Investigative labs in a large-enrollment, mixed-majors, introductory biology course.

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Abstract

To promote student understanding of the process of science, we replaced traditional "cookbook" labs with investigative ones. For each, students begin with a general question stemming from a short story related to a lecture topic. Working in collaborative groups, they pose hypotheses, design and conduct experiments, and write a short report, within a three-hour period. To help students prepare, we require them to perform pre-lab activities in our Learning Resources Center, on the WWW, or on their own. We also require them to prepare a planning form describing their hypotheses, predictions, and experiment. During the lab, the students choose from the standard set of equipment available to them. For certain labs, specific equipment is made available to them. Each group of students is equipped with a computer workstation and laboratory instrument interface, an assortment of laboratory probes, a spectrophotometer, a video-microscope camera and additional equipment. During this session, we described the design criteria behind the lab, the laboratory manual, the pre-laboratory exercises, the laboratory exercises, and the student assessment procedures. We demonstrated some of the procedures and types of experiments students perform and presented data on student behavior, students' and teaching assistants' opinions, and student performance.

To obtain a lab manual contact Harcourt Brace Custom Publishing, Rhonda_Goedeker@harcourt.com, 636-530-9943

Funding to develop this course was provided in part by the National Science Foundation, the Howard Hughes Medical Institute, and OSU.

Goal

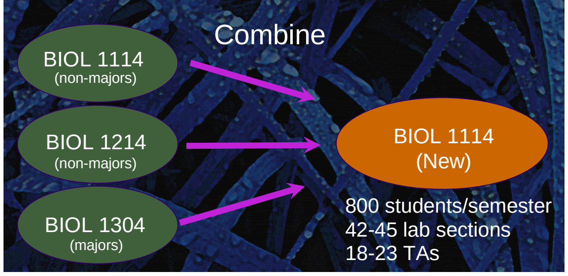
- To promote student understanding of the process of science
  - Forming testable hypotheses to answer questions
  - Designing, refining, and conducting original experiments
  - Analyze data and report findings graphically and in prose
  - Coping with false hypotheses and design flaws
- To familiarize students with current technology and techniques.

Plan

To...

- create a lab suitable for all majors
- replace traditional “cookbook” labs with investigative ones
- integrate equipment into laboratories

Plan



Motivating Factors

Pedagogy/Educational needs

- Student performance/attitude was lower than desired (by students, faculty, upper-division faculty)
- Too much material was covered with too much detail
- Lab exercises were primarily verification

National Science Education Standards

Promote science education that stresses inquiry, experimentation, and critical thinking over memorization of detail

Design Committee Recommendations

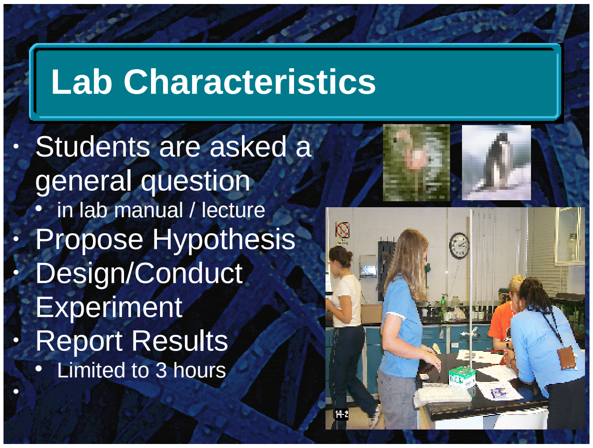
Labs should

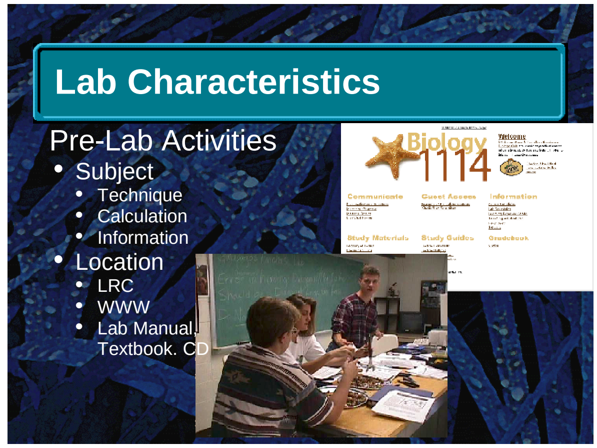
- include use of contemporary instruments & techniques
- be extended to 3 hrs
- focus on general questions to be answered
- **investigate** questions posed in lecture
- be based on hypotheses generated by students
- involve collaboration
- be assessed based on report writing

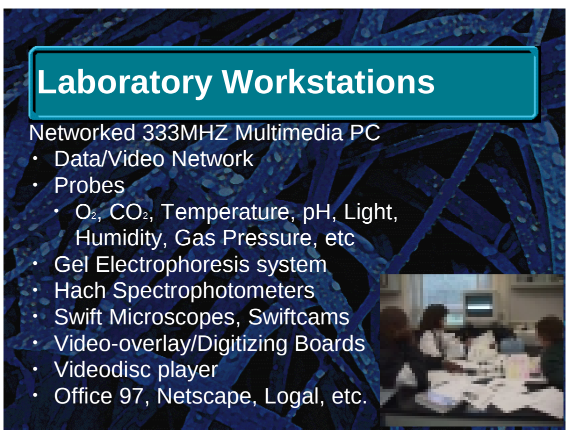
Lab Characteristics

Collaborative Work

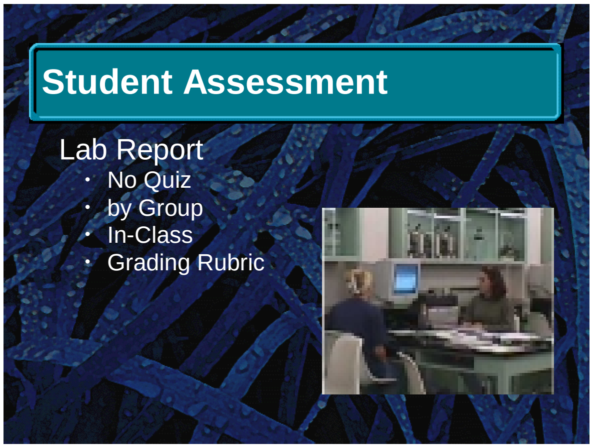
- Three students per group
- Lab reports written as a group
- Same groups in Lecture & Lab

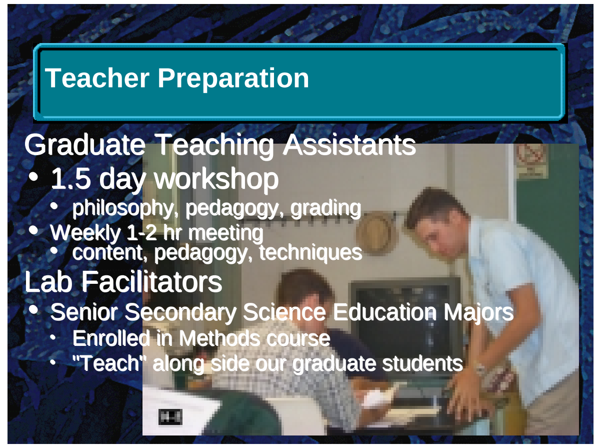

Lab Characteristics
Students are asked a general question
in lab manual / lecture
Propose Hypothesis
Design/Conduct Experiment
Report Results
Limited to 3 hours

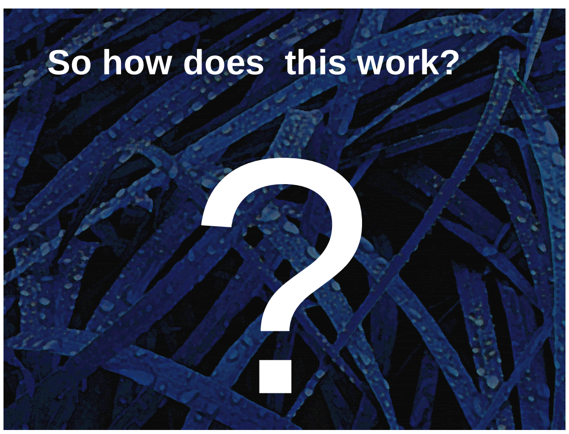

Lab Characteristics
Pre-Lab Activities
Subject
Technique
Calculation
Information
Location
LRC
WWW
Lab Manual
Textbook. CD
Biology 1114


Laboratory Workstations
Networked 333MHZ Multimedia PC
Data/Video Network
Probes
O_2, CO_2, Temperature, pH, Light, Humidity, Gas Pressure, etc
Gel Electrophoresis system
Hach Spectrophotometers
Swift Microscopes, Swiftcams
Video-overlay/Digitizing Boards
Videodisc player
Office 97, Netscape, Logal, etc.


Computer Assisted Experimentation
Use computers for:
Data collection
Simulations
Data Analysis
Literature Search
Report Writing

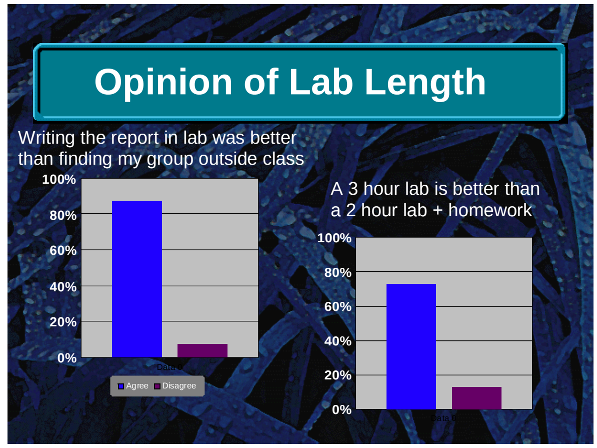

Student Assessment
Lab Report
No Quiz
by Group
In-Class
Grading Rubric

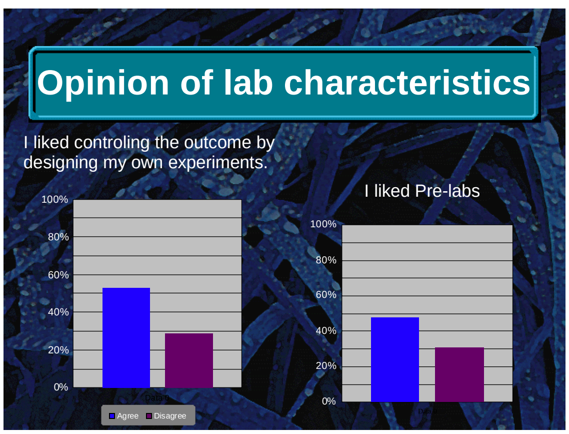

Teacher Preparation
Graduate Teaching Assistants
1.5 day workshop
philosophy, pedagogy, grading
Weekly 1-2 hr meeting
content, pedagogy, techniques
Lab Facilitators
Senior Secondary Science Education Majors
Enrolled in Methods course
"Teach" along side our graduate students

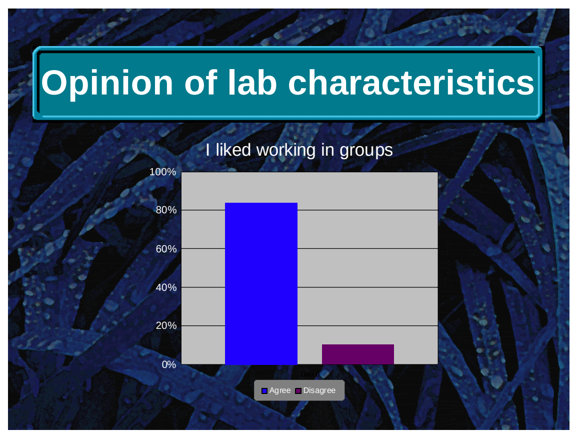

So how does this work?
?


Assessment
End of Semester Survey
At end of final exam
Component specific satisfaction questions
Form of " I liked......"
Strongly Agree, Agree, Neither, Disagree, Strongly Disagree

I liked the lab Lab Investigation…	Agree	Disagree
"Are larger Quattro variegatus eaten more often because they are easier to see?"	41%	35%
"Do body shapes influence the rate of heat gain or loss in a predictable way?"	61%	17%
"How is metabolic rate influenced by ambient temperature?"	60%	17%
"How do various factors influence the passage of materials through a membrane?"	44%	24%
"Can cell structure be used to identify cell type, function, or location?"	51%	24%
"How does seed diversity and abundance influence survival of birds with different beak types?"	72%	13%
"How does the color of light influence plant growth?"	52%	20%
"What factor(s) result in the greatest water loss from soil with plant cover?"	39%	27%
"Does drug type or UV radiation influence the evolution of antibiotic resistance?"	54%	23%
"How can the genetic composition of bacteria be altered in the laboratory?"	52%	26%
"How can genetic material be identified in the laboratory?"	54%	25%
"Does sewage affect benthic and algal species diversity in streams?"	61%	20%
"What leads to anoxia in polluted streams?"	54%	22%
"On what basis do male or female guppies select mates?"	63%	21%
Average opinion of lab investigations	54%	22%







Student Behavior

Beginning in 1997, we conducted a study to look at the effect the change in curriculum would have on student behavior.

- Used traditional animal behavior methods to observe students and collect data
- Conducted qualitative interviews of students
- Conducted semi-formal interviews of TA's
- Conducted a survey of TA's and students at the end of each semster.

Results of Behavior Study

Overall trends:

- Students were more likely to spend time actively participating in the inquiry-based labs (e.g. performing experiments, recording data)
- Students who were more active participants had more positive change in attitude scores and higher change in content knowledge scores than those who did not participate as actively.

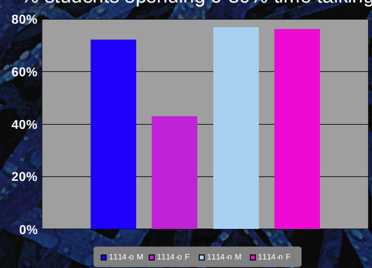
Results of Behavior Study

Gender-related Trends:

- In the "cookbook" type labs males spent significantly ($p<0.045$) more time talking on task, performing hands on experiments, and time waiting off task.
- These differences disappeared in the new inquiry-based laboratories

Results of Behavioral Study

% students spending 6-30% time talking



Quote

Question: What did you like best about the labs?

Answer: The lab had a lot of hands-on stuff, I mean, like the gels--I loved doing the DNA gels--that was so cool.

Quote

Question: What did you like best about the labs?

Answer: One thing I really liked... we got to make up our own experiments. Cause I'd never been able to do that before.....Just working through all these different ideas because there were no bounds, no limits on it and that was really neat

Quote

Question: What did you like best about the labs?

Answer: I think the best thing was being introduced to all that equipment and learning how to use it. And getting familiar with the lab experience, in general....active rather than passive learning...being a part of it...not being a spectator.

TA - Quote

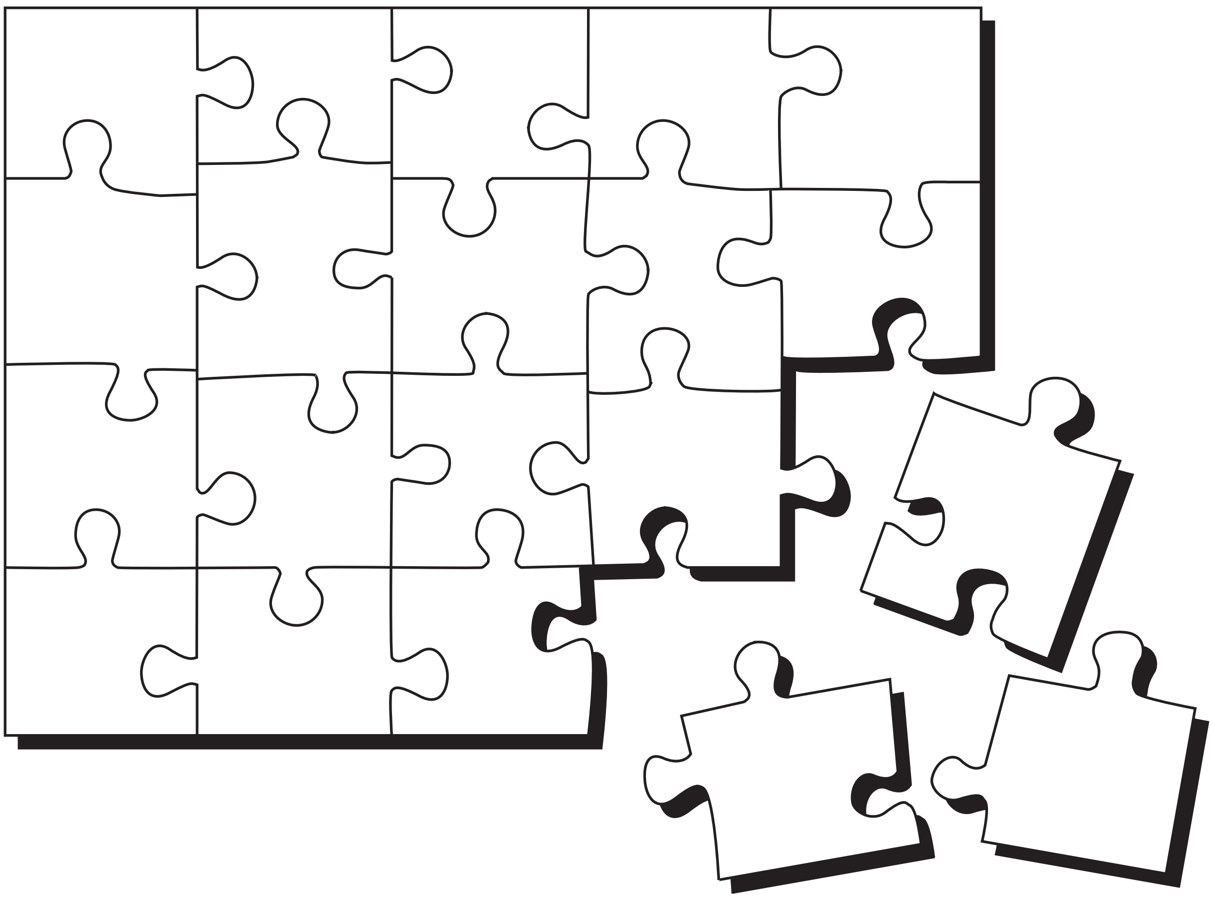
Question: Has your style of teaching changed since teaching in BIOL 1114 Laboratories? If so, how?

Answer: As compared to the past intro BIOL labs, this lab is much better for the student and the TA whether they realize it (sic)....Now the students actually have to think rather than memorize, and the writing component for both the students and the TA's.

INVESTIGATING BIOLOGY

SECOND EDITION

A LABORATORY RESOURCE MANUAL



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Illustrated by Connie Russell

TABLE OF CONTENTS

GUIDE TO SUCCESS

REFERENCE MODULES

INVESTIGATIONS

II. Frequently Asked Questions about How to Do Stuff in Lab

You will be collecting many different kinds of data in your laboratory investigations. The prelab assignments and reference materials should be especially helpful to you in designing your lab investigations week by week. However, you may have a question as you develop your plan of investigation that is difficult to track down using the standard table of contents. We have developed the cross-referenced list below to help you answer questions about measurement, data collection, and data interpretation. If you think of any other questions that should be added to this list, tell your lab instructor.

How do I . . .

magnetic stirrer. Remember that the sensor uses up the D.O. as it is measured. Remember too that turbulence adds oxygen to the water. Be sure no air bubbles contact the tip.

e. When the reading has stabilized record your data.

f. Replace the sensor in the storage solution.

E. Light Sensor

1. Function

This sensor (Figure R4.20) measures light intensity for visible light. (No kidding!)

2. Mechanism

It contains a photocell. (Again—no kidding!)

Figure R4.20—Light Sensor

3. Use

a. Attach the sensor to the serial box in the correct port.

b. Select an experiment file from the 

menu to start *Logger Pro*.

c. Select the appropriate range for the best sensitivity in low, indoor or outdoor conditions using the switch on the box between the sensor and the serial box.

d. Record your data.

F. pH Sensor

1. Function

This sensor (Figure R4.21) measures how acidic or basic a solution is. The pH scale ranges from 0–14 with 7 being neutral (water). Values below 7 correspond to acids; values above 7 correspond to bases. Each unit is ten times more or less acidic than the adjacent unit.

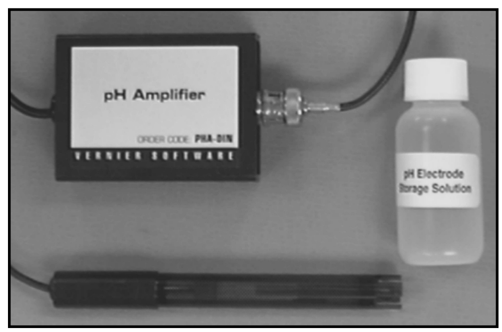


Figure R4.21—pH sensor

2. Mechanism

The sensor consists of a gel-filled electrode that produces a voltage in proportion to the number of hydrogen ions present. The sensor needs no normal servicing but requires that it be stored in a special storage solution and not be allowed to dry out or be stored in distilled water.

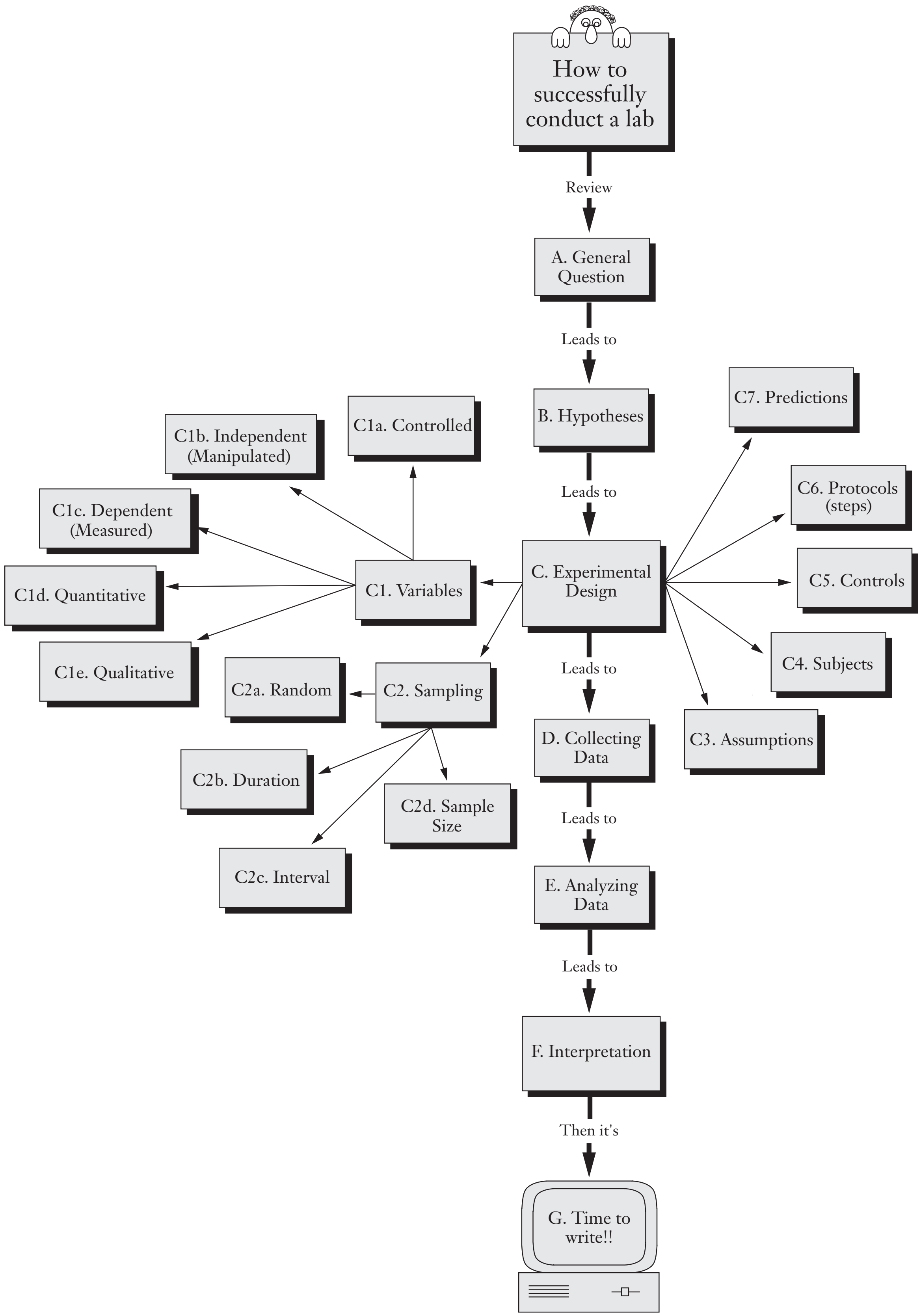
3. Use

a. Connect the sensor to it's amplifier.

b. Insert the sensor into the sample solution so that it covers the tip and stir gently.

c. Take a reading when the pH appears stable (typically after about 30 sec).

d. **When transferring between solutions, the pH sensor needs to be rinsed with distilled water. EVERY TIME YOU REMOVE THIS SENSOR FROM A SOLUTION *RINSE IT OFF WITH DEIONIZED WATER!!!***


How to successfully conduct a lab
Review
A. General Question
Leads to
B. Hypotheses
Leads to
C. Experimental Design
C1. Variables
C1a. Controlled
C1b. Independent (Manipulated)
C1c. Dependent (Measured)
C1d. Quantitative
C1e. Qualitative
C2. Sampling
C2a. Random
C2b. Duration
C2c. Interval
C2d. Sample Size
C3. Assumptions
C4. Subjects
C5. Controls
C6. Protocols (steps)
C7. Predictions
Leads to
D. Collecting Data
Leads to
E. Analyzing Data
Leads to
F. Interpretation
Then it's
G. Time to write!!

Larger *Quattro variegatus* are eaten more often because they are easier to see.

I. BACKGROUND

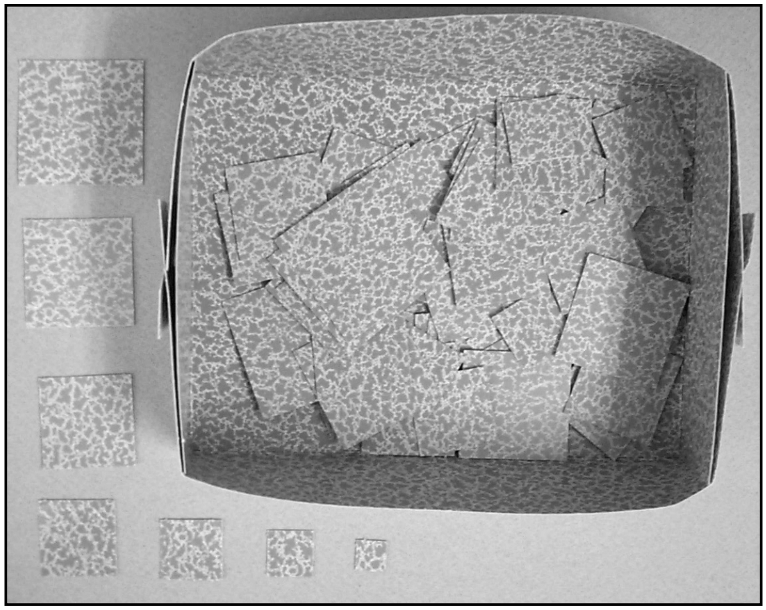


Figure I1.1—*Quattro variegatus* in its natural habitat. Surrounding the "live" individuals in the container are seven museum specimens representing the seven commonly found sizes. For reference, the largest *Q. variegatus* pictured is 51 mm on a side.

A scientist is investigating the alarming rate of disappearance of the largest, most mature, and best breeding *Quattro variegatus*. This species is four-sided in shape and highly dorso-ventrally compressed. It lives communally in a highly patterned environment and is extremely cryptic, taking advantage of disruptive coloration. Its major predator is a large, bipedal, ambidextrous mammal with binocular, color vision. The scientist spends time observing predation techniques and examining the stomach contents of the predator and finds that the larger *Q. variegatus* are eaten more frequently than the smaller ones. Unfortunately, there has never been an easy way to determine the gender or age of a *Q. variegatus*. When she samples populations, she does not find equal numbers of all sizes. She hypothesizes that larger individuals are eaten more frequently than smaller ones because they are more readily seen. Is she correct?

A. Pre-lab Activities

After completing this pre-lab, you should be:

- familiar with the organization of the lab manual
- aware of how to conduct lab and write a report
- familiar with the experimental conditions for this lab
- able to discuss some mechanisms that organisms use for camouflage and how they work
- able to explain how the probability of capturing a particular type of prey is related to its relative abundance

Because this is your first laboratory, you may not have had time to complete a pre-lab activity so there are none required. However, to prepare for lab, you might try some of the following.

1. Carefully read the sections "How to successfully conduct a lab" and "How to write a lab report" in this lab manual.
2. Observe the photograph of *Quattro variegatus* in its natural habitat (Figure I1.1) and be prepared to discusses your ideas on how it is predated and why certain sizes are eaten more frequently. There are "live" *Q. variegatus* in the LRC.
3. Complete the tutorial on Disruptive Coloration and/or Predator Avoidance Mechanisms on your lab computer, the LRC computers or the WWW.
4. Find the bucket of beads or marbles in the lab or LRC. In it are two colors of beads or marbles. If you reach in and grab ten of them, how many of each color would you expect to have? Why? Test your prediction. How many did you actually get? If you replaced the beads and repeated the procedure again, what would you expect? What happened? Why? What would the results of 100 repetitions be?

B. Terms/ Concepts of Potential Interest for use in Report

Disruptive Coloration	Foraging Theory	Visual Acuity
Encounter Rate	Size Distribution	Alternate Hypotheses
Crypsis	Search Image	Double-blind Experiment

C. Special Equipment and Materials

Quattro variegatus squares and box

D. Special Instructions

None

Planning Form

Name ________________________________ Section # ______

General Question Under Investigation:

Hypothesis(es) to be investigated:

Predictions:

Outline of Experiment

1. Procedures

2. Equipment

3. Type of Analysis ❑ Table ❑ Mean ❑ Descriptive ❑ Statistical ❑ Graph ❑ Other

   Describe:

References (textbook, library articles, URL)

____

____

____

Summary of results from Pre-Lab activities: (Use other side)

Lab Instructor Only											
Score	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**

Lab Notes

Name ________________________________ Section # ______ Date __________

Objective:

Experiment #____ —Goal

Hypothesis to be tested: Alternate Hypotheses: Rationale for hypotheses:

Experiment #____ —Design

Independent (Manipulated) Variable(s) Dependent (Measured) Variable(s) Prediction(s) and what they would tell you Modification(s) of laboratory manual procedures

Experiment #____ —Observations during experiments

Name:	Section #	Score				
	Grading Scheme for Lab Reports	**1**	¾	½	¼	**0**
Introduction						
1	Statements of question & hypothesis(es) under investigation are clear and correct.					
2	Provides logical argument for why question & hypothesis(es) are being investigated.					
Methods						
3	Experimental design is described completely and clearly.					
4	Steps/procedures are justified.					
5	Experimental and control variables and assumptions are correctly chosen and justified.					
6	Methods provide for appropriate test of selected hypothesis.					
Results						
7	Data are presented without causal interpretation or implications.					
8	Data are summarized and displayed appropriately in graphs or tables.					
9	Trends in data are made clear in text without repeating the information in tables or graphs.					
10	Figures and tables are properly numbered, captioned, and are referred to in text.					
11	Figures and tables can be properly interpreted without reference to text.					
Discussion						
12	Questions and hypotheses stated in introduction are addressed.					
13	Conclusions are supported by the data.					
14	Alternative explanations are discussed.					
15	Speculations are clearly stated as such and logically derived from data.					
16	Additional hypotheses are generated.					
17	Unexpected results are interpreted without unnecessary reference to experimenter error.					
18	Appropriate comparisons to textbook(s) are made and properly cited.					
19	Interpretations and information presented are correct given sources available to student.					
General						
20	Writing is clear and free of grammar, spelling, and punctuation errors.					
Extra Credit (+ 1 pt each)						
1	Data are analyzed statistically. (x3)					
2	Appropriate comparisons to literature are made and properly cited.					
3	Methods are illustrated by images or graphics.					
4	Additional experiments are designed.					
5	Additional experiments are completed.					
	Subtotal:					
	Total:					

How do environmental or anatomical factors affect the rate at which plants remove water from the soil?

Lab developed with the help of Reonna Slagell-Gossen and Jim Ownby

I. Background

The Acme Frozen Okra company is extremely environmentally conscious and is concerned with the problem of erosion. To reduce erosion, they intend to plant fields that they are not using and to erect wind breaks, other shade, etc., as needed. However, they are concerned about the costs of irrigation and the threat of desertification. Your research team is charged with determining which factors will affect the rate at which plants will draw water out of the ground by transpiration.

A. Pre-lab Activities

After completing this pre-lab, you should be able to:

- design a transpiration set-up
- list several factors that could affect transpiration
- describe the function of stomata and how they work
- explain how pressure is used to measure volume

1. View the setup of the apparatus for measuring transpiration in the LRC. Explain how it works and identify the points where the system could fail.
2. Imagine a glass of water sitting on a table. List the factors that would cause it to evaporate faster or slower.
3. Complete the "Humidity" segment of the *Logal*—Photosynthesis simulation. Fill in the following table:

Humidity (%)	Stomatal Opening Factor	Photosynthetic Rate
0		
25		
50		
100		

B. Terms/Concepts of Potential Interest for Use in Your Lab Report

Transpiration	Surface Area	Xylem
Stomata	Temperature-Pressure-Volume	Evaporation
Guard Cells		

C. Special Equipment and Materials

Plants (sunflower, tomato, cotton)	Tubing with luer lock for sensor
Vacuum grease	Tygon tubing
Bowl with water (set out over night)	Alcohol
Syringe with luer lock	Heat source
Scalpel or scissors	Petri dish with iron ring holder
Plastic hose clamp	Plastic bag

D. Special Instructions

Do not allow water to back up into the biology gas pressure sensor! Water will ruin the sensor.

Experimental Set-Up (Figure I8.1)

Figure I8.1—Experimental set-up

1. The three way valve on the sensor tubing has a blue control handle that indicates which stem is closed (See Figure R4.13a). The blue control handle should be turned toward sensor. This closes off the sensor and allows air or water to flow between the environment and the tubing.
2. Select tubing that will fit the stem size of your plant, connect to end of luer lock tubing. Connect tubing (luer lock end) to three way valve and leave the free end of tubing in the pan of water.
3. Screw luer lock syringe (90º angle) to three way valve with a gentle turn and pull water up through tubing. Leave syringe attached to sensor. **Do not allow air bubbles in the continuum of water in the tubing.** Leave the end of the tubing in the water while preparing the plant.
4. **<u>Slowly</u>** unscrew syringe with the luer lock end (near sensor) to allow an air pocket to form near the top of the tubing connected to the sensor (Figure I8.2) and tighten lock back gently. The air space in the tubing allows one to see the water level descending and water will not back up into the sensor.
5. Smear vacuum grease around plant stem base, near soil, and upwards approximately an inch. **Cut the plant near the base of stem** (below the grease), and soil interface.
6. Place end of plant stem in pan of water and make a fresh 45º angle cut **<u>under water</u>** approximately one inch above the end of stem. Discard the cut piece of stem. Connect the end of the plant stem to the tubing in the water pushing about one inch of the stem end into the tubing. DO NOT ALLOW THE END OF THE STEM AND TUBING TO COME OUT OF THE WATER AND DO NOT ALLOW THE LEAVES TO GET WET. While under water make sure that the vacuum grease has covered the area between the stem and tubing to complete the seal (Figure I8.3). Gently tighten the tubing around the stem using the plastic hose clamp.

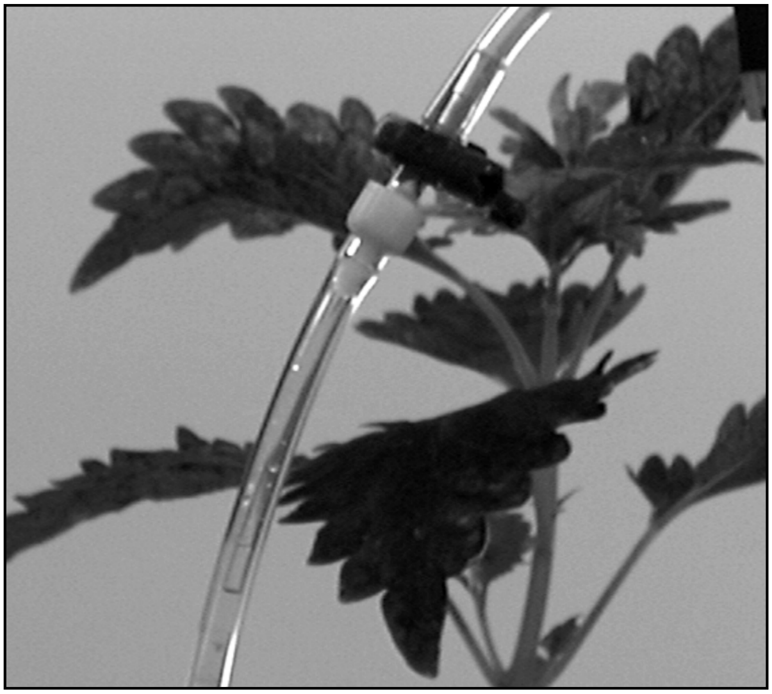


Figure I8.2—Air pocket

Figure I8.3—Attach tubing to plant stem.

7. Take plant setup out of the water and place plant in clamp, tight enough to hold the plant, but not so tight that it interrupts the flow of water through the plant stem. The sensor must be situated on the ring stand above the base of the stem of the plant.
8. Unscrew the luer lock syringe on three way valve. If a proper seal has been formed the water level in the tubing will remain steady with no air bubbles forming.

9. Choose the appropriate sensor set up from the **Start > Vernier > [Sensor combination]** that corresponds to the experiment that you have designed. At least one of the setups should be for the Biology Gas Pressure Sensor.
10. Leave valve turned toward sensor for the first four minutes of the run to allow equilibration (maintain a steady constant reading).
11. After the first four minutes of the run, you should have maintained a steady constant reading. Turn the blue valve handle on the three-stem valve toward the syringe (OFF), opening the pathway to the sensor which allows for the collection of data.
12. Unless you change the defaults, the computer will stop collecting data after 10 minutes.
13. After running the control, **leave data on computer screen and close valve to sensor.**
14. Leave plant setup the same for your next variable. While setting up your experimental variable, leave the valve to the sensor closed.
15. Repeat steps 10–12.
16. After completing your experiment(s), clean vacuum grease marks off all tubing.

**Allow at least 5 minutes between control and variable, or 5 minutes after setting up variable before collecting data