Santa Cruz-Watsonville Inquiry-Based Learning in Environmental Sciences

An NSF GK-12 Project

Ecosystem in a Jar

Experimenting with Growing Plants

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Field-tested with: 9th grade Integrated Science, Watsonville High School, Watsonville, CA (December 2011-February 2012, June-July 2012)

Concepts: Ecosystem ecology, environmental factors impacting plant growth, experiment design & analysis

Skills: designing experiments, observing, measuring, statistical analysis

Module Type: Long-term experiment over several weeks

Duration: 2-hour class periods to plan & start experiment at beginning and to analyze at end, plus 15 minutes every week

Key materials:

- Glass jars
- Soil
- Plant seeds
- Water
- Fluorescent grow lights
- Calculators and/or computers

Science Education Standards:

National: Science As Inquiry; Life Science

California: Biology-Life Sciences: 6. Ecology; Investigation and Experimentation

Overview: Students, as a class, develop, conduct, and analyze an experiment to determine what affects the growth of an "ecosystem in a jar." The class, with guidance by instructor, chooses a factor (such as light, nutrients, and soil type); determine a question, hypothesis, and methods; design a datasheet; collect data for several weeks; and analyze their data using statistics to make a conclusion. "Ecosystems" include soil, water, plant seeds, and other items decided by the class in glass jars. Discussion should focus on experimental design and analysis, but instructor can incorporate ecosystem ecology, biodiversity, food chains and webs, photosynthesis and respiration, and other concepts of ecology and biology.

This project is an opportunity for students to:

- Develop a research question and methods to answer their question.
- Analyze the results of their investigation using basic statistics (e.g., mean, bar graph).
- Think about the elements of an ecosystem and how they interact and apply the concepts of ecology to a model ecosystem

SCWIBLES is an NSF-GK-12 project, #DGE-0947923, a partnership between the University of California, Santa Cruz, and the Pájaro Valley Unified School District. For more information, see: http://scwibles.ucsc.edu

Background for Teachers

The focus of this module is truly the opportunity for open inquiry and experimental design and analysis, so emphasis should be placed on understanding and using the following concepts (defined with example below in Glossary):

- Testable research question and hypothesis
- Replication
- Randomization of treatments
- Control groups
- Altering only one variable at a time (or two in a factorial design)
- Quantitative measurement
- Observation vs. experiment – observations only show correlation of factors, only an experiment can actually demonstrate causation because it controls all other factors

Depending on the question used, students may also use the following statistical terms:

- Mean
- Standard deviation
- Student's T-test (for only 2 treatments using a categorical variable, such as high or low light, animals or no animals)
- ANOVA (analysis of variation for more than 2 treatments or a factorial design)
- Linear regression (for a continuous variable, such as 10 different levels of water or nutrients)

For more information, see appendix or statistics reference websites such as www.biology.ed.ac.uk/archive/jdeacon/statistics/tress1.html or http://udel.edu/~mcdonald/statintro.html.

The module is also useful for explaining the concepts of ecology and is appropriate to accompany a basic ecology unit:

- Population, community, ecosystem
- Succession (primary succession is occurring in the jars as organisms grow and/or multiply)
- Producers, consumers, decomposers,
- Biogeochemical (nutrient) cycles (water and carbon cycle are occurring in the jars particularly if they are closed because closed jars demonstrate the full water cycle and open jars dry out through transpiration and evaporation if water is not added by mimicking precipitation, closed jars demonstrate carbon cycle through photosynthesis and respiration)
- Open and closed ecosystems, which is easily demonstrated in open and closed jars

These concepts are explained in any basic biology or ecology textbook, such as Chapter 16: Ecosystems of the Holt Biology book by Johnson and Raven (2005).

Students should think about what biotic and abiotic factors impact how plants and animals interact with each other and their physical environment, such as in a garden or forest. These may include:

- Intensity of light (mimicking natural conditions such as shade)
- Time of exposure to light (mimicking natural conditions such as seasons or latitude)
- Water (mimicking natural conditions such as desert, fog, etc.)
- Nutrients (mimicking conditions such as fertilizer, presence of nitrogen-fixing plants)
- Temperature
- Presence of animals (herbivory)
- Soil type (potting soil, gravel, sand, etc.)
- Location (greenhouse, garden, inside with artificial lights, etc.)
- Open or closed jars

Glossary

Observation = act of noting or perceiving objects or events using the senses

- Ex: Some plants grow better in some types of soil than others.

Qualitative observation = observation based on description using words (color, taste, touch, smell, sound, etc.), rather than numbers

- Ex: There are more airspaces in gravel than there are in potting soil.

Quantitative observation = observation using numbers (length, volume, speed, etc.)

- Ex: A liter of water drains through 400 ml of gravel in 20 seconds and through 400 ml of potting soil in 4 minutes.

Hypothesis = an explanation that might be true – a statement that can be tested by additional observations of experimentation – an educated guess based on what is already known

- Ex: Plants grow better in potting soil than gravel (because gardening stores sell potting soil specifically for growing plants).

Experiment = a planned procedure to test a hypothesis

- Ex: Grow the same seeds in the same containers with the same amount of water and light, but the only difference is the type of soil.

Control group = group in an experiment that receives no experimental treatment, but otherwise is identical in every way to the experimental group

- Ex: Jars with soil

Independent variable = factor that is changed in an experiment (only difference between control and experimental groups)

- Ex: Soil type – potting soil, gravel, and mix of soil and gravel

Dependent variable = variable that is measured

- Ex: Number of germinating seeds, plant height

Prediction = expected outcome of a tests, assuming the hypothesis is correct

- Ex: More plants will germinate and plants will be taller in jars with soil than in jars with gravel or gravel and soil mix.

Replication = repetition of experimental conditions so that the variability associated with the phenomenon can be estimated

- Ex: 10 jars each with soil, gravel, and mix of soil and gravel, so that we can estimate standard deviation and mean for each soil type

Theory = set of related hypotheses that have been tested and confirmed many times by many scientists

- Ex: In order to conduct photosynthesis, grow, and reproduce, plants need light, water, nutrients, air (containing carbon dioxide) and soil.

Science Education Standards Addressed

This module addresses National Science Education Standards A. Science As Inquiry (p.173-176) and B. Life Sciences (Interdependence of Organisms; Matter, Energy, and Organization in Living Systems; p.181-187), as well as the following Science Content Standards for California Public Schools:

Biology/Life Sciences
6. Ecology: Stability in an ecosystem is a balance between competing effects.
d. Students know how water, carbon, and nitrogen cycle between abiotic resources and organic matter in the ecosystem and how oxygen cycles through photosynthesis and respiration.
e. Students know a vital part of an ecosystem is the stability of its producers and decomposers. (p. 45).

Investigation and Experimentation, 1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing content in the other four strands, students should develop their own questions and perform investigations. Students will:

a. Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.
c. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
d. Formulate explanations by using logic and evidence.
f. Distinguish between hypothesis and theory as scientific terms.
j. Recognize the issues of statistical variability and the need for controlled tests.

NSES (http://www.nap.edu/catalog/4962.html)
SCSCPS (http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf);

Project Description

Students, as a class, develop, conduct, and analyze an experiment to determine what affects the growth of an "ecosystem in a jar." The class, with guidance by instructor, chooses a factor (such as light, nutrients, and sound); determine a question, hypothesis, and methods; design a datasheet; collect data for several weeks; and analyze their data using statistics to make a conclusion. "Ecosystems" include soil, water, plant seeds, and other items decided by the class in glass jars. Discussion should focus on experimental design and analysis, but instructor can incorporate ecosystem ecology, biodiversity, food chains and webs, photosynthesis and respiration, and other concepts of ecology and biology.

This project is an opportunity for students to:

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Materials

Day 1:

- Glass quart canning jars (1 per group of 1-3 students)
- Fast-draining soil such as palm & cactus mix (about 300 ml per group)
- Seeds (white clover *Trifolium repens* and/or grass mix work well because they germinate quickly)
- Water (deionized or distilled if possible)
- Masking tape to label jars
- Permanent marker to label jars

- Beakers and/or plastic cups to measure soil and water
- Special supplies for your treatments (high-intensity lights, fertilizer, mealworms from petstore or earthworms from fishing store, etc.)
- Fluorescent grow lights (available from garden stores)

Middle days:
- Datasheets
- Tool(s) of quantifying experiment (e.g., ruler, digital scale, digital camera, etc.)
- Water (if jars are open)
- Tools for any other measurements (soil moisture meter, thermometer, etc.)

Last day:
- Datasheets
- Way to dispose of plants and soil (school garden, trashcan)
- Scientific calculator and/or spreadsheet program (e.g., Microsoft Excel) on one or more computers

Preparation

The instructor should gather materials and at least consider growing at least one jar before attempting experiment with the class to make sure that selected materials will work. The instructor should probably also review tenets of experimental design and the statistical tests he or she plans to introduce and/or use.

Timeline

First Day (1 hr 45 min or 2 1-hr periods):

1. Brainstorm as a class factors that may impact ecosystem (10 minutes)
2. Develop experimental design (20 minutes)
3. Develop procedure and datasheet (30 minutes)
4. Prepare jars (30-45 minutes - can be a different day if instructor needs to gather supplies)

Intervening Days:
1. Measure dependent variable and record observations (5-10 minutes)
2. Add water, if necessary

Final Day (1 hr 50 minutes):

1. Measure dependent variable and record observations (5-10 minutes)
2. Dispose of jars' contents and clean jars (5-10 minutes)
3. Compile class data (10 minutes)
4. Discuss and demonstrate statistical analysis (30-40 minutes)
5. Students begin statistical analysis with facilitation by instructor (20 minutes)
6. Discuss conclusion, future steps, and lab report format (20 minutes)

Procedure

Day 1:

1. Brainstorm as a class factors that may impact ecosystem (10 minutes)

   Brainstorm on whiteboard about what biotic and abiotic factors impact how plants and animals interact with each other and their physical environment, such as in a garden or forest. These may include:
   - Intensity of light
   - Time of exposure to light
   - Water
   - Nutrients
   - Temperature
   - Presence of animals
   - Soil type (potting soil, gravel, sand, etc.)
   - Location (greenhouse, garden, inside with artificial lights, etc.)
   - Open or closed jars

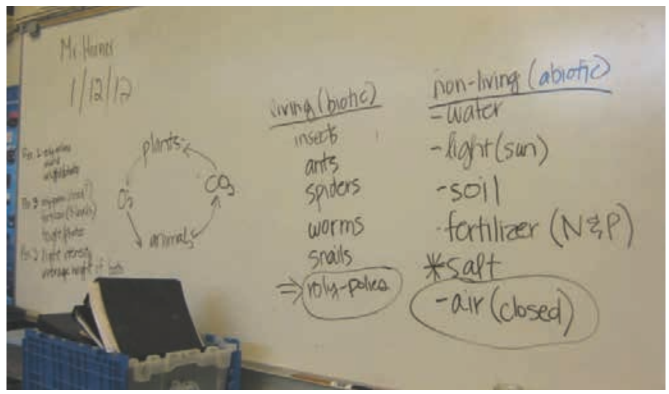

Figure 1: Discussing carbon cycle and brainstorming biotic and abiotic factors to test in experiment

2. Instructors should facilitate class designing their experiment: choosing a testable factor, research question, hypothesis, independent and dependent variables, and control group. Instructor should either explain or review definitions of these concepts. Definitions and examples for an Ecosystem in the Jar experiment are given above in Glossary.

   Each class should choose one or at most two factors. If the class chooses two factors, the instructor should either explain factorial design (crossing the two factors for a total of 4 treatments) or analyze the two experiments separately.

3. Develop procedure and datasheet (30 minutes)
   - Students should decide how many levels of the factor they want (e.g., low, medium, and high fertilizer; high and low light intensity, 10 and 20 hours of

light). It's probably simplest to keep the number of levels to 2 or 3 for simplicity of analysis and in order to have sufficient replication.
  - Instructor should here discuss replication (having several jars (at least 5) for each treatment to determine the average value, estimate variability, and reduce the chance of error).
  - Class should decide how often they will check their jars and exactly what their procedures are for preparing the jars and measuring their dependent variable. If class decides to measure % germination, they should probably check jars daily for a week or two. If class decides to measure plant height or mass, they should probably check jars weekly for a month or two.
  - If instructor has equipment available, class may choose to measure temperature, soil moisture, or other factors.
  - Class should discuss how to randomly assign each jar to a treatment (picking pieces of paper out of a hat, online random number generator, etc.).
4. Prepare jars (30-45 minutes - can be a different day if instructor needs to gather supplies)
   - This can be done on another day or even done before the discussion of experimental design. See Notes to Teachers and Appendix for our tested handout and procedure.
   - Instructor may pre-determine the amount of soil, water, seeds and give this procedure to students or have previously discussed this before preparing the jars and decided on a procedure.
   - Students should randomly assign their jars to treatments (evenly divided between treatments) and label their jars with names and treatment.

Intervening Days:
1. Measure dependent variable and record observations (5-10 minutes)
2. Add water, if necessary

Final Day (1 hr 50 minutes):
1. Measure dependent variable and record observations (5-10 minutes)
2. Dispose of jars' contents and clean jars (5-10 minutes)
   - Soil and plants may be planted in a school garden or disposed in trash.
   - Students should rinse jars for future re-use.
3. Compile class data (on computer with projector, on paper with document camera, or on whiteboard) (10 minutes)
   - Students can come to computer, document camera, or whiteboard to compile the data to analyze using statistics.
4. Discuss and demonstrate statistical analysis (30-40 minutes)
   - Instructor may want to review the class research question, hypothesis,

independent and dependent variable.
- Instructor should explain, using simple examples, descriptive statistics (mean/average, standard deviation, graphs) and the appropriate hypothesis testing method (Student's t-test for only 2 treatments, ANOVA for more than 2 treatments or factorial treatments).

5. Students begin statistical analysis with facilitation by instructor (20 minutes)
   - Students may use Microsoft Excel or a similar program on a computer, a scientific calculator, or pen and paper to conduct statistical analysis.
   - Instructor should circulate and help where needed.
6. Discuss conclusion, future steps, and lab report format (20 minutes)
   - Instructor should lead discussion of conclusion, how students would improve the experiment, what future steps might be, and how to prepare a lab report.

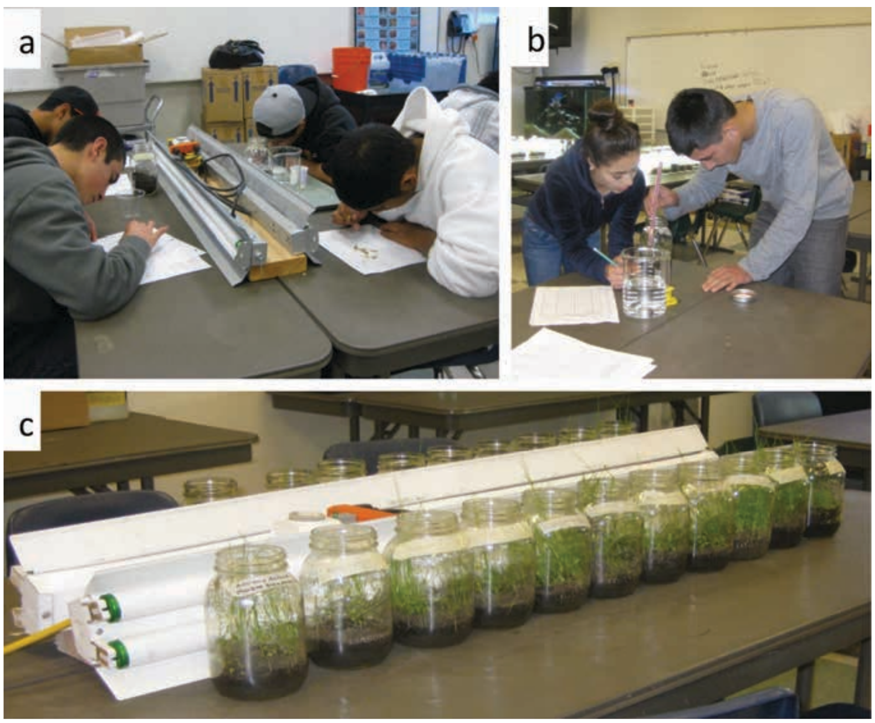

Figure 2: Students prepare jars on first day by counting seeds, measure plant height, and place their jars next to lights (one month after starting jars).

Assessment Methods

Class discussion
Worksheet on experimental design
Worksheet on statistics
Lab report

Notes to Teachers

In the initial trial of this module, our 4 classes chose 2 levels of light intensity (depended on plant), 3 levels of nutrients (obvious results in Figure 2a below), presence of music (suggestive, but not statistically significant results), and closing jars or leaving them open (but measuring through glass and not watering for entire period – very obvious results as in Figure 2b below). We were pretty sure how nutrients and closing jars would turn out, which they did, but were surprised to find that playing music did seem to make plants grow larger and that one plant grew well in high light, but the other did not.

We actually prepared the jars just before winter vacation and waited until returning a month later to see that most of the seeds had germinated and designing and enacting our experiment for 6 weeks. Thus, we couldn't use the dependent variable, % germination, which is most useful for short experiments if the class is using fast-germinating plants.

On the final day of the module, we explained and showed an example of computing mean and standard deviation on the board, but allowed students to compute mean and SD using a prepared spreadsheet on Microsoft Excel. Students graphed their mean and SD and that of another group using the opposite treatment. We did not have time to create graphs for the whole class or explain or use t-test. Also, I'm not sure how well students understood standard deviation since this was the only time they used it the whole year.

We also used this module as the first basic experiment and experimental design experience for two science fair classes with only 8 students. One class choose to focus on soil type and used potting soil, gravel and a mix of potting soil and gravel as their treatments. Another class decided to test location and put jars in a greenhouse and a garden and observed differences between the two locations extensively. Unfortunately, these jars did not germinate much at all over 2 weeks – it may have been too hot outdoors and in the greenhouse, as this experiment occurred in mid-summer.

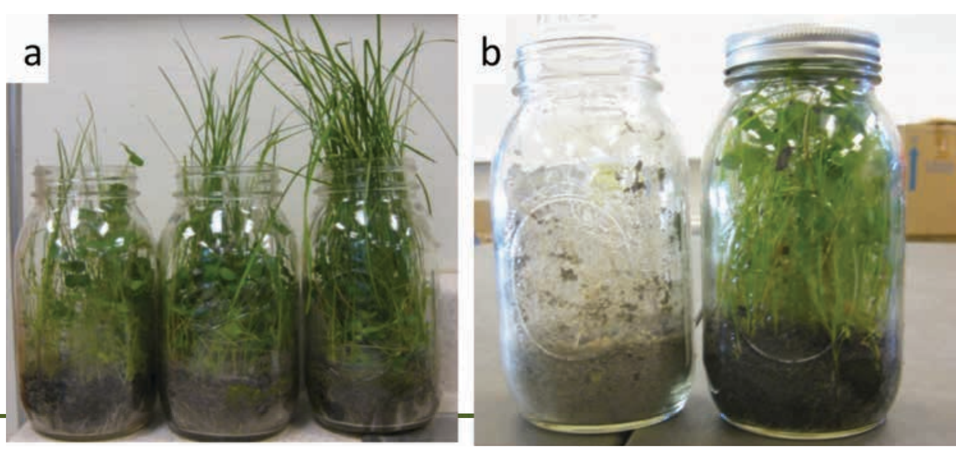

Figure 3: Typical results of experiments on nutrients (from left, low, medium, and high fertilizer) and closing jars.

Because this is a long-term module that may last several days or weeks, the instructor may wish to combine the module with more conventional ecology instruction, such as the long-term "Otters and Urchins: Ecology of the Kelp Forest" module, and/or short 1 or 2-day inquiry modules such as the "What Can We Learn From Seabird Barf? Seabirds and Marine Debris" on the SCWIBLES website.

Appendices

Worksheets on experimental design and analysis (as used in 2012 9th grade Integrated Science classes at Watsonville High School)

List of References and Supplemental Resources

- Statistics reference websites: http://www.sjsu.edu/faculty/gerstman/StatPrimer/, www.biology.ed.ac.uk/archive/jdeacon/statistics/tress1.html or http://udel.edu/~mcdonald/statintro.html.
- Experimental design website: http://mjksciteachingideas.com/design.html
- Johnson, J.B. and P.H. Raven. 2005. Chapter 16: Ecosystems. Holt Biology textbook.

Similar lessons:

- Wisconsin Fast Plants Program. 2010. Bottle Biology. Kendall Hunt Publishing. www.bottlebiology.com
- Johnson, J.B. and P.H Raven. 2005."Exploratory Lab: Modeling Ecosystem Change Over Time." Pages 358-359 in: Johnson, J.B. and P.H. Raven. 2005. Chapter 16: Ecosystems. Holt Biology textbook.