Contents

Introduction and Background

Ideally, science education should develop the process skills involved in practicing science, such as problem solving and evaluating data, improve content mastery, and leave the student with a lasting interest in science (National Science Board, 1986). It seems reasonable to expect that laboratories would excel at teaching scientific process skills, but traditional biology laboratories require that students perform only the basic skills of observing, classifying, and graphing. There is little evidence that these laboratories increase student achievement in any process skills (Bates, 1978). In fact, traditional biology laboratories devote themselves mostly to content mastery by having students repeat carefully choreographed experiments which reinforce material given in lecture. But despite this emphasis, studies show that the laboratory actually does little to improve content mastery (Bates, 1978; Hofstein and Lunetta, 1982). The principle accomplishment of laboratories seems to be promoting a positive attitude toward science courses (e.g., Bybee, 1970) and improving the ability of students to perform laboratory techniques (Bates, 1978).

Perhaps traditional laboratories add so little to lecture instruction because their methods are so similar to those of lecture and demonstration. As Reif (1987) observes, “One cannot learn to interpret and use scientific concepts merely by reading books or listening to lectures, no more than one can learn to speak French merely by reading books about French.” One consequence of the content emphasis of laboratories is the perception that laboratory education is “uninspired, tedious and dull” (National Science Board, 1986). A more serious result is that traditional laboratories confirm the misconception that science is a body of arcane, irrelevant information to be memorized, rather than a method of intellectual operation that students can use themselves in their future lives. Our failure to produce scientifically literate students can be at least partly attributed to our failure to use laboratories effectively.

These issues are not new. Educators ranging from John Dewey (1916) to the Commission on Undergraduate Education in the Biological Sciences (cited in Holt et al., 1969) have recommended a solution: investigative laboratories, in which students plan and execute their own investigations rather than following directions in a laboratory manual. These recommendations have been almost universally endorsed by biology educators, but investigative laboratories remain rare due to problems of implementation. We have developed a program which solves these problems and which is flexible enough to be adapted to other institutions. The major components of our program include modular “wetlab” exercises organized around a series of videotapes about laboratory techniques, a computer simulation called FISHFARM, and exercises to improve student oral and written communication skills.

Many variations of the investigative laboratory format have been reported in the literature (Abell, 1972; Boohar, 1975; Burke, 1979; Davis and Black, 1986; Fogle, 1985; Hancock, 1972; Janners, 1988; Lacy and Funk, 1972; Manteuffel and Laetsch, 1980; Mills, 1981; Moll and Allen, 1982; Murray, 1972; Sestili, 1974; Thomson, 1972). Differences among programs may result from differing philosophies, resources, or student populations. However, all investigative laboratories have certain common elements (e.g. Holt et al., 1969; Thornton, 1972), including de-emphasis on lecture content, and student-designed investigations characterized by a planning stage, the experimental work itself, and oral and/or written summation of the investigation.

Despite encouragement from the scientific community and the intellectual attractiveness of the idea, investigative laboratories have not been widely adopted, and some programs described in the literature have been abandoned. Cited problems, reviewed in Thornton (1972) and Champagne and Klopfer (1977), have included a low level of student skill, logistics difficulty, insufficient time for students to design and discuss their experiments, and the necessity for most investigations to be so simple that students see little relevance to real-world problems. Our investigative laboratory program addresses each of these difficulties.

Investigative Wetlabs

Students in introductory biology are generally not familiar with methods which they might employ in their own experiments. Unless the number of students is small enough to be handled by faculty members in their research laboratories, students will have difficulty coming up with ideas for investigations, and will probably not be capable of performing the techniques they may find through library research.

Related to the problem of a low level of student skill is the logistic nightmare which could result from allowing large numbers of students to determine their own investigations. Our program solves both these problems through the use of “methods modules” which present students with techniques that can be used for their investigations. Each of the fourteen modules developed for our course includes a videotape which explains how the method works and demonstrates the techniques involved, plus written step-by-step directions for the procedures, and a list of required materials. The videotape shows how to measure a dependent variable (e.g., the amount of oxygen produced by *Elodea* during photosynthesis); it is then up to the students to decide upon an independent variable to use for their investigation. The methods chosen for these modules were drawn from exercises which are already widely used in introductory biology laboratories; most people who teach biology at this level will be familiar with how the techniques work, what kinds of variables might be investigated, and how to troubleshoot problems with the procedures or equipment. Basic materials requests are also predictable, alleviating much of the logistic uncertainty inherent in investigative laboratories. A list of the modules is included as Appendix A.

In order to allow time for students to develop their own ideas for investigations, discuss them with the laboratory instructor, and present their proposals and results to the class, we require students to perform only three wetlab experiments during the 11 weeks of laboratory devoted to wetlabs during the semester. While students in traditional laboratories are kept busy performing numerous “cookbook” exercises during each laboratory period, students in investigative laboratories are spending more time on mental operations.

A schedule of our laboratory activities is included as Appendix B. For the first experiment, which is not performed until the fifth week of the semester, students have a choice of seven modules on the topics of pH, diffusion, and osmosis. Modules available for the second wetlab experiment include methods for investigating enzymes, photosynthesis, and cellular respiration. Working in groups of three or four, students first watch an introductory videotape on each topic. They then view “techniques” tapes and select the method they will use for their investigation. After working out an experimental design, each group consults with the laboratory instructor, who answers technical questions and directs students to other sources of information. For the third wetlab experiment, students have a chance to revise one of their hypotheses based on the results from the first or second wetlab and perform an experiment which will extend their previous investigation.

Communication Skills

Our laboratory program emphasizes communication skills as well as science process skills. During one laboratory session, each group presents its proposed experiment to the class for critique. These discussions have been very successful in stimulating students to critically evaluate the work of others. After the experiment, each group makes an oral presentation of the results. Each student also turns in a paper written in scientific report format. We have produced a Writing Guide to help students with this aspect of the course.

In the first year of implementing investigative laboratories, we observed that students had a great deal of difficulty in writing the Introduction and Discussion sections of their reports. We now spend 2–3 hours of laboratory time on exercises which help students become more familiar with the contents of these sections. Students also write a practice Introduction and Discussion, which are critiqued by their peers. The first wetlab report is turned in as three assignments: the Introduction is due when the proposal is presented, the Materials and Methods sections is due when the experiment is performed, and the Results, Discussion, and Conclusion are due 2 weeks later. By turning in the first report in stages, students can receive feedback from the laboratory instructor before completing the entire report. We also allow students to improve and resubmit the first wetlab report for a better grade before the second report is due; the highest grade possible on the resubmission is a B. The second and third wetlab reports are submitted as a whole rather than piecemeal, and they may not be resubmitted.

FISHFARM

One of the weaknesses of our investigative wetlabs is that they are necessarily short, simple investigations. Also, in order to minimize the possibility for confusion, we insist that our students plan their methods and material requirements in detail. While these two steps make investigative wetlabs practical, we also wished to give the students practice at constructing a complex, more “spontaneous” series of experiments in which the experiments performed at the later stages depend on the early results. This is the role of FISHFARM.

FISHFARM Overview

FISHFARM is a computer simulation (for Apple IIe or IIGS and IBM computers) of the biology and economics of a commercial aquaculture operation. It simulates fish growth in both highly controlled indoor aquaria and in outdoor ponds in coastal South Carolina. Its scenario is that the student is in charge of the research division of an aquaculture company which has been a profitable channel catfish "grow-out" operation. That is, the company purchases catfish fingerlings (about 15 cm long, weighing about 25 g each), stocks them in ponds in late March, and feeds them until early November when they are about 30 cm long and 600 g each. Then it processes them into fillets and sells them to restaurant chains. In keeping with this history, the program allows the user to simulate catfish culture. But recently, the company has acquired a new variety of fish (called Fish A, Fish B or Fish C in the program) which appears to have commercial promise. The company plans to devote a South Carolina production unit with 200 hectares (495 acres) of ponds to its production.

As head of the research division, it is the student's task to optimize the profitability of the culture of the new fish. If the student performs a systematic series of experiments and uses the data correctly, the simulated production unit will efficiently grow large numbers of fish to market weight and will make about $300,000 per growing season. However, if the experimental program is flawed, the fish will grow poorly, disease and oxygen depletion will kill large numbers, and the unit may lose millions of dollars.

By using a computer simulation, we remove the usual barriers to student experiments: lack of manipulative skill, lack of time, and lack of resources. Merely by pressing keys, students may simulate months or years of expensive experiments in a few minutes. And by using aquaculture, we engage the students in a complex and highly biological problem with competition for the highest profit adding motivation.

The FISHFARM Manual

The FISHFARM manual is part of our investigative laboratory manual, and gives the students necessary background in aquaculture plus step-by-step directions for operating the computer program. After introductory material, the manual gives an overview of world aquaculture and then a more detailed description of American catfish culture. Then three chapters describe specific exercises (for example experiments on fish oxygen tolerance or feed requirements), following specific background material with step-by-step instructions. These chapters contain no blank data tables, however; the students are expected to record their results in their laboratory notebooks. Finally, the last chapter gives the students advice on writing their FISHFARM reports.

Student Activities

The four FISHFARM activities are an orientation exercise, a series of experiments on temperature, oxygen and ration requirements of their unknown fish, a series of experiments to determine correct stocking density, and a "production run" which simulates 5 years of commercial operation and tests the profitability of their culturing conditions. The first two activities take one laboratory period and the second two another period.

Each of the two laboratory periods results in a student "progress report" which is the source of their FISHFARM grade. Presentation, orderly experimentation, and correct interpretation of data are graded in these progress reports. Profitability is irrelevant to the FISHFARM grade, although we do hold an informal competition between student teams with the same unknown fish for the most profitable production run.

The Orientation Session

This exercise introduces the students to the program, shows some of its more dramatic outcomes, and demonstrates that culturing fish (even simulated fish) profitably is not a trivially easy problem. The manual challenges the students to grow catfish profitably, but gives only the most general guidance on six different culturing decisions. For example, it advises them to stock between 1,000 and 500,000 catfish per hectare (provided other conditions are correct, the best stocking density is about 7,500–12,000); it tells them that fish usually require between 10% and 80% protein in their diets (not telling them that for catfish the protein percentage must be very close to 30% for profitable production). Consequently, very few students get all the conditions right, profits are low, and spectacular fish kills are common. Thus interest is increased in the prospect of learning a systematic method to solve complex problems such as the aquaculture problem.

The Temperature/Oxygen/Feeding Exercise

The first of the “organized” experiments uses simulated indoor tanks with rapid water flowthrough. Success of one of the tank experiments is judged by fish survival and weight gain, and especially by the cost of weight gain. The student may vary the water temperature, dissolved oxygen, feed protein percentage, and feed amount to learn the answers to three practical questions about the unknown fish:

1. Can the fish tolerate the high summer temperatures of the outdoor ponds, or must there be a flow of cool groundwater through the pond to moderate the temperature?

2. At what dissolved oxygen concentration does the fish start to grow poorly? This is the dissolved oxygen concentration at which the automatic aerators in the pond should be turned on.

3. What protein content in the feed allows the fish to grow most economically?

While the students are given general directions on how to perform these experiments, it is up to them to plan a systematic series of controlled experiments and to choose the levels of the independent variable they wish to test. The program also includes variability between runs under the same conditions, and so they must also perform replicate experiments. An example of a feed protein experiment is shown in Figure 10.1; the program will plot a similar graph on the screen.

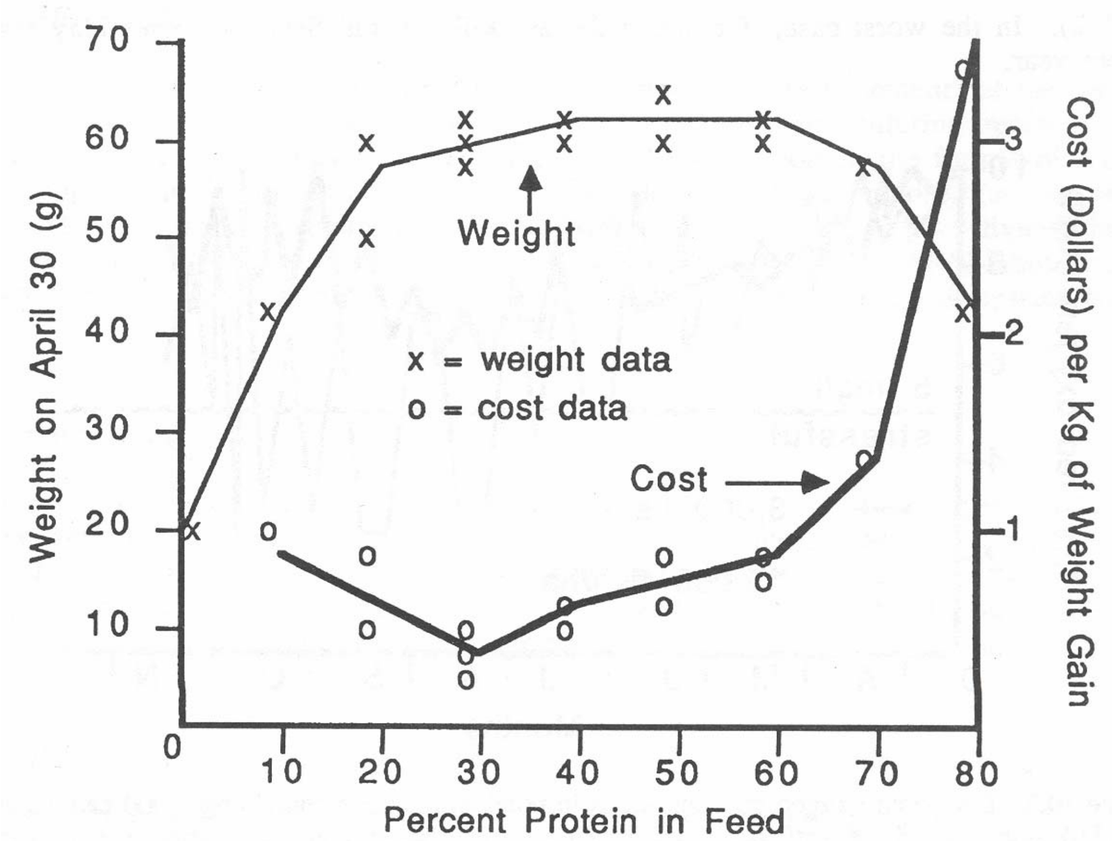

Figure 10.1. Typical results for simulated growth of catfish as a function of protein content of the diet. Growth was simulated in tanks with temperature set at 25°C, oxygen set at 10 mg/liter, and with a feeding rate which was varied to match the feed consumption rate of the fish.

The Stocking Density Experiment

During the second FISHFARM laboratory period, the students must apply their temperature/oxygen/feeding results to simulated culture in outdoor ponds. If they have done these previous experiments correctly, they should know whether they should use static ponds or an input of groundwater, at what dissolved oxygen concentration to begin mechanical aeration, and what kind of feed to use. Then they can observe the profit results of different stocking densities with confidence that all conditions except stocking density are optimal. In practice, one or more of the earlier conditions (especially feed protein percentage) may be wrong, and so the students will have to fine-tune their tank results before they can proceed with their pond experiments.

The stocking density experiments also use profit and loss as a measure of success. The program computes expenses from fixed costs (costs of pond maintenance, taxes, vehicle repair, and so forth), the cost of the fingerlings placed in the pond, and the cost of the feed. Gross profits are computed from the weight and per gram selling price of the fish. In order to make a profit, the fish must have a low mortality rate and gain weight efficiently, and there must be an adequate number of fish to recover fixed costs. On the other hand, if students get greedy and overstock, oxygen concentrations will dip below the lethal limit, ammonia will accumulate, and disease will kill thousands of fish (see Figure 10.2). In the worst case, if rampant disease kills all the fish, the losses may reach $10 million per year.

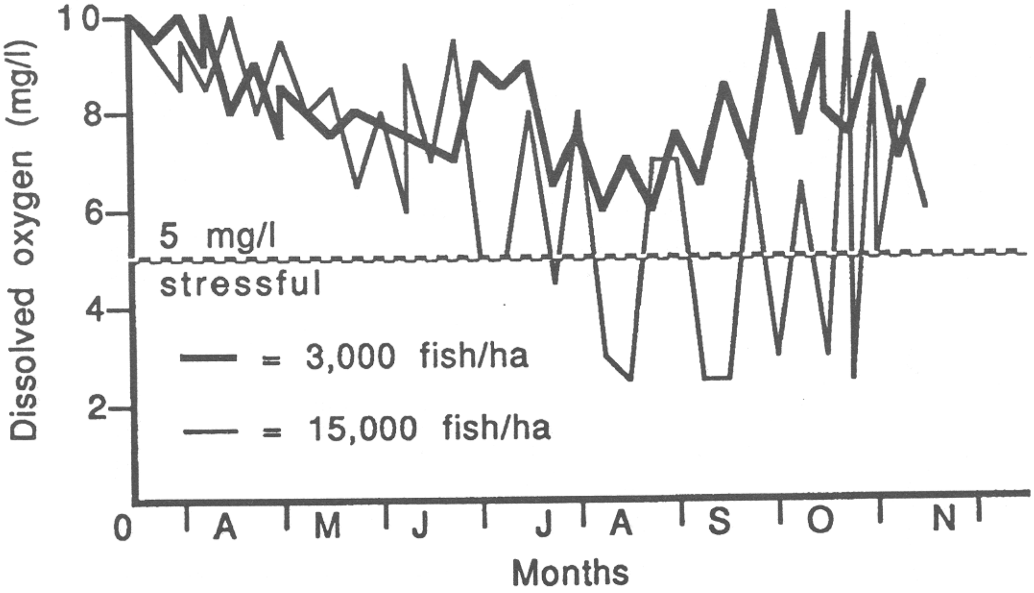

Figure 10.2. Dissolved oxygen concentrations in pond simulations containing 3,000 catfish/hectare (dark line) and 15,000 catfish per hectare (light line). No emergency aeration was used in either case. The low oxygen concentrations in the 15,000 fish/hectare case caused 10.6% mortality.

To help the students diagnose these problems, the program follows the harvest data with a “Pathologist's Report” which gives the percentage of fish death caused by low oxygen, high ammonia, disease, heat stress, cold stress, sudden temperature change or malnutrition.

The Production Run

Immediately after determination of most profitable stocking density and confirmation of the correctness of the other culturing conditions, the students record their profits from five consecutive pond experiments. They report these profits to their instructor so they can be compared with the profits attained by teams working on the same unknown fish in other sections.

The profit competition heightens interest to an obsessive level among some students, although some other students seem to find a profit-driven competition distasteful. Therefore we have de-emphasized the profit contest in recent semesters, although we do intend to keep it as part of our program.

The FISHFARM Progress Reports

The FISHFARM grade is based on two progress reports to “management” of the company in which the students describe their experiments and defend their culturing recommendations. Originally, we had the students write one final FISHFARM report in the format of a complete scientific paper. But due to complaints about the workload which this imposed (and the inevitable student tendency to ignore assignments until just before they were due) we have divided the writing requirement into two progress reports, one due 2 weeks after each FISHFARM laboratory period. Each progress report consists of a raw data section, a results section, and a discussion/conclusion section.

The Raw Data Section

This section consists of the raw data records on the laboratory notebook pages, and its purpose is to give credit for proper use of the students' notebooks. Neatness is **not** a factor in grading, but we insist that all data be recorded here and every data point be clearly associated with the methods which produced it. Bonus points are given for evidence of thoughtful notebook use (e.g., observations in the margins about trends in the data, questions which the data raise, etc.).

The Results Section

Formal tables and graphs derived from the raw data (and presented in the pages of the notebook) make up this section. Grading is based on the usual criteria of clarity, neatness, labeling of axes, specification of units, and appropriate presentation. Only data which do not appear in the Raw Data section can be presented here.

The Discussion/Conclusions Section

This final section consists of a typewritten page in which the students summarize and interpret their results. Emphasis in grading is on good scientific writing style, frequent reference to the data, discussion of weaknesses in the results, and intelligent use of knowledge of aquaculture. Bonus points are awarded for citation of aquaculture material which is not in the FISHFARM manual.

A More Investigative FISHFARM?

FISHFARM and its manual have undergone many modifications to increase their ease of use. As a result, the students can easily follow the manual directions, and if they do, almost all teams will discover the correct culture conditions and will have profitable production runs. However, concern has been raised that FISHFARM has become too directed and that the exercises move along so well because the students are required to do too little original thinking.

Therefore, we are considering implementing a more investigative use of FISHFARM. For example, we might give the students a list of aquaculture questions which they might investigate (some of which might concern questions of fish physiology or ecology rather than profits), have them choose one, and then leave the design of the investigation up to them. Of course, in that case FISHFARM would require a larger input of class time and instructor time, with students submitting proposals, presenting them to the class, and so forth. At this point the question of how to use FISHFARM best is unresolved.

Results

Our data on results came mostly from the fall of 1989 when there were 15 investigative sections taught by 11 laboratory instructors. At that time, there were only two wetlab investigations, and investigative laboratories occupied only about two-thirds of our first semester laboratory course. We gathered data on lecture course grades, scores on an in-house process skills test, student perceptions of the nature of science, student opinionnaires, and instructor opinionnaires.

Lecture Grades

One of the criticisms of investigative laboratories (voiced by students as well as faculty) is that they deprive students of reinforcement of lecture content. Therefore, one might expect that lecture scores would decline in investigative sections. However, there were no statistically significant differences in the lecture exam results between traditional and investigative students, indicating that investigative laboratories apparently did not decrease the performance of students in our content-oriented, traditional lecture course.

Process Skills Test

The process skills test consisted of 26 multiple-choice questions on reading tables and graphs, interpretation of results, experimental design, and troubleshooting of experiments. It was given as a pre-test during the first laboratory meeting and as a post-test at the end of the investigative portion of the course to both traditional and investigative students. In order to get students to take the post-test seriously, students in both treatments were given varying numbers of bonus points (ranging up to 3% of their grade in the course) for doing well on the post-test.

Unfortunately, there were no significant treatment effects on pre-test, post-test, or gain. Therefore, if our test is a valid measure of process skills, we cannot claim that two-thirds of a semester of investigative laboratories improves the process skills of students more than the same period of traditional laboratories.

Opinions on the Nature of Science

The last nine questions of the post-test were opinion questions on how the students think science operates. The only significant difference between treatments occurred on the statement, “The scientific approach can be used to solve any problem.” Here, 54% of the investigative students agreed with the statement, but only 44% of the traditional students agreed. There are many problems outside the province of the scientific approach, so this is not a good result for the investigative students. However, overall the results indicate fairly good knowledge of and attitudes towards the methods of science by all treatments.

Student Opinion

Data were compiled on the number of students who agreed with, were neutral about, or disagreed with a series of statements about investigative laboratories. Over three semesters of implementation, an average of 65% of the students indicated that they enjoyed having the freedom to design their own experiments (only 15% disagreed) and 47% said that they enjoyed using FISHFARM. Large majorities (usually over 80%) agreed that the videotapes and written materials were helpful in doing the laboratories, and similar numbers acknowledged the helpfulness of their team members and laboratory instructors. About 60% of the students thought that they were more confident than at the beginning of the course in their abilities to analyze problems, design experiments, and analyze data. One of our major objectives was to give the students transferrable skills, and 43.5% agreed that they would be able to apply skills learned in our course to other courses (24.3% disagreed).

The surveys also disclosed the major student criticism of investigative laboratories—62.2% thought the course required too much work out of class (17.5% disagreed). We perceive this as a problem as well, and have taken steps to reduce and spread out the workload over time. But since past surveys show that a majority of students claim to spend 30 minutes or less per week studying for the traditional, quiz-oriented course, we do not regard student complaints about workload as a decisive criticism of our program.

Instructor Evaluation

Instructor evaluation is of two types: surveys of our own laboratory instructors, and opinion data from a 5-day workshop in which faculty from 30 institutions in the US and Canada evaluated our program in summer of 1990.

Clemson Laboratory Instructors

Results came from a questionnaire administered to 11 laboratory instructors in the fall of 1989, when each instructor taught both a traditional and an investigative section so comparisons could readily be made: 78% of the instructors said investigative students learned more about how science operates, 71% said that investigative students were better prepared for future science courses, 86% said investigative students were better writers, 83% thought investigative students were better able to solve problems, and 55% thought investigative students took the laboratory course more seriously. On the other hand, 66% thought traditional students were more enthusiastic about the traditional laboratory, and 90% acknowledged that investigative laboratories were more work for the instructor.

Workshop Attendees

The 1990 summer workshop hosted 30 experienced faculty with responsibility for introductory biology laboratories. After 5 days with our materials, the attendees heavily endorsed our program: 100% agreed or strongly agreed that teaching science process skills is an important part of the traditional laboratory, that our videotapes and FISHFARM would help them implement investigative laboratories at their own institutions, and that FISHFARM was a valuable adjunct to wetlab investigations. As the strongest endorsement, 100% said that they planned to implement investigative laboratories at their own institutions. Subsequent questions made it clear that this last result did not mean that the attendees planned to adopt our program intact, but rather that parts would be used. One of the major reasons was lack of equipment (e.g., computers and VCRs) at the home institutions. But overall, reaction of these experienced faculty to our program was very encouraging.

Availability of Materials

The materials we have developed for our investigative laboratory program include the videotapes, student and instructor versions of the Wetlab Manual, Prep Guide, Writing Guide, the FISHFARM program, and the FISHFARM manual. At present, our materials are copied locally for use in our laboratories; we do not have the capability of producing copies for general distribution. We are currently exploring opportunities for commercial publication.

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APPENDIX A

Videotapes for Methods Modules

Methods for Investigating pH

Measuring pH with Red Cabbage Indicator (Duration: 6:58)

A solution of anthocyanins extracted from red cabbage is used as a pH indicator. Color standards are prepared with pH 2, 4, 6, 7, 8, 10, and 12 buffers. The method is demonstrated by adding cabbage extract to sodium bicarbonate and to 7-Up and comparing the resulting colors to the standards. This tape also demonstrates how to measure with a delivery pipet and pi-pump.

Measuring pH with a pH Meter (3:22)

Use of a pH meter is demonstrated with a Fisher Accumet® Model 140 (analog) pH meter. A Beckman Model 3500 digital pH meter is also shown briefly. The videotape assumes calibration of the instrument will be done by the technician or instructor, and simply shows students how to handle the electrode, use the function selector, and read the pH scale. Use of a magnetic stir plate is also demonstrated.

Determining the Buffering Capacity of a Solution (8:56)

The buffering capacity of “solution A” is determined by adding 1 ml 0.1N HCl to a 40-ml aliquot. The pH, as measured by a pH meter, drops immediately from 6.6 to 3. When 1 ml 0.1N NaOH is added to a fresh sample of solution A, the pH rises drastically, demonstrating that this solution has no buffering capacity. The pH of solution B is measured as 8. The addition of 15 ml of HCl in 1-ml increments produces only a gradual lowering of pH. Addition of NaOH to a fresh aliquot of solution B also produces very gradual change in pH, demonstrating that solution B is a good buffer around pH 8. This tape also demonstrates use of a delivery pipet with a pi-pump.

Methods for Investigating Diffusion and Osmosis

Using Microscopic Observation of Plasmolysis to Determine a Solution Isotonic to Plant Tissue (7:30)

Epidermal peels from red onion are placed in a graded series of sucrose solutions. After equilibration, the tissue is observed under the microscope to determine the number of cells which have plasmolyzed. The objective is to find the concentration of a solution which causes 50% plasmolysis; this solution is considered to be isotonic to the plant cells.

The Weight-Change Method of Estimating a Solution Osmotically Equivalent to Plant Tissue (9:00)

A cork borer is used to obtain equal-sized sections of potato tissue. The sections are weighed, then soaked in a graded series of sucrose solutions for 1 hour. They are then reweighed, and the percent change in weight is calculated and graphed against the sucrose concentrations. The sucrose concentration at which no weight change would occur can be inferred from the graph. This solution is considered to be osmotically equivalent to the potato tissue. This tape also demonstrates the use of a triple beam balance.

The “Falling Drop” Method of Estimating a Solution Osmotically Equivalent to Plant Tissue (9:00)

A cork borer is used to obtain equal-sized sections of potato tissue. The sections are soaked in test tubes containing a graded series of sucrose solutions long enough for some osmosis to occur (about 30 minutes). Osmosis changes the concentration, and thus the density, of the soaking solution. The soaking solution is compared with the original concentration of the solution to determine whether osmosis has increased or decreased its density. The objective is to find the concentration of a solution which neither gains water from nor loses water to the potato. This solution is considered to be osmotically equivalent to the potato tissue. (This is a modification of the Chardakov method of determining water potential.)

Using dialysis tubing as an artificial membrane (7:46)

Dialysis tubing is compared with the plasma membrane, and the use of dialysis tubing to study diffusion and osmosis is demonstrated. It is shown that starch is too large a molecule to cross the membrane, but IKI and glucose cross the membrane by simple diffusion (tubing with MWCO 12,000–15,000 is used).

Methods for Investigating Enzyme Activity

An Assay for Peroxidase Activity (10:08)

An aqueous extract from turnip tissue is used as a source of peroxidase. This enzyme catalyzes the oxidation of (in this assay) guaiacol by hydrogen peroxide. Oxidized guaiacol is brown; product formation is measured using the Spec 20. To illustrate the technique, the assay is performed using two levels of enzyme concentration. This tape gives a brief explanation of how the Spec 20 works, and instructions for its use in this assay.

An Assay for Catecholase Activity (8:58)

An aqueous extract from potato tissue is used as a source of catecholase. This enzyme, also known as polyphenol oxidase (PPO), catalyzes the oxidation of polyphenols to quinones. We use catechol as a substrate, and measure formation of the colored product benzoquinone using the Spec 20. To illustrate the technique, the assay is performed using two levels of enzyme concentration. This tape gives a brief explanation of how the Spec 20 works, and instructions for its use in this assay.

An Assay for Catalase Activity (14:00)

An aqueous extract of beef liver is used as a source of catalase. This enzyme catalyzes the decomposition of hydrogen peroxide to water and oxygen. In this assay, the reaction is stopped with sulfuric acid and an aliquot of the reaction mixture is titrated with potassium permanganate to provide a measure of how much hydrogen peroxide remains. To illustrate the technique, the assay is done using 0, 0.2, and 1.0 ml of liver extract.

Methods for Investigating Photosynthesis

A Measure of Photosynthetic Rate in *Elodea* (5:22)

Elodea plants are immersed in a sodium bicarbonate solution with their stems inserted in a water-filled plastic tube. As photosynthesis proceeds, oxygen bubbles are released from the stems and collected in the tube, providing a measure of photosynthetic rate. An experiment testing the effect of light intensity on photosynthesis is set up to demonstrate this method.

A Measure of Photosynthetic Rate in Spinach Leaf Disks (7:15)

Leaf disks of uniform size are cut from spinach leaves and infiltrated with a sodium bicarbonate solution under vacuum. This removes gases from the intercellular spaces, causing the disks to sink. As oxygen accumulates during photosynthesis, the disks rise to the surface again, providing a measure of photosynthetic activity. An experiment testing the effects of red, blue, and green light on photosynthesis is performed to demonstrate this method.

Methods for Investigating Cellular Respiration

An Assay of Mitochondrial Activity (14:38)

A mitochondrial suspension from white lima beans is prepared before class for student use (procedure not shown). The assay is based on the succinate ---> fumarate reaction of the Krebs cycle. Substrate, buffer, and dichlorophenol-indophenol (DPIP) are added to the mitochondrial suspension. Oxidized DPIP is blue, but turns colorless when it accepts electrons generated by the succinate-to-fumarate reaction. The color change is quantified by measuring percent transmittance of light in the Spec 20. A brief explanation of how the Spec 20 works and instructions for its use in this experiment are included on the tape.

Measuring of Carbon Dioxide Evolution During Alcoholic Fermentation (4:00)

The fermentation kit available from Carolina Biological Supply Company is used in this experiment (the old model which puts the two vials in a cup is shown, rather than the new version in which one vial is put inside the other). The tape illustrates how to set up the apparatus. A reaction mixture of corn syrup and a yeast suspension is put in the fermentation vial to demonstrate how the CO_2 evolved is collected and measured.

Introductory Tapes

The tapes in this series give brief introductions to the topic covered in the methods tapes. They are intended to help students understand the methods and give them ideas about variables to investigate.

Introduction to pH (4:20)
Regulation of pH by Buffer Systems (4:32)
Principles of Diffusion (2:37)
The Importance of Osmosis to Biological Systems (6:00)
Use of Assays to Determine Enzyme Activity (2:40)
Factors Affecting Enzyme Activity (3:20)
The Summary Equation for Photosynthesis (1:16)
Factors Affecting Photosynthesis (2:19)
A Summary of Aerobic Respiration (2:49)
A Summary of Alcoholic Fermentation (2:14)
Measuring Pulse and Blood Pressure (4:00)

APPENDIX B

Biology 105 Laboratory Schedule (Fall 1990)

Week	Laboratory Activity	Assignments Due
Aug. 27–31	Orientation Introduction to wetlabs: scientific inquiry, experimental design, data analysis	
Sept. 3–7	Design wetlab Experiment 1	Graphing exercise
Sept. 10–14	Advice on writing Introduction of laboratory report Group discussions of proposals	Writing exercise
Sept. 17–21	Present wetlab Proposal 1 to class Advice on writing discussion of laboratory report	Wetlab Report 1: Introduction Wetlab Proposal 1 Writing exercise
Sept. 24–28	Perform wetlab Experiment 1	Wetlab Report 1: Methods
Oct. 1–5	Perform FISHFARM experiments on temperature, oxygen, and feeding	FISHFARM Worksheet 1
Oct. 8–12	Present results from wetlab Experiment 1 Design wetlab Experiment 2	Wetlab Report 1: Results, Discussion, Conclusion, and Literature Cited
Oct. 15–19	Perform FISHFARM stocking density experiments and production run	FISHFARM Progress Report 1 FISHFARM Worksheet 2
Oct. 22–26	Present proposal for wetlab Experiment 2	Wetlab Proposal 2
Oct. 29–Nov. 2	Perform wetlab Experiment 2	FISHFARM Progress Report 2 (Resubmission of Report 1)
Nov. 5–9	Labs do not meet (Fall Break Nov. 5–6) Discuss proposal for Experiment 3	
Nov. 12–16	Present results for wetlab Experiment 2 Present proposal for wetlab Experiment 3	Entire report for wetlab 2 Wetlab Proposal 3
Nov. 19–23	Labs do not meet (Thanksgiving holiday Nov. 22–23)	
Nov. 26–30	Perform wetlab Experiment 3	
Dec. 3–7	Present results for wetlab Experiment 3	Entire report for wetlab 3