
   b. Add 5 ml of tap water.  
   c. Place test tube in boiling water bath for a minimum of 2 minutes. 

3. Add 1 pellet mixture of heat killed algae once a week to each planting tray in experimental tank for the duration of the experiment. 

   **Procedure for distributing Algae**  
   a. Once a pellet of algae is heat killed, remove test tube and shake to re-suspend algae.  
   b. Using a bereal pipet, pipet all solution from 1 pellet to the surface of a planting tray. Distribute ALL algal material as evenly as possible over the entire planting tray. 

4. Record data weekly. 

   - Measuring Total Shoots: - Count the number of live green shoots in each planting tray.  
   - Measuring Total Shoot Length: - Measure the length of each shoot in a planting tray, then sum the lengths for that tray.  
   - Measuring Total Leaves: - Count the total number of green leaves for each planting tray. 

5. Results should be seen by week 6-7. 

6. Graph data for the control tank and the experimental tank. 

   - Three Lines: 
     - X-axis = Week of growth 
     - Y-axis = Total Shoot Length 
     - Total Leaf # 
     - Total # of Shoots 

7. Analyze data. Answer the following questions; 
   
   a. Is there a difference in the total shoot length between the control and experimental setups? 
   b. Is there a difference in the leaf # between the control and the experimental setups? 
   c. Is there a difference in the total # of shoots between the control and experimental setups? 
   d. Does the data support your hypothesis?  
   
   If yes, what does this tell you about the effect of POM on *P. perfoliatus* growth? 
   If no, what is a possible change in your hypothesis that should be tested with further research? 

8. Students should write up a research paper following guidelines provided. This paper should be used as a summative assessment. 

9. If extension is assigned, follow the rubric provided.
## Data Log

**School:** ____________________________  **Teacher:** ____________________________

**Grade/Class:** ____________________________  **Week:** 1 2 3 4 5 6 7 8 9 10 11 12 13 14

**Chamber Type:** (Control: No algae added or Experimental: Algae added)

### Daily Monitoring

<table>
<thead>
<tr>
<th>Date (month/day)</th>
<th>Water Temp (°C)</th>
<th>Water Depth (fill to 6 1/2&quot;)</th>
<th>Light Height (should be 10&quot;)</th>
<th>Comments (Date plants first visible, heavy algal growth)</th>
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<td><strong>Average Temp:</strong></td>
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## Weekly Monitoring

<table>
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<tr>
<th>Planting Tray</th>
<th>Shoot #</th>
<th>Total Shoot Length (cm)</th>
<th>Total Leaf #</th>
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On-Line Real Time Data Resources

Regional Weather and coastal estuaries
Precipitation websites and on-line data resources

Question: what are the annual precipitation patterns for the Chesapeake Bay region?

1. View graph of annual precipitation (1950-1999) at BWI, MD
   http://www.atmos.umd.edu/~climate/precip.html

2. View and download historical precipitation data for other places (e.g. Baltimore city station: 18 0470 )
   http://dipper.nws.noaa.gov/hdsb/data/archived/legacy/dlytran.html

   1). Filing station number: click on stainy, then filing MD in state block, then click on “get station”.
   2). Filing station number in previous page, and choosing “PTPX/PRCP-precipitation”, and filing time period (1900-2002), unit, etc, then click on “create time series”.
   3). Copy the data table to notepad file and save on disk. You can open it through excel later and make it a excel table.

Streamflow websites and on-line data resources

View graphs of total estimated annual inflow into Chesapeake Bay (1937-2002)
http://md.water.usgs.gov/monthly/bay.html

View streamflow data resources for a specific site, e.g. Susquehanah River
http://waterdata.usgs.gov/md/nwis/uv?01578310

(for more sites, look website: http://waterdata.usgs.gov/nwis/rt)

Click on one of the following choice at “Available data for this site” to view various data resources for this site:
Real time
Recent daily
Daily streamflow (historical data archive)
Daily streamflow statistics
Monthly streamflow statistics
Annual streamflow statistics

Nutrient websites and on-line data resources

Nutrient data for the Chesapeake Bay and its tributaries: station maps and data.
Flagship website
http://www.chesapeakebay.net/wquality.htm

Chlorophyll-a websites and on line data resources.

Explore surface chlorophyll graphic for: A MEASURE OF PHYTOPLANKTON
Chesapeake Bay (e.g. 4/18/1995 vs. 4/18/1996) from remote sensing graphic.
http://www.cbrsp.org/cbrsp_mainbay_chl_toc_page.htm
Northeast US from NOAA real time satellite graphic (e.g. June 26, 2003)
http://wwwv2c.nesdis.noaa.gov/ocolor/ODATA/O2003175172355_chlor_amask_FullRegionNE0HUSF.gif
(for image of other time, please check through this link:
http://wwwv2c.nesdis.noaa.gov/ocolor/color_browse_open_2.htm)
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Get annual precipitation graph at:  
http://www.atmos.umd.edu/~climate/precip.html

Get annual inflow graph at:  
http://md.water.usgs.gov/monthly/bay.html

Stream-flow on line resources:**********

Estimated total annual inflow into Chesapeake Bay (1950-2002)  
http://md.water.usgs.gov/monthly/bay.html

The estimated monthly inflow into Chesapeake Bay in the last 3 years  
http://md.water.usgs.gov/monthly/bay1.html

1951-Present estimated monthly mean inflow into Chesapeake Bay (data table)  

Historic and real-time stream flow data and graphic for US  
http://waterdata.usgs.gov/usa/nwis/rt

Nutrient on line resources:**********

Chesapeake Bay River Input Monitoring Program (RIMP) providing historical nutrients load and concentration data.  
http://www-va.usgs.gov/chesbay/RIMP/

Historical nutrient input data for some tributaries of Chesapeake Bay.  
http://md.water.usgs.gov/watershed/MD118/data.html

Nutrient Criteria Database  
http://www.epa.gov/waterscience/criteria/nutrient/database/index.html

Chlorophyll-a on line resources:  
Historical chlorophyll remote sensing graphs for Chesapeake Bay.  
http://www.cbrsp.org/cbrsp_mainbay_chl_toc_page.htm

NOAA real time satellite graphic for chlorophyll-a  
http://www02c.nesdis.noaa.gov/ocolor/color_browse_open_2.htm

LEO-15 real time and archived surface chlorophyll-a satellite images  
http://marine.rutgers.edu/mrs/newevery.fyc.html

Weather and production  
Data are based on on-line data resources from following websites:  
http://dipper.nws.noaa.gov/hdsb/data/archived/legacy/dlytran.html = Precipitation**********  
http://waterdata.usgs.gov/nwis/rt = Streamflow  
http://www.chesapeakebay.net/wquality.htm = Nutrient and Chlorophyll

Observe the Chlorophyll remote sensing graphs in the Chesapeake Bay and the Choptank River for the following groups of events from the following website.  
http://www.cbrsp.org/cbrsp_index.htm **********
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vims.edu

EVALUATION RUBRICS

Research Article Analysis for Literature Review
1. Choose a research article that relates to your topic.
2. Identify the following: 1 pt. @
   1. Title
   2. Author and/or scientist presenting the research
   3. What is the hypothesis?
   4. What are the independent and dependent variables?
   5. What is the control?
   6. List the constants
   7. How was data quantified?
   8. What conclusions were drawn from the data?
   9. What follow up research could be carried out?
  10. How could they modify this research to do a comparable study in our class?

*********Any terms that you do not understand……………..LOOK THEM UP IN A DICTIONARY!!!!!!!!!

Research Presentation

A. Scientific Paper- Follow How to Write a Scientific Paper guidelines.

   Title                                      5 pts
   Abstract                                   5 pts

   Introduction
       - Purpose 10 pts
       - Literature Review 25 pts
       - Hypothesis 10 pts

   Materials & Methods (Experimental Design) 25 pts

   Results (Data) 10 pts

   Discussion
       - Data Analysis/ Interpretation 10 pts
       - Conclusions 10 pts
       - Error Analysis/ Discussion 10 pts

   Literature Cited 10 pts
                         130 pts
B. Tri-fold Board Presentation

Arrangement:
- Title: 10 pt
- Purpose: 10 pts
- Hypothesis: 10 pts
- Experimental Design: 10 pts
- Data: 10 pts
- Data Analysis: 10 pts
- Support Materials (equip., etc): 10 pts

Neatness: 15 pts

Visuals: Pictures, etc. 15 pts

100 pts

C. Oral Presentation

- Powerpoint Program: 25 pts
- Background Knowledge: 25 pts
- Clarity of Presentation: 25 pts
- Ability to Answer Questions: 25 pts

100 pts
Jean Hayhurst
Easton High School

How to Write A Scientific Paper
(This information was modified from a document developed by Mrs. Lee Hutchison, Easton High School.)

The purpose of any communication is to communicate. The purpose of a scientific paper is to introduce a topic to the reader, explain how an experiment was performed, describe results and discuss the significance of the findings. Unlike a textbook or magazine article, a scientific paper is separated into specific sections. This is a very stylized form of writing with a lot of rules. Your adherence to this format will indicate the care with which you prepared your report and will determine to a large extent your grade on your paper. Your paper must be typed with 12 point type, double spaced with one inch margins on the top, bottom, left and right. Diagrams must be drawn by you in pen or by computer and properly cited if they are not original.

The specific sections of a scientific paper in order:
Title
Abstract
Introduction
Materials and Methods (Experimental Design)
Results (Data)
Discussion (Data analysis, Conclusions, Error analysis)
Literature Cited

Each section is identified by these specific words (except for title). Scientific papers are written in a clear and concise manner using the more formal grammar. Journals differ somewhat in their exact format, but authors are required to adhere strictly to the specific format dictated by a particular journal. Since you will be “submitting” your paper, you will use the following format with NO variation:

TITLE

The title is a phrase that states the purpose of the project, and should contain the independent and dependent variables of the research.

Poor Example: “My biology Laboratory Report”…This is bad for obvious reasons.

Good Example: “What is the Effect of Salinity Gradients on the Growth of Potamogeton perfoliatus (redhead grass)”

This title explains briefly to the reader what specifically the research was about. It is the author’s responsibility to include all of the significant terms but not make the title so long that it reads like the next section.

ABSTRACT

Following the title of a research paper is a brief summary of the paper, the abstract. The abstract is a paragraph, not a sentence, that includes an introductory statement, what was done and what the results were of the research.

Poor Example: “The Salinity had an effect on the Redhead Grass”…..Tells the reader nothing!!!!!!

Good Example: “Potamogeton perfoliatus cuttings were grown in salinity concentrations of 0 ppt, 10 ppt, and 20 ppt. Measurements of the number shoots, total shoot length, and number of leaves were measured weekly. P. perfoliatus growth rate was greater in the 10 ppt salinity.”

The details such as how the plants were grown are only necessary if it is essential to the understanding of the observations. Conclusions do not include the reasoning that lead to these ideas. The abstract should be no more than a short paragraph.
INTRODUCTION

The introduction acquaints the reader with the ideas that led to the investigation. This includes any background knowledge relative to the study and cites individual scientists who helped develop this information.

Poor Example: “A lot of people have known a lot about SAV for a long time.”

Good Example: “Submerged aquatic vegetation (SAV) beds are critical habitat for esturine species (p. 86, BioScience, Vol.43 No. 2. Dennison, et.al. Feb. 1993). The restoration of SAV beds in the Chesapeake Bay is now one of many initiatives launched to improve the health of the bay. Determining the effect of various conditions on SAV growth will provide valuable data for future restoration efforts.”

In your paper use the “author-date” format for documentation as illustrated above. The date is the year of publication. For one or two authors, the individual last names are used for more than two, the first author’s last name is followed by “et al.”

Do not copy portions of a reference word for word. Claiming someone else’s idea as your own is a breach of academic integrity. Instead, rephrase the statements without changing the original idea.

The introduction should conclude with a description of why the research was performed and the significance of the investigation. If there is a hypothesis and prediction, it should be included.

MATERIALS AND METHODS
(EXPERIMENTAL DESIGN)

In this portion you describe briefly how you performed the experiment. This does not read like your lab reports; meaning you do not describe individual numbered steps. This should be in paragraph form and not numbered. You need to include enough information to make it clear to the reader what was done, but not describe every little step. The complete sentences are written in the past tense using the passive form of construction.

Poor Example: “I obtained 6 test tubes and numbered them 1 through 5.”

Good Example: “Sixteen planting units of approximately six shoots each were planted in each quadrat. The transplants were allowed to grow for 4 weeks. Measurements were taken on July 23 and July 24 (J. Bunnell, 2003).”

This tells the reader how the experiment was set up and when observations were made. If the reader wants to repeat the experiment, they can refer to the citation to learn the specific details. Details on specific instruments, methods of gathering data, types of controls used, etc. may be included if the reader needs to know this information to understand how you collected your data.
RESULTS

Here you describe what you observed. Include all significant data along with an explanation of what you saw. Specific data may be presented as a graph (in a figure) or in a table, but the same data cannot be given in both. Several data points are more easily summarized in a graph; a few values, in a table. Use whichever communicates your data best. Do not interpret the results in this section.

Poor Example: “The results are in Fig. 1 and 2.” If this is the entire results section, it is completely unacceptable!

Good Example: “Measurements of total shoot length, number of leaves, and total number of shoots may be found in Table 1.”

All figures and tables must be cited. And include all figures and tables that you cite. Figures and tables are numbered in sequence cited and included at the end of your paper. All figures and tables must be titled properly, i.e., include a short statement about their contents (for example, “Table 1 P. perfoliatus Transplant Measurements.”) These titles are at the top of a table and at the bottom of a figure. All graphs must have labeled x and y axes, a title, and a key if necessary.

Again, all statements are in the past tense since they described what you observed. Present tense indicates that it will always be that way and that is contrary to the scientific approach to reality. All things change.

DISCUSSION

(DATA ANALYSIS, CONCLUSIONS, ERROR ANALYSIS)

In the above section, you gave the reader the “facts” (data) and just the facts. Now you discuss these facts by comparing them to each other and to values in the literature. You also interpret the data, and relate your ideas to those published by other scientists. The thought process behind your conclusions must be carefully articulated. You may also propose further investigations suggested by your study. Be careful to make statements that can be logically drawn from your results.

Poor Example: “The above study told us how SAV grows.”

Good Example: “P. perfoliatus transplants showed greater survivorship in the youngest established bed (Table 1). There was no significant difference in the survivorship between the vegetated and unvegetated quadrats. The wet spring and heavy runoff led to decreased survivorship of all SAV throughout the Chesapeake Bay the summer of 2003. Repeating this investigation, and monitoring the growth on a two week basis may lead to a better understanding of effect of site on transplant survivorship.”

If you want to cite someone else’s data or ideas that you talked to, use the person’s name followed by “(Pers. Comm.)” (for personal communication). This is not placed in the Literature Cited section but as a footnote at the bottom of the page as shown. General discussions with classmates should not be included.

\textsuperscript{1}Cox, T., Dept. of Molecular Biology, Princeton University, Princeton, NJ.
Jean Hayhurst  
Easton High School

LITERATURE CITED

This section lists all cited publications in alphabetical order according to the last name of the author (or first author) and is included on a page of its own. All references listed in “Literature Cited” must be cited in the paper and vice versa. References left out indicate a lack of thoroughness on the part of the person preparing the manuscript. Pay particular attention to punctuation.

Citation sequence for books: (The title is not underlined and only the first word is capitalized except for proper nouns).

Author(s) (use initials for first names and after the first author all other author initials come before their last name). Year of publication. Title (not capitalized, except first word and proper nouns). Publisher, Location. Number of total pages.

Citation sequence for journals:

Author(s). Year. Title (not capitalized, except first word and proper nouns). Journal name (abbreviated). Volume: pages.

Citation sequence example for a textbook:

LITERATURE REVIEW

The literature review will be incorporated as a part of your formal research proposal for your project. This part of the proposal should show that you have a thorough grasp of your proposed area of research, and are aware of important recent developments. It is crucial that the experimental work you do is backed by a thorough understanding of the background.

The literature review should include two parts: general background information and analysis of prior research. Be sure to cite references, using proper form. Include a numbered bibliography at the end of the paper. When a reference is used in the review, refer to the source by giving the bibliography number or numbers, in parentheses at the end of the sentence (1,2). Though your review of the literature should be comprehensive, it must be clear and succinct. The review should be limited to 1-4 typed double spaced pages.

Background Information. Textbooks as well as lab manuals and periodicals can be used to provide background information in the area of your project. In this section, you should define and describe the important characteristics of your topic. For example, if you are comparing the growth of bacteria in various locations around the school, you would want to describe the important features of bacterial growth and explain why growth may be different in different areas. The quality and diversity of your sources will be evaluated; exclusive reliance on internet sources is not adequate.

Analysis of Prior Research. Briefly summarize scientific research studies directly related to your study. For the example listed above, you would find and summarize research that has been done regarding the environmental conditions needed for bacterial growth. These studies will be found in scientific and technical journals (examples; Science, Nature, American Scientist).

References (Use this format)

RESOURCES

The general protocol for setting up SAV tanks and procedure for planting was developed by the Maryland Department of Natural Resources Chesapeake Bay Grasses and Classes Program staff. The diagrams and pictures were also designed and taken by the Grasses in Classes staff. If you have any questions about the Bay Grasses in Classes systems, the following people can be contacted.

Technical Questions, Equipment Concerns       Mike Naylor       MD Department of Natural Resources  
                                                                 (410) 260-8652  
                                                                 mnnaylor@dnr.state.md.us

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                                                                 (410) 260-8634  
                                                                 mhoran@dnr.state.md.us

Field Trip Questions Curriculum Questions  Jamie Baxter       Chesapeake Bay Foundation  
                                                                 (800) 445-5572 ext. 714  
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