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ABSTRACT

This project originated with the desire to offer general biology students a laboratory experience which emphasizes scientific thinking rather than a review of lecture content. To create investigative laboratories without many of the practical problems of their implementation, this project uses a combination of "methods modules" for wetlabs and FISHFARM, a computer simulation of a commercial aquaculture enterprise. FISHFARM served as an introduction to the process of scientific inquiry and data analysis. In the wetlabs part of the course, students designed and carried out experiments using traditional "bench" science. Methods modules were used to help students develop the necessary skills. These modules used videotapes to demonstrate procedures. The program was evaluated on four aspects of student achievement: lecture exam scores, process skills, opinions on the nature of science, and writing ability. There were no differences between students in this experimental group when compared to a control group. Data on student opinion was also collected and showed positive views for the approach. The following topics are found in the appendix: list of methods module videotapes; summer schedule for investigative labs; database summary of student projects; process skills and nature of science test; and student opinion data. (PR)

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Our project has successfully implemented an investigative laboratory program (in which students design their own experiments) in our first-semester general biology course. Materials produced include videotapes which show laboratory techniques, FISHFARM (a computer simulation of a commercial aquaculture enterprise), student manuals for the wetlab and FISHFARM components, a writing guide, instructor's guide and prep directions. Grades are based largely on written reports. Students in investigative laboratories did not have significantly better process skill development or writing skills (or significantly lower lecture course scores) than students in traditional laboratories, and often preferred traditional laboratories because of their lower workload. Nevertheless, investigative labs have attracted strong instructor and administrative support because of their inherent appeal to science faculty.

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Project Overview

Our project originated with the desire of the PI and Co-PI to offer general biology students a laboratory experience which emphasizes scientific thinking rather than a review of lecture content. To overcome the obstacles which have plagued similar efforts at other institutions, we developed new materials and reorganized the laboratory course. We have recently completed two years of successful implementation with participation of over 700 students. Faculty acceptance has been strong, and student opinion has generally been positive.

We have given five presentations and workshops at national meetings to describe our program, and have also obtained two NSF grants in support of our project.

Purpose

One of the purposes of science laboratories should be to develop the process skills used in practicing science. However, most "traditional" biology laboratories are used to reinforce lecture content. "Investigative" laboratories, in which students design their own experiments, remain rare due to problems of implementation. Our project attempted to develop practical solutions to these implementation problems.

As we developed and evaluated our project, it became clear that we had two distinct goals. Our first goal was pragmatic: to develop and successfully implement an investigative laboratory program in our large non-majors biology course. Our second goal depended upon achieving the first: to make a contribution to our students' education in process and communication skills.

Background and Origins

The primary mission of the Biology Program at Clemson University is providing high-quality instruction in introductory biology and improving instructional methods, so our project received strong departmental and college support.

Our laboratory course affects over 1200 students per year, and the radical changes we made affected several groups of people. The graduate teaching assistants were cooperative from the outset. Enthusiastic support of the teaching assistants is a critical factor for implementation of our program at any institution. The laboratory prep staff did not welcome the changes initially, but they have improved their organizational approach and are now quite happy with investigative labs.

The major opposition to our project has been expressed by a minority of faculty members in the Biology Program who maintain that traditional laboratories serve our students adequately. The vigorous support of the administration has been an important factor for neutralizing faculty opposition as well as in securing the cooperation of the graduate teaching assistants and the laboratory prep staff.

Project description

Our project addressed the practical problems of implementing investigative laboratories: student-designed experiments have unpredictable requirements for materials, students have low skill levels and insufficient knowledge to design a worthwhile investigation by themselves, and the investigations students can perform in an introductory-level lab are necessarily brief and unsophisticated. We solved these problems by a combination of "methods modules" for wetlabs and FISHFARM, a computer simulation of a commercial aquaculture enterprise. The materials needed for these new laboratories, including videotapes for the methods modules and FISHFARM, were developed by the PI and Co-PI for this project.

FISHFARM served as an introduction to the process of scientific inquiry and data analysis. In FISHFARM the students were asked to perform simulated experiments to determine the economically optimum culturing conditions for a hypothetical new fish hybrid. As culturing conditions were changed, fish growth and profits varied realistically. Peak profits were only reached with the correct settings of groundwater influx into the ponds, aeration of the ponds, feed protein content, and stocking density of fingerlings. The best value for each culturing variable was determined by student experiment. In the final exercise, students used their experimentally-obtained values in "production runs" which totalled the profits from five years of simulated commercial operation. Since the experimental objectives of FISHFARM are clearly defined, it served as an excellent introduction to "wetlabs."

In the wetlab part of the course, students designed and carried out experiments using traditional "bench" science. Potential problems of logistics and a low level of student skill and background knowledge were addressed by the development of fourteen "methods modules" which provided students with specific techniques that they could employ for their investigations. Each methods module was based upon a laboratory technique which is commonly used in introductory biology. A module consists of a videotape which demonstrates the method, a set of step-by-step procedures for students to follow, instructor's guide and preparator's guide. Brief introductory videotapes for each topic provide further background information. The methods modules perform three important functions. Illustration of the methods by videotape is an effective remedy for the low level of student skill in laboratory procedures. The methods modules also offer a selection of techniques which are appropriate for our students' levels of comprehension and abilities. Finally, each module has a known, familiar list of materials associated with it.

Students working in groups of three or four view the videotapes and design an experiment based upon one of the techniques presented. Their proposal is discussed with the instructor and presented to the rest of the class for critique. After performing the experiment, each group presents its results to the class, and each student writes a report. We collaborated with the Clemson English Department on the production of a Writing Guide which students found helpful for writing the reports. Thus our investigative lab project has emphasized the development of written and oral communication skills, as well as the development of the organized thinking and process skills needed to design and complete a scientific investigation. Student grades are based upon the written report for each wetlab investigation, two FISHFARM reports and several smaller assignments such as in-class writing and graphing exercises, written proposals for experiments and laboratory notebooks.

We originally planned to replace only the first seven laboratories (eight weeks) in our first-semester general biology course with investigative labs. After the first year of implementation we expanded the investigative labs to the full semester by adding a third wetlab experiment, which was to be based upon one of the previous two experiments. Our grading criteria also changed. These modifications represent both practical and pedagogical improvements in response to criticisms by students and instructors. Our original purpose -- to convert from a traditional "cookbook" format to investigative laboratories -- has not been altered. In fact, we have now eliminated cookbook labs from our first-semester course.

Project Results

Although investigative labs eliminate the review of lecture material provided by traditional labs, there was no significant difference between the lecture exam scores of students in traditional and investigative sections. However, despite the fact that investigative labs emphasize process skills, there was also no significant difference between traditional and investigative students in scores on our in-house process skills test. At the end of the semester, investigative students and traditional students also had the same understanding of the nature of science and similar writing abilities.

Students in investigative labs strongly endorsed the individual parts of the program: they expressed high opinions of the materials and their instructors and they generally liked the course activities. They also were convinced that they had gained the specific skills involved in scientific problem-solving. On the other hand, students tended to prefer traditional labs, mostly because of a significantly increased workload in investigative labs.

Our project has been presented to various audiences of college biology educators, and has received strongly positive responses. We are currently in the process of further dissemination through publication of the materials and results.

Purpose

Our project attempted to develop an investigative laboratory program which solves the practical problems that have discouraged biology educators from adopting this approach to laboratories.

Ideally, science education should develop the process skills involved in practicing science, such as problem solving and evaluating data, it should improve content mastery, and it should leave the student with a lasting interest in science. The logical setting for teaching process skills is the laboratory, but most "traditional" biology laboratories are used to reinforce lecture content. National panels of scientists as well as grassroots educators have recommended that "investigative" laboratories, in which students perform experiments of their own design, should replace the traditional "cookbook" laboratory. Such programs remain rare due to problems of implementation, including a low level of student skill, logistics difficulties, insufficient time, and the necessity for most investigations to be so simple that students see little relevance to real-world problems. We proposed to solve these problems by a combination of "methods modules" which allow student to perform bench science (wetlabs), and FISHFARM, a computer simulation which allows students to perform an extended series of experiments.

As we developed and evaluated our project, it became clear that we had two distinct goals. Our first goal was pragmatic: to develop and successfully implement an investigative laboratory program in our large non-majors biology course. Our second goal depended upon achieving the first: to make a contribution to our students' education in process and communication skills.

Background and Origins

The Biology Program at Clemson University is a unique environment for developing and testing innovations in biology education. Despite being housed in the research-oriented College of Sciences, the primary mission of our department is teaching. There is a separate Department of Biological Sciences whose faculty carry out discipline-based research in biology. Our faculty is charged with providing high-quality instruction in introductory biology and with improving instructional methods. Our project was therefore strongly supported by our departmental and college administration; this support was essential in obtaining the FIPSE grant as well as the two followup grants we received from the National Science Foundation.

Our project made radical changes in a laboratory course which typically serves over 1200 students a year. In addition to changing course policies such as the syllabus and grading criteria, several groups of faculty and staff were affected. The graduate teaching assistants, who actually teach the laboratories, were cooperative from the outset. We initially used TAs who were familiar with our traditional laboratory program; many welcomed investigative laboratories as a way to teach students about real science. In addition, we employed them as consultants to help us revise the course and materials during the project. The opportunity to influence the course, plus the extra income, were strong incentives for active cooperation. We believe that the enthusiastic support of the teaching assistants was essential to the success of our project, and it is a critical factor for implementation of our program at any institution.

The laboratory prep staff was not as enthusiastic about the changes, since they had been accustomed to setting up labs the same way for many years. Their trepidation was mainly a fear of the unknown. Over the course of the project, they have developed a better organizational approach to setting up the investigative labs, which will be extremely important when we attempt full implementation.

The major opposition to our project has been expressed by a minority of faculty members in the Biology Program who believe that our traditional laboratories contain enough emphasis on process skills and that an important (perhaps the most important) function of laboratories is to give the students a review of lecture course content. We cannot change the opinions of these individuals, but support from the lab instructors and our department head have largely neutralized their threat to the program.

The vigorous support of our department head has been an important factor for securing the cooperation of the graduate teaching assistants and the laboratory prep staff. The Biology Program underwent a change of heads during the course of our grant, but support for the project was not affected. In fact, our former head, who has become an Associate Dean of the College of Sciences, often publically cites our project as an example of the kind of instructional development which the College's faculty should be doing.

Project Description

Our project addressed the practical problems of implementing investigative laboratories: student-designed experiments have unpredictable requirements for materials, students have low skill levels and insufficient knowledge to design a worthwhile investigation by themselves, and the investigations students can perform in an introductory-level lab are necessarily brief and unsophisticated. We solved these problems by a combination of "methods modules" for wetlabs and FISHFARM, a computer simulation of the economics and biology of a commercial aquaculture enterprise. The materials needed for these new laboratories, including videotapes for the methods modules and FISHFARM were developed by the PI and Co-PI for this project.

Although we originally intended to convert only two-thirds of our first-semester laboratory course to an investigative format, at the end of the project we had replaced the entire course, which consisted of approximately 50 directed exercises, with FISHFARM and three student-designed experiments. The following section describes the current status of our laboratories which has been reached after four semesters of implementation (we are now in the fifth semester). The modifications made over the course of the project are described in the next section.

Current Investigative Laboratories

In FISHFARM the students were asked to perform simulated experiments (in either indoor tanks or outdoor ponds) to determine the economically optimum culturing conditions for a hypothetical new fish hybrid. As culturing conditions were changed, the fish responded realistically with more or less growth, and perhaps with mortality as well (FISHFARM simulates a "grow-out" culture system in which the fish are too young to reproduce). Profits varied accordingly, and peak profits were only reached with a specific set of culturing conditions. The culturing conditions which the students varied were use or non-use of groundwater influx into the ponds, aeration of the ponds when oxygen got low, feed protein content, and initial stocking density of fingerlings.

In an exploratory orientation session, students were invited to attempt to make a target profit with catfish (not one of the unknown fish they would be using later). Typically, they made arbitrary and simultaneous changes in several variables at once, or ignored some variables and experimented extensively with others. After experiencing consistently low or negative profits, the message was clear that systematic, controlled experimentation was the only practical way to solve the problem.

Over the rest of the first session and two other session, the students designed a series of experiments to determine the best value for each independent culturing variable. In the final exercise, students used their experimentally-obtained values in "production runs" which totalled the profits from five years of simulated commercial operation. Students with the same unknown fish competed for the highest profits.

FISHFARM served as an introduction to the process of scientific inquiry. By using the program, students learned about independent, dependent and controlled variables, choosing appropriate levels of treatment for the independent variable, and the importance of performing adequate replication. The simulation also provided an introduction to data analysis. FISHFARM results are graphed on-screen so students can receive constant feedback on their progress toward the experimental goals. The program's graphs provided a model for good graphing technique, as well.

FISHFARM was also used to introduce the practice of using a laboratory notebook to record predicted outcomes for experiments, collect data in a systematic fashion and graph the results. The notebooks were graded as part of the two progress reports submitted to "management."

FISHFARM allowed the students to design a *series* of experiments and to apply their investigative skills to an economically important problem. Student competition to produce the most successful aquaculture operation and the profit/loss incentives brought student interest to a high level. Since the experimental objectives and outcomes in FISHFARM are clearly defined, it served as an excellent introduction to "wetlabs."

In the wetlab part of the course, students designed and carried out experiments using traditional "bench" science. Potential problems of logistics and a low level of student skill and background knowledge were addressed by the development of fourteen "methods modules." Each methods module was based upon a laboratory technique which is commonly used in introductory biology (e.g. using a pH meter, performing an enzyme assay). A module consists of a videotape which demonstrates the method, a set of step-by-step procedures for students to follow, instructor's guide and preparator's guide. The modules cover topics in two units: the physical and chemical nature of cells and cellular metabolism. Brief introductory videotapes for each topic provide further background information.

The methods modules perform three important functions. First, and most basically, illustration of the methods by videotape is an effective remedy for the low level of student skill in laboratory procedures. Second, since our students have little or no scientific background, they are not prepared to devise original methods for their investigations. The methods modules offer a selection of techniques which are appropriate for their levels of comprehension and abilities. Finally, we know that we will be able to supply the equipment and materials required to perform investigations with these techniques.

A list of the videotapes is included in Appendix 2.

Before students began designing their own investigations, the process was modelled in lab. Students were shown a videotape illustrating a technique which was familiar to them (measuring pulse and blood pressure) but which would not be available as a selection for their own experiments. The class discussed possible investigations which could be done using the technique. Then the lab instructor presented "his" proposal for comparing the cardiovascular fitness of athletes and non-athletes, which was a superficially reasonable but flawed plan for an experiment. The class critiqued the proposal, and this resulted in an improved version. This exercise accomplished several objectives. The students saw how a specific technique can be applied to answer a question. Second, they learned that experimental design is a topic they could discuss with some degree of confidence. Third, it was clear that scientific endeavor is a collaborative process in which the project benefits from the ideas of others. The instructor's presentation also showed students how they would be expected to present their own proposals to the class. Overall, modelling the proposal stage of an investigation in this way provided a positive introduction to wetlabs.

In order to design their own experiments, each student team viewed the introductory videotapes and then watched techniques tapes until they decided which particular method they wanted to use. They then began planning their experiment. Each group met with their lab instructor before the next lab to discuss their proposal. The instructor raised questions which the group should consider and offered expert advice on the technical aspects of the investigation. At the next laboratory meeting, each group presented its proposal orally to the class. A class discussion followed each proposal; students were permitted to change their written proposals (which were done on a standard form) to incorporate suggestions made by their classmates before they handed in the proposal for a grade.

When students turned in their proposals, they also turned in a materials request form. Each methods module has an associated "prep kit," a list of the equipment, glassware and solutions which are automatically provided when the students request that module. The list is also printed in the student lab manual, so the students know what supplies will be available. In many cases the prep kit contains everything the team needs for its investigation, but the team can also request additional materials, or state that they will supply certain items themselves. The preparators assembled the kits and left them in boxes in the lab. The materials in each box were used and replaced by students throughout the week. Thus with the organizational tool of methods modules, the logistics requirements for investigative labs were quite predictable and therefore manageable.

Students completed their data collection in one laboratory period. The following week each student turned in a report written in standard scientific format. Each group also presented its results orally to the class.

After completing one wetlab investigation in each of the two units, each team designed and performed a third experiment which extended one of their previous investigations. This gave students an opportunity to apply the results of one experiment to developing a revised hypothesis or improving the experimental design, a realistic scientific experience.

Most of our students are unprepared to write in scientific style, and many are poorly prepared to write anything at all. We collaborated with Dr. Dixie Goswami of the Clemson English Department on the production of a Writing Guide which proved to be both popular and helpful. We also developed in-class writing exercises to help students with the two most difficult parts of a scientific report, the Introduction and the Discussion. In order to teach students the value of writing multiple drafts of a paper, we allowed students to revise and resubmit the first wetlab report for a higher grade. Thus our investigative lab project has emphasized the development of written and oral communication skills, as well as the development of the organized thinking and process skills needed to design and complete a scientific investigation.

A summary of the events of a recent investigative semester is included in Appendix 3.

Instructor preparation is a critical element of investigative labs. Student opinionnaires have shown that student perception of the laboratory is strongly influenced by the instructor. Most of our laboratory sections are led by graduate teaching assistants, some of whom have never taught before. Investigative labs require that instructors act as mentors, guiding students through a difficult process. This can be an uncomfortable role even for an experienced instructor because of the unpredictability of students' questions and needs as they design their experiments. The instructor must resist the temptation to take the path of least resistance and simply tell the students what to do as they would in a traditional laboratory setting. And when the experiments are performed, the instructor may be as surprised by the results as the students.

Our method of instructor training included aids to improve TA confidence about the subject matter plus suggestions for improving interactions with students in the laboratory. The instructor's version of the lab manual has a section containing suggestions for possible investigations and pitfalls to avoid for each experimental technique. We have kept a data base of all the investigations which students in previous semesters have carried out for each technique, including a brief synopsis of results and comments on their outcomes. A list of these experiments is printed in the instructor's guide, and some sample pages are included in Appendix 4. Since we have kept all the student papers turned in to date, instructors can consult the original paper to get more information about a past project which is similar to an investigation his or her students have proposed. In addition, course faculty were available for consultation with TAs about the feasibility of proposed investigations.

To prepare TAs for their teaching activities in the laboratories, we had weekly meetings to discuss the upcoming lab. TAs were given notes which described the objectives and the organizational structure of the lab period and gave any instructions on grading or logistics matters which were relevant to the week's activities. The notes also included teaching suggestions such as how to develop class discussion and how to help students design their experiments. In addition to these written aids, TAs benefitted from the comments of their colleagues who had previously taught investigative labs. Some new instructors were able to attend the laboratory of an experienced instructor before they taught; this was probably the best preparation of all, but unfortunately it was not possible for all TAs.

Modifications to the laboratory program

In our original proposal, we planned to replace the first seven laboratories (eight weeks) in our first-semester general biology course with two student-designed "wetlab" experiments and five separate FISHFARM sessions. Student grades for the investigative portion of the course were to be determined by a proposal and a report for each wetlab experiment and a FISHFARM final report which would integrate and synthesize the data collected in all the sessions. After the investigative labs were completed, students would finish the semester with five traditional labs which were designed to reinforce the content students were learning in the lecture course. In the traditional labs, students take quizzes over the material rather than write reports. In our first two semesters of implementation, Spring and Fall 1989, we followed that plan. The schedule was constrained by the allotted time period; each wetlab experiment required a separate week to plan, propose, perform and present results for the experiment. We therefore fit the FISHFARM sessions into the schedule by combining them in the same lab period with the short wetlab sessions such as presenting proposals.

Student and instructor feedback caused us to modify the schedule considerably. Students were disoriented by the mid-semester switch to traditional labs. They felt that they had spent several weeks adapting to our expectations, which were very different from what they expected a biology lab to be, only to have the rules changed in mid-course. Both students and instructors felt rushed by the need to accomplish so much in eight weeks. We had also observed that many students could have improved their experiments and obtained more meaningful results if they had had an opportunity to modify and repeat their experiments as real scientists do.

Therefore, beginning in the Spring semester of 1990, we expanded the investigative labs to the full semester by adding a third wetlab experiment, which was to be based upon one of the previous two experiments. This change allowed more time for the critical introductory material at the beginning of the semester and more time to assimilate and apply those lessons to designing the first wetlab experiment. Expanding the investigative labs also allowed us to schedule three separate weeks for FISHFARM rather than crowding it in with the wetlabs. In addition, instructors had observed that students had particular difficulty writing the introduction and discussion sections of the lab report. The new schedule enabled us to add two exercises to help students better understand scientific writing. Finally, this semester we have consolidated the FISHFARM sessions into a block at the beginning of the semester so that we can use the simulation to introduce scientific inquiry methods.

Our grading criteria also changed as we gained experience with the investigative laboratories. Originally, most of the grade depended upon 3 major reports: two for the wetlabs plus the FISHFARM final report. The first report wasn't due until the fifth week of the semester, so students received little feedback about their grades until then. We have broken up the first wetlab report into two assignments. The Introduction and Methods sections are due the week the experiment is performed in lab. The remainder of the report is due the following week. The concept of the FISHFARM final report proved to be impractical. Students tended to ignore the impending deadline and then get caught with a low grade on the biggest assignment in the course. The FISHFARM report was longer and more complex than the wetlab reports, and it was a major source of student complaints on the evaluations. We have substituted two "progress reports" for the final report.

We also decided that we needed to give students more varied opportunities to earn points besides writing reports, so we have added graded assignments on graphing and writing. Poor student understanding of the biological concepts involved in their wetlab experiments and FISHFARM prompted us to create worksheets which students turned in for a grade. For a time we offered "participation points" for some of the discussion activities in lab. After last semester, the teaching assistants decided that those points were not accomplishing their purpose, so this semester we are using short quizzes over material which is discussed in class.

The modifications to our program have been made in response to student and instructor feedback, and have consisted of a combination of practical and pedagogical improvements. Our original purpose -- to convert from a traditional "cookbook" format to investigative laboratories -- has not been altered. In fact, we have increased the amount of time devoted to investigative laboratories and have eliminated traditional labs from our first-semester course.

Project Results

Our project resulted in a thorough reorganization of our laboratory course, which prior to the project had been fairly stable for ten years. The advent of investigative laboratories affected students, laboratory teaching assistants who taught investigative sections, laboratory preparators, and lecture course instructors (who could no longer assume that topics they failed to cover would be covered in lab). Therefore the impact was both intellectual and organizational.

Our major evaluation effort occurred in the second semester of the project, the fall of 1989, when there were 15 investigative sections taught by 11 lab instructors. Two of these instructors taught only intestigative sections, and nine taught an investigative section and a traditional section. In the discussion below, "investigative" means sections taught by an instructor who taught at least one investigative section, and "traditional" means sections which had the traditional lab format, but were taught by an instructor who also taught an investigative section. In addition, there were 38 sections which were taught by instructors who never taught investigative sections--these are called "other."

We gathered data on lecture course grades, scores on our in-house process skills test, opinions on the nature of science, student writing, student opinion, and instructor opinion. Significance is at the 0.05 level, and "highly significant" refers to the 0.01 level.

Lecture Grades

Probably the most frequently heard criticism of investigative labs (voiced by students as well as faculty) is that they reduce lecture course content review in the laboratory course. 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 labs apparently did not decrease the performance of students in our content-oriented, traditional lecture course.

There were four lecture exams in fall of 1989, but only the first two of these covered material which was displaced by the investigative format. During lecture exams 3 and 4, the investigative students had the same (traditional) laboratories as the other treatment groups. All grades shown in Table 1 are percentages:

Table 1. Lecture course scores on exams 1+2 (laboratory content replaced by investigative labs) and exams 3+4 (laboratory content traditional in all lab sections) in fall, 1989.

Treatment	n	Mean, Exams 1+2	Mean, Exams 3+4
Investigative	259	66.50%	69.70%
Traditional	144	67.59%	70.21%
Other	703	67.13%	70.15%

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. The test is included in Appendix 5.

The test was given as a pretest during the first laboratory meeting and as a posttest at the end of the investigative portion of the course to both traditional and investigative students. The pretest was also administered to four "other" sections (traditional sections not taught by instructors who taught investigative labs). In the past, it had been difficult to get students to take such tests seriously, and so we offered students a small point bonus in the lab course which was proportional to their test scores on the posttest. Although this bonus (maximum of 3%) was offered to all investigative, traditional and "other" sections in the course, the only "other" sections which appear in Table 2 below are the four which took the pretest.

Table 2. Mean pretest, posttest and pretest-posttest gains on our process skills test in fall, 1989. All scores are percents.

Treatment	n	Pretest	Posttest	Gain
Investigative	220	49.67%	60.81%	11.14%
Traditional	151	49.38%	62.55%	13.17%
"Other"	75	48.33%	59.34%	11.01%

There were no significant treatment effects on the pretest, posttest or gain. An analysis by treatment and instructor disclosed a significant instructor by treatment interaction and an almost-significant instructor main effect on the pretest, no instructor, treatment or interaction effects on the posttest, and a significant instructor effect on gain. The significant effects all come from the same source--on the pretest, two instructors failed to give their traditional sections enough time to complete the test. Therefore, these two traditional sections appeared to have scored spectacular gains of 24% from the pretest. Actually, most of the effect was due to low pretest scores (average of 40% for the two sections), rather than high posttest scores (average of 64% for the two sections).

Of course, the lack of a significant investigative lab effect on process skills is disappointing. If our test is a valid measure of process skills, we cannot claim that 2/3 of a semester of investigative labs improves the process skills of students more than the same period of traditional labs. As noted above, since the time the data above were gathered, we have expanded the investigative format to cover the whole first course.

Opinions on the Nature of Science

The last 9 questions of the posttest were opinion questions on how the students think science operates. Results here include all sections, and students did not have to be excluded because they lacked a pretest. Thus we polled 250 investigative students, 165 traditional students and 697 "other" students. Results are shown in Table 3.

Table 3. Percent of students in each treatment agreeing with each of nine statements about the nature of science in fall 1989.

Statement Percent Agreeing...	Inves.	Trad.	Other
Any organized, systematic body of knowledge is scientific.	50	49	46
All the investigators who repeat an experiment might not obtain exactly the same results, even if they all perform it correctly.	94	93	92
Science depends on orderly, systematic work, so unplanned observations and accidental findings should be excluded from scientific data.	6	4	4
Science is objective and rational, and is not influenced by the cultural experiences of the scientist.	30	23	25

Table 3, continued.

Statement Percent Agreeing...	Inves.	Trad.	Other
The scientific approach can be used to solve any problem.	54	44	44
Once it has been widely accepted, scientific truth cannot be challeneged by new data.	2	4	2
Scientific methods can be used successfully by non-scientists.	92	95	93
I understand the general methods by which scientists work.	83	78	79
I think that training in scientific methods is useful for all educated people.	88	86	85

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 either the traditionals or the "others" agreed. In our opinion, this is not a good result, since there are many problems outside the province of the scientific approach. For example, the scientific approach can tell us the cause of AIDS, but it cannot tell us how to act towards AIDS patients and their families.

While it is disappointing that that investigative labs produced no opinion differences from the traditional labs on the nature of science, the results indicate fairly good knowledge of and attitudes towards the methods of science by all treatments. So this result may not be so much a criticism of investigative labs as an endorsement of our traditional labs, which the PI's on this project have worked to improve since we both came to Clemson in 1984.

Student Writing Ability

Investigative lab students did a large amount of writing. We were interested in whether this discipline-based writing would improve the general ability of the students to interpret and do technical writing. To determine this, we included Dr. Dixie Goswami of the Clemson English Department in our project. Dr. Goswami, in turn, retained Lori Gray, a Languages graduate student (in 1987-1988), and Chris Benson, an English graduate student (in 1989-1990). Lori Gray and Dr. Goswami collaborated on producing the writing guide, and Chris Benson was Dr. Goswami's "field representative" in assessing the writing results of investigative labs.

In fall of 1989 Chris Benson collected 315 samples from traditional and investigative students at the beginning of the semester and 398 at the end of the semester. There was no attempt to compare the pretest and posttest of individual students. The samples gave the students a data table about the yield of four varieties of crops in three different regions of South Carolina, and asked them to revise a paragraph which summarized the table.

Chris asked four Biology instructors and four English instructors to write a set of grading criteria (to his surprise the two groups were in almost complete agreement), and then asked six English graduate students to grade the samples using the criteria. Each sample was evaluated by two graders, and the graders did not know to which treatment a sample belonged. The results were as follows:

Table 4. Numbers of writing samples in five categories of quality.

Sample	Good	Above Average	Below Average	Poor	No Effort
Traditional Pretest	7	27	55	7	3
Traditional Posttest	9	21	50	16	3
Investigative Pretest	1	20	66	10	3
Investigative Posttest	6	14	51	19	7

In the pretest, the ratings of investigative students were significantly lower than the ratings of traditional students. In the posttest, there was no significant difference between the two groups. Neither group improved--in fact, the largest tendency was for the "below average" group to shift to "poor" in both treatments. Chris ascribes this effect to a large number of students who did not take posttest seriously because they knew it would have had no effect on their grade. We would have liked to award course points for the writing sample posttest (as we did for the process skills test), but then all 398 posttests would have had to be graded by the time lab grades were turned in, an impossible burden.

So although it was reasonable to suppose that the large amount of writing in investigative labs would improve the students' communication skills, we have no quantitative data to support that assertion.

Student Opinion

In all four semesters of implementation, data was compiled on the number of students who agreed with, were neutral about, or disagreed with a series of statements about investigative laboratories. In certain cases, the same questions were asked of traditional and investigative students, and their frequency of replies was compared. The data are extensively described in Appendix 6.

Opinion in investigative sections

Two overall trends are visible in the investigative opinion data. First, the student response to the individual parts of our program was often more approving than their response to the whole program, although overall response improved in the most recent semesters of implementation. Also, there was a sharp decline in student approval in Fall of 1989, possibly because it was the first semester in which large numbers of new TA's were being brought into the program, and also because two investigative TA's who had had a dispute with the course administration (over traditional labs, not investigative labs) graded their students' reports very harshly and then deliberately encouraged student discontent with the grades and the increased workload of investigative labs.

Students in investigative labs usually strongly endorsed the individual parts of the program, agreeing in proportions ranging from 50% to over 85% that the wetlab manual, the FISHFARM manual, the writing guide, and the videotapes were helpful for achieving course goals. By margins ranging from 74% to 95%, investigative students praised their laboratory instructors and lab partners for being helpful in designing and doing experiments and for acting as important contributors to success in the course. They generally liked the course activities. From 50-75% said they enjoyed having the freedom to design experiments, and in all semesters except Fall of 1989 over 50% said they enjoyed doing wetlab experiments and doing the FISHFARM exercises.

When asked about specific skills they thought they had gained, the students also were positive. From 53% to 72% agreed that they were more confident than at the beginning of the course in their ability to analyze problems scientifically, design experiments, analyze data and present their conclusions orally and in writing. On all these questions, 14% or less maintained that their skills had <u>not</u> improved. Except in Fall of 1989, 40-50% <u>disagreed</u> with the statement that they would have learned more about science in a traditional section. From 40-47% of the investigative students agreed that they would be able to apply these skills to their other courses (15-27% disagreed).

The showing of investigative labs was not so strong some other "overall reaction" questions, we think, for two reasons. First, our freshman students tend to equate learning with memorization and recital of facts, and believe that when they are memorizing, they are doing what a student is supposed to do. They were quite comfortable with a content-heavy traditional laboratory course with a short-answer quiz every week (which had the added benefit that it helped them review for lecture course tests). But investigative labs seek to teach skills, not content, and superficially do not appear to relate to the lecture course. As Dr. Kosinski was asked by one of his investigative students, "But what do we have to know from this?"

The second reason is more important--investigative labs required significantly more work. In Fall of 1990, traditional students claimed to spend an average of 0.81 hours per week preparing for lab, and investigative students claimed to spend a mean of 2.37 hours per week. This contrast in workload was obvious to the students in both treatments. In addition to the simple time requirement, investigative labs were stressful because they included activities which were unfamiliar to many of our students. In traditional labs, an unambitious student might pass by doing less than half an hour of routine memorization per week. But throughout the semester, investigative lab teams had to devise an experiment, do independent research on its biology, write three research proposals and three final reports (and two FISHFARM progress reports), and make six oral presentations.

From 46 to 63% of the students said investigative labs were *not* what they expected when they signed up for Biology 105. In spring and fall of 1989, when a third of the investigative labs were still traditional exercises, 45-52% of the investigative students agreed that lab helped them with lecture content, but after the shift to a totally investigative format in spring of 1990, these percentages dropped to 17-21%. From 35% to 60% of the investigative students said they would rather take quizzes than write lab reports (the 35% was in the most recent semester of implementation). Lastly, from 54%-64% thought the investigative labs were too much work. However, the students are not just looking for an easy way out--60%-65% disagreed with the statement that they would have been satisfied with a C if they could have gotten it without doing out-of-class work or studying.

Comparison of investigative and traditional opinion

Comparison of opinion in the traditional and investigative sections showed some differences which were favorable to investigative labs and others which were not. Generalizing over semesters from Appendix 6, investigative students were significantly more likely than traditional students to think that Biology 105 was not what they expected, they were more likely to think that their knowledge of science and their grades would have benefitted from a switch to a traditional section, and they were less likely to think that the course had helped them with lecture content. By very large margins, they declared the course required too much work outside of class. But at the same time, they were significantly less likely than traditional students to opt for the "easy C" mentioned above.

On the other hand, investigative students were significantly more likely than traditional students to think that the course had given them ability to analyze problems scientifically, design experiments, analyze data, and present their work to others orally and in writing (the questions on experimental design and presentation garnered particularly large margins favoring investigative labs). In two out of three semesters in which comparisons are possible, investigative students were more likely than traditional students to prefer writing reports over quizzes as a method of evaluation. In Fall of 1990, investigative students were significantly more likely than traditional students to say that the course had increased their interest in biology, and that they would be able to apply the skills they learned to other courses.

Given the inherent advantages for student acceptance which traditional labs have in terms of the familiarity of the format and their minimal time requirement, we are pleased that investigative labs fared so well in the ratings. We are also pleased that the students were able to see past the workload and appreciate the skills which they perceived that the program was giving them.

Chris Benson's Interviews

Chris Benson, who helped Dixie Goswami assess the writing skills of the students, also did a more qualitative study of student attitudes by interviewing six student volunteers three times throughout the spring 1989 semester (the first semester of implementation). This group included two freshmen, one sophomore, one junior, and two older students in their mid-thirties. Chris's main interest was how the students perceived their writing tasks, but the interviews shed some additional light on the general acceptance of investigative labs. In general, these students were initially very uneasy about the unfamiliar investigative environment, and often expressed a wish for more guidance and feedback from their instructors. They criticized certain policies, especially with respect to grading of reports (often feeling that the biology instructors were grading their writing as harshly as English instructors, and that this was unfair). They all felt that the course was far too much work for one credit.

But, in comparison to investigative labs, five of the six had nothing but harsh words for the last third of the course, which was traditional in spring of 1989. While it was easy, they said, it was "boring" and "a joke." They felt the traditional course "doesn't force you to do your own work," and is merely "a supplement to the textbook." The lock-step schedule of weekly quizzes and fill-in-the-blank lab manual exercises made them regret that they had left the freedom of investigative labs behind. When one student criticized the workload and was asked whether she would recommend investigative labs or traditional labs to another student, she said that if the student "was just trying to get through," he should go with the traditional labs. On the other hand, if he "was trying to get the best out of his education," he should choose investigative labs.

Instructor Evaluation

Instructor evaluation is of two types: surveys of our own lab instructors, and the opinions of colleagues from other institutions.

Clemson laboratory instructors

Results here came from a questionnaire administered to 11 laboratory instructors in 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 lab course more seriously. On the other hand, 50% were not satisfied with their students' understanding of their experiments (with a similar result for the understanding of lab exercises by traditional students), 64% were dissatisfied with the level of discussion among students in their section, and 90% acknowledged that investigative labs were more work for the instructor. Overall, the opinionnaires disclosed a high level of instructor support for investigative labs.

On a more anecdotal level, we have have had no difficulty getting strong instructor acceptance of investigative labs here at Clemson. Several experienced instructors, both TA and faculty, have remarked that investigative labs teach what a lab should teach--the process of investigation, and that they are less boring to teach. We (Kosinski and Dickey) can testify from our own experience that whereas traditional labs cast us as watchdogs who must catch and punish students who have not studied their lab manuals, in investigative labs we are research mentors, partners with the students in a common effort. Sometimes we are just as surprised by experimental results as the students are, and so even our non-majors laboratories can experience some of the excitement of original research.

As a result of this widespread feeling, we have the strong support of our department head. Our former department head, who is now our associate dean of instruction, often cites investigative labs to other faculty as an example of the kind of instructional development which she hopes the faculty of the College of Sciences will do.

Colleagues from other institutions

Reaction of colleagues from other institutions includes implementation of FISHFARM at a local technical college, our presentation of our work at several meetings, and an extensive workshop which we had for 30 faculty from across the US and Canada in summer of 1990.

Tri-County Technical College is a state-run junior college a few miles from Clemson. Tri-County has 2327 full-time students but about 19,000 students who take single courses in connection with their work. The average student age is 28 and the student orientation is very vocational. Mr. Frank Breazeale, the main biology instructor at Tri-County, was in no position to adopt the elaborate investigative wetlabs we used at Clemson, but did agree to use FISHFARM during the spring, summer and fall quarters of 1989. In spring, 1989, FISHFARM was introduced in the first general biology lab, and then forty students were allowed to finish it on their own by using a manual which had been modified for use by Tri-County Tech. In summer 1989, Mr. Breazeale offered FISHFARM as an extra credit exercise and also as an in-class graphing exercise to eleven Medical Technology students. Finally, in fall 1989, he used the program as an optional exercise for general biology, but gave one-on-one help to the six students (out of forty) who elected to do it. He indicated that he planned to use FISHFARM in the future as an introduction to the scientific method with very basic students, some of whom might never have taken high school biology.

Mr. Breazeale evaluated FISHFARM very positively every time it was used. However, there were some problems. In the first two quarters of use, Mr. Breazeale let students work at their own pace, and students complained that they had insufficient instructor support. Student reports showed some basic misconceptions about the objectives of the experiments, and conclusions often could not be justified by the data. The situation improved in fall of 1989 when Mr. Breazeale decided that FISHFARM could not be used as a totally self-guided exercise and devoted class time to explaining it and helping students with problems. This time, the best reports were on a par with the best reports from Clemson students.

We have presented our materials to college faculty at several meetings: a Writing across the Curriculum workshop at Clemson in 1989, National Science Teachers Association meetings in 1988 and 1990, and National Biology Teachers meetings in 1988 and 1989. Reception was good from all of these audiences, but in most cases we were merely giving short slide presentations. In June of 1990, we presented our project in more detail at the meeting of the Association for Biology Laboratory Education in Springfield, Missouri. This organization represents the audience we are trying to convince--college faculty with responsibility for or interest in the laboratories of mostly introductory biology courses. Although we could only give two (very crowded) three-hour workshops, faculty enthusiasm was high, and Dr. Kosinski ended the afternoon workshop by giving out all the FISHFARM disks and written materials to eager users. A representative from Benjamin Cummings Publishing Company (who was interested in publishing our materials) later told us that she had been told that our workshops had been "the high point of the ABLE meeting."

We were able to gather more systematic data from an NSF-funded workshop which we hosted at Clemson in summer of 1990. This workshop brought together 30 experienced faculty with responsibility for introductory biology labs from institutions across the US and Canada. After five 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 lab, that our videotapes and FISHFARM would help them implement investigative labs at their own institutions, and that FISHFARM was a valuable adjunct to wetlab investigations. As the strongest endorsement, 100% either agreed or strongly agreed that they planned to implement investigative labs at their own institutions. Subsequent questions made it clear that this last result did not mean that they attendees planned to adopt our program intact, but rather that parts would be used. But overall, reaction of these experienced faculty to our program was very encouraging, particularly when combined with written comments such as "overall, a supreme performance," and "I'd like to put the entire workshop into my suitcase and take it all home."

One interesting feature of the participants' reaction was that, as "in-the-trenches" instructors, they were intensely interested in practical details of implementation. However, they dismissed our disappointing process skills and writing results with a shrug as they asked about additional implementation details. A probable explanation is that these instructors have wanted to do investigative labs for years, but have never been able to determine how to go about it without crippling logistic problems. At our workshop, they suddenly saw the way out of the dilemma, and this is what excited them. That is, they saw that we could help them do what they had wanted to do themselves all along.

Of course, these instructors were a self-selected sample. It is doubtful that everyone at their home institutions will be equally dedicated to investigative labs. But the workshop did all it could, which was to get them started.

The report from the workshop evaluator (Dr. James Okey of the University of Georgia) is attached in Appendix 7. His conclusions on the workshop are:

- "Virtually every participant plans to implement some aspects of the investigative approach at his own institution."
- "Participants strongly supported the notion that the workshop provided them with the experience and materials needed to implement investigative laboratories."

Non-FIPSE Support

Peer acceptance of our program is also shown by funding it has attracted. In 1988, we received an Instrumentation and Laboratory Improvement grant ($32,928) from NSF which allowed us to purchase videotape players and computers for the investigative lab rooms. In 1989 we received an NSF Undergraduate Faculty Enhancement Program grant ($57,747) which funded the summer workshop for laboratory coordinators to disseminate our current project. Finally, we have received $32,928 of matching funds from the Clemson College of Sciences and $10,000 from our department to support both equipment purchases and the summer workshop.

Dissemination

Our dissemination effort so far has been partially described above. From 1988 to 1990, we gave five short presentations at national meetings, two three hour workshops at the 1990 ABLE meeting, and one major workshop which lasted five days.

Our future plans include publication in journals such as the *Journal of Research in Science Teaching*, *Journal of College Science Teaching*, and *American*

Biology Teacher. As a result of our ABLE presentation, an article describing our program will soon be appearing in the *Proceedings of the 11th ABLE Workshop/ Conference*.

Here at Clemson, the future of investigative labs seems secure. As mentioned above, our department head strongly supports the program and our associate dean cites it approvingly as her favorite example of instructional innovation in the College of Sciences. She teaches in our majors general biology course, and frequently suggests that it is time to make the majors labs investigative.

At this writing, one quarter of all Biology 105 labs in the fall semester and all Biology 105 labs in the spring semester are investigative. We cannot move to a completely investigative format at this point because we have a long-term contract with the publisher of our traditional lab manual. However, when this contract runs out in fall of 1992, all Biology 105 labs will be investigative. This in itself will solve some problems because the preparators will no longer have to prep two kinds of labs at once, and the students will no longer have the constant reminder that investigative labs are more work than traditional labs.

Although it is not part of the current project, we have been working for about a year on plans to extend the investigative format into Biology 106, the lab course which follows Biology 105. This course has an emphasis on human physiology, and we hope to make investigative physiology labs possible and interesting by interfacing our laboratory computers to physiological sensors. Once interfaced, the computers can record and analyze the data from a great variety of sophisticated experiments, and at a relatively modest price per student station. A proposal to do the necessary development work is pending before FIPSE at this writing.

A last aspect of dissemination, and probably the most important, is commercial publication of our materials. In late September of 1990, we opened negotiations with Benjamin/Cummings Publishing Company for the publication of our videotapes, software and written materials. We were told that Benjamin/ Cummings' interest was attracted by the comments of Neil Campbell, the author of a popular general biology textbook, who had attended one of our ABLE workshops and had been impressed by our materials.

Very soon, Dr. Dickey will sign a contract with Benjamin/Cummings for the production of a lab manual which incorporates the major features of our investigative wetlabs. At this writing in March of 1991, both Benjamin/Cummings and Worth Publishers are negotiating with Dr. Kosinski for the publication of FISHFARM.

Summary and Conclusions

We have developed an investigative laboratory program for general biology which allows students to perform experiments which they have designed themselves rather than complete the cookbook-type exercises typically found in content-heavy traditional laboratory courses. The materials we have developed include videotapes of laboratory techniques, both student and instructor versions of a lab manual, a preparators's guide, and FISHFARM, a computer simulation of the economics and biology of a commercial aquaculture enterprise.

From a practical standpoint, we have been extremely successful in implementing our program on a fairly large scale for the past two years. We consider this a major achievement, since past efforts at introducing investigative laboratory programs at other institutions have been severely hampered by logistic and other practical problems. Our program has won the support of the lab instructors, laboratory prep staff and our departmental and college administration. We have also received a strong positive response from faculty members at other institutions who have attended presentations about our project.

We evaluated the effect of the investigative lab program on four aspects of student achievement: lecture exam scores, process skills, opinions on the nature of science and writing ability. We also collected extensive data on student opinion.

Although investigative labs eliminate the review of lecture material provided by traditional labs, there was no significant difference between the lecture exam scores of students in traditional and investigative sections. However, despite the fact that investigative labs emphasize process skills and require much writing from the students, there was also no significant score difference between traditional and investigative students on a process skills test, on a test on the nature of science, or on student writing samples.

Students in investigative labs strongly endorsed the individual parts of the program: they expressed high opinions of the materials and their instructors and they generally liked the course activities. They also thought that they had learned the specific skills involved in scientific problem-solving. On the other hand, many students preferred traditional labs; the increased workload in comparison to traditional labs was a major complaint. In recent semesters, however, student approval of investigative labs has increased, perhaps in response to our efforts to reduce and spread out the investigative workload over a larger part of the semester.

Despite these problems, however, investigative labs are heavily favored by our instructors. We have now exceeded our original proposal, which was to install investigative laboratories in the first 2/3 of one of our two laboratory courses. In fact, we now have eliminated "cookbook" labs entirely from our first-semester course, and are planning an extension of investigative labs to our second-semester laboratory course.

Appendix 1

Information for FIPSE

Assistance from FIPSE

Our project officer, Ed Goldin, was very helpful to us. Not only was he prompt and forthcoming when we needed information, but we always felt that he supported our project fully. It was good to have him as our "friend at FIPSE."

We also felt that we were allowed ample flexibility with our budget. Shifting money between categories was generally no problem, and we were permitted carryovers each year to accommodate mid-project changes in our plans. However, we felt that the need to submit a proposal for continuation each year was unneccessary and cumbersome. Minor but frustrating technical problems cropped up each year in the budget office, usually requiring mailing or faxing of additional materials. We prefer the system used by NSF, which grants a budget for the length of the project. An annual progress report would suffice to be sure grantees are on-track.

We enjoyed the annual project directors meetings. Although there were very few of our colleagues in science at the meetings, we found many interesting sessions related to other issues which concern us.

Future Proposals in Science Education

In our area of interest, which is science laboratory education, recent reports from national panels of experts (e.g. The National Science Board, Sigma Xi) have strongly recommended laboratory experiences which involve the students in doing original pieces of research rather than merely performing highly directed laboratory exercises. For non-science majors, investigative laboratories such as the program we developed for our project, fit this category. For science majors, laboratories should introduce students to techniques and equipment which are used by researchers as well as giving students an opportunity to perform simple investigations of their own design. Upper-division science students should have a research experience through collaboration with faculty in their labs. The trend to encourage the use of laboratories as a research experience can be easily integrated with two more general trends: collaborative learning and communication-across-the-curriculum.

The lack of funding for equipment is a serious drawback for science educators who consider applying for FIPSE grants. While we understand the FIPSE policy of providing seed money to get projects started so that larger grants can be obtained later, we don't understand why this concept doesn't apply to equipment for pilot projects. Many science laboratories, for example, are stuck in the traditional rut because equipment which could allow students to do their own investigations is not available, and administrators won't pay for innovation as long as the traditional method generates no complaints. We were fortunate enough to have the equipment available to run a pilot project, but we could not have done our FIPSE-sponsored project without that equipment. It seems that the no-equipment policy has a larger impact on science-related projects than on projects in most other fields.

Appendix 2

Methods Module Videotapes

Videotapes for Methods Modules

Jean L. Dickey
Biology Program
Clemson University

Methods for Investigating pH

Measuring pH with red cabbage indicator (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 7Up 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 one 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 one 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 mls 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 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 Videotapes

The tapes in this series give brief introductions to the topics 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 3

Semester Schedule for Investigative Labs

COURSE OPERATIONS
BIOLOGY 105
SPRING 1991

Laboratory Manual:

You will need to buy the **looseleaf** version of the Biology 105 lab manual, which has cartoon drawings on the cover. It is available only in the Union Copy Center. You will probably want to get a loose-leaf notebook to hold it.

You will need to buy a lab notebook, 10" X 7 7/8 ", 5X5 quad ruled. The bookstore in the University Union carries this type of notebook, which is called a "Comp Book."

Laboratory Coordinator:

Dr. Jean Dickey is in charge of Biology 105 policies and personnel. Please feel free to contact her regarding any problem you encounter with the course. Office: 330C Long Hall (in the Biology Program office); phone 656-3827.

Attendance:

Attendance in Biology 105 is mandatory. Students missing a laboratory must contact Mr. Cummings in Room 323 Long Hall (Phone: 656-3601). If your absence is excused, you will be rescheduled into another section if space is available. Prior arrangements must be made for university-scheduled excused absences. All makeups must be done during the same week the lab is missed.

Excused absences:

You must have authorization from Mr. Cummings to attend a lab section other than your own. This is permitted only for excused absences. You will be required to complete a form stating the reason for your absence and give the name and phone number of a person who can be contacted for verification.

You will participate in your makeup lab just as if it were your own section. If you make up lab during a week when proposal or results presentations are made, you will present your group's work. If you make up during a week when wetlab or FISHFARM experiments are scheduled, the instructor will assign you to a group. You will be responsible for contacting the members of your regular group to obtain data for the session you missed with them. If you make up during a week when an assignment is due, your assignment is due at the makeup lab.

Please note: The privilege of making up a missed lab is allowed only when the absence was caused by circumstances beyond the student's control (e.g. illness, death in the family, University-sponsored trip). If you choose to miss your regular lab session to study for tests or attend social events, you may not make up the lab, and your grade will be affected. Absence from campus when school is in session will not be excused unless a University excuse is presented. Absence due to leaving early for vacations or returning late will **not** be excused.

Unexcused absences:

If you miss any lab due to an unexcused absence, no makeup is possible. A penalty of 25 points per absence will be subtracted from your total points at the end of the semester. This point penalty includes the zero you will receive on any assignments other than FISHFARM progress reports or wetlab reports which are due or scheduled to be completed in class on the day of the absence. FISHFARM and wetlab reports may be handed in late, and the usual penalties for late assignments will be applied. You will need to contact your team members to get a copy of the proposal, data, or whatever you missed so you can complete your work to hand in.

You are expected to stay in lab until your instructor gives you permission to leave. Once the class is dismissed, your instructor will sign your attendance card. Your instructor will not sign your card if you leave early. If your card is not signed, you did not attend the lab, and the appropriate grade penalty applies.

More than two absences is considered excessive. The Biology Program has the option of dropping students who have excessive absences.

Grading Policy:

There are 315 total points available in the course. Our grading scale is:

283-315 points = A (90 - 100%)
252-283 points = B (80 - 89%)
220-252 points = C (70 - 79%)
189-220 points = D (60 - 69%)
below 189 points = F (below 60%)

The points are distributed as follows:

FISHFARM worksheets: 2 @ 5 points
FISHFARM progress reports: 2 @ 30 points
Writing exercises: 2 @ 10 points
Wetlab proposals: 3 @ 10 points
Wetlab reports: 3 @ 50 points (The first wetlab report may be resubmitted for a maximum grade of B.)
Lab notebook: 30 points
Quizzes on proposal presentations: 3 @ 5 points

It is our policy that late assignments will be penalized.

An optional final quiz will be given during the last lab for students who have missed a lab but were not able to make it up. This quiz grade may be used only to replace the 25-point penalty; students who have not missed a lab should not take the quiz.

Academic dishonesty:

The policy on academic dishonesty at Clemson University is stated in the Student Handbook. It is your responsibility to familiarize yourself with the official definition of and penalties for academic dishonesty. A Biology 105 student guilty of a first offense will receive a grade of zero on the work attempted. The student may **not** substitute the final quiz grade for this zero.

Be very certain you understand what plagiarism is. Any passage which is a direct quotation must be enclosed in quotation marks. Changing a few words of someone else's work is still plagiarism. You must learn to absorb information you read, and express it in your own words.

Your entire lab team will work together on the proposal and receive one grade for that work. Other work, including the wetlab and FISHFARM reports, however, must be **your own** individual work. If you need help, your lab instructor is the appropriate person to see. Protect yourself against charges of plagiarism or collusion. Do not work with your classmates while you are writing, do not show drafts of your report to classmates, and do not show your final report to classmates.

Responsibility:

Students are responsible for all furniture, equipment, specimens, etc. used during the laboratory period. Abuse of the facilities, equipment or materials will not be tolerated. Students who engage in destructive or disruptive behavior may be asked by the instructor to leave the lab. Penalties for such behavior will be determined by the course instructor in consultation with the head of the Biology Program, and may include a zero for the week's lab or permanent expulsion from the laboratory. The student may **not** substitute the final quiz grade for a zero given for this reason.

Tentative Biology 105 Lab Schedule
Spring, 1991

Week	Laboratory Activities	Assignments due
1/14-18	Introduction to Biology 105 FISHFARM orientation and temperature experiments	
1/21-25	Data analysis and presentation FISHFARM experiments on oxygen and feeding Advice on writing FISHFARM progress report	Writing exercise in class FISHFARM worksheet 1
1/28-2/1	Perform FISHFARM stocking density experiments and production run	FISHFARM progress report 1 FISHFARM worksheet 2
2/4-8	Introduction to wetlabs and experimental design Design investigation 1	
2/11-15	Advice on writing introduction of lab report Present proposal 1 to class	FISHFARM progress report 2 Quiz on Unit 1 experiments Proposal 1
2/18-22	Perform investigation 1	Report 1: Introduction and Methods
2/25-3/1	Present results from investigation 1	Report 1: Results, Discussion, Conclusion and Literature Cited
3/4-8	Design investigation 2	
3/11-15	Present proposal for investigation 2	Proposal 2 Quiz over proposals
3/18-22	SPRING BREAK	
3/25-29	Perform investigation 2	(Resubmission of report 1)
4/1-5	No lab scheduled (meet to design investigation 3, pick up graded resubs)	
4/8-12	Present results for investigation 2 Present proposal for investigation 3	Entire report for inves. 2 Proposal 3 Quiz over proposals
4/15-19	Perform investigation 3	
4/22-26	Present results for investigation 3	Entire report for investigation 3

Appendix 4

Database Summaries of Student Projects
(Used by Teaching Assistants Only)

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
The Effect of Temperature on the Rate of Alcoholic Fermentation. CO_2 evolved after 30 min (ave of 3 reps, data given for every 5 min). 1 °C: 0 mm; 23 °C: 0 mm; 35 °C: 7.3 mm; 67 °C: 21 mm.	Bayles/2 Fall 1989	Stephanie Davis, Jeff Fricano, Karen Judy
Measuring Carbon Dioxide Evolution During Alcoholic kFermentation Using Different Sugar Measured the amount of CO_2 produced following 20 minutes of yeast fermentation. The substrates tested were; Karo syrup, honey, molasses, and table sugar. All sugar sources were used as 50% solutions (w/v or v/v). The amounts of CO_2 produced were molasses-22.6mm, honey-9mm, table sugar-23.8mm, and Karo syrup-15.5mm.	Bayles/5 Spring 1990	Victor Bouchillon, Scott Moore, and Chad Windham.
Measuring Carbon Dioxide Evolution During Alcoholic Fermentation Using Different Sugar Measured the amount of CO_2 produced every 5 minutes for 30 minutes during yeast fermentation. The substrates tested were; Karo syrup, honey, molasses, and table sugar. All sugar sources were used as 50% solutions (w/v or v/v). The amounts of CO_2 produced after 30 min. were molasses-27mm, honey-25mm, table sugar-42.5mm, and Karo syrup-50mm. The average amount of CO_2 produced every five minutes was: molasses-3.8mm, honey-4.2mm, table sugar-7.0mm, and Karo syrup-8.4mm. This experiment proved fairly sucessful.	Bayles/5 Spring 1990	Victor Bouchillon, Scott Moore, and Chad Windham.
The Effect of Sugar and Vinegar When Added to Honey in the Production of CO_2 in Alcoholic The exreriment was performed to observe the effect of sucrose, Sweet and Low and vinegar on honey in the production of CO_2 during alcoholic fermentation. Honey , when used by itself, produced the most CO_2, followed by honey+Sweet and Low, honey+sucrose and lastly, by honey+vinegar. It seems strange that honey+Sweet and Low produced more CO_2 than honey+sucrose. In the whole the experiment was a good one, exept for the observation I mentioned.	Bebek 30 Fall 1990	Katherine Plummer, Kathleen Brown, Rachel Mosley
The Effect of Other Ingredients on Fermentation Rates Alcoholic fermentation was performed with fructose only, or with a mixture of 1:1 ratio of fructose and	Bebek 30 Fall 1990	Jason Spitzer, Charles Foster, Todd Rowley

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
coffee. Their results show that fructose+coffee produced more CO_2 than fructose alone. They had cracks and kinks in their fermentation vials ,so results are not reliable.		
Alcoholic Fermentation- Regular Soft Drinks vs. Diet Soft Drinks Experiment performed to test whether diet drinks or else regular ones produce more CO_2 in alcoholic fermentation. No CO_2 was produced with the diet soft drinks.	Bebek 30 Fall 1990	Allen Leland, Wendy Linder, Hugh Nichols
The Effect on the Amount of Alcohol Produced When Different Juices are used in a Fermenting Juices used are: grape, orange, apple and cranberry juice. Grape juice produced the most CO_2. They did have some problems with the fermentation vials.	Bebek 38 Fall 1990	Jack Cleland, Missy furrow, James Poole
The Effect of Alcoholic Fermentation on Juices The juices used were: apple, grape, orange and lemon juice. Apple juice appeared to contain the highest amount of sugar.	Bebek 38 Fall 1990	Kristina Milan, Sandra Trautwein, Tiffany Blanton
Alcoholic Fermentation Rates Used 2.5 mls of sucrose and 2.5 mls of fructose, separately and combined, to see how much CO_2 would be produced. Fructose produced the most CO_2 during a 30 min period of time. One of the problems were the kinks formed in the fermentation vial tubings.	Bebek/30 Fall 1990	Jason Spitzer, Todd Rowley, Charles Foster
Alcoholic Fermentation Used 2.5 mls of Coke, Pepsi and Jolt. Coke produced the most CO_2 while Jolt the least.	Bebek/30 Fall 1990	Wendy Linder, Hugh Nichols, Allen Lealand
The Effect of Sugar on the Amount of CO2 Produced During Alcoholic Fermentation Used 2.5 mls of Karo, honey, chocolate and maple syrup. Honey produced the most CO_2(26.5 mls in 20 min). The only problem they encountered was the kinking of the tubes.	Bebek/30 Fall 1990	Rachel Mosley, Katherine Plummer, Kathleen Brown

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
Alcoholic Fermentation Used 2.5 mls of grape juice and mixed it with different amounts of yeast (2, 4, 6, 8 mls). The more yeast was added, the more CO2 was produced.	Bebek/38 Fall 1990	Jack Cleland, Missy Furrow, James Poole
The Effect of Alcoholic Fermentation on Beverages Used 4 mls of Coke, Sprite ,grape juice and apple juice. Grape juice and apple juice worked the best and produced the most CO2.	Bebek/38 Fall 1990	Kristina Milan, Sandra Tratwein, Tiffany Blanton
The effect of Sucrose, Fructose, Glucose, Equal, and Sweet-n-low on alcohol fermentation. Amount CO2 evolved after 30 minutes (ave of 2 reps). 50% sucrose, 16.5 mm; 50% fructose, 16.0 mm; 50% glucose, 18.0 mm; Sweet-n-Low (2 packets in 20 ml water), 0 mm; Equal (2 packets in 20 ml water), 0 mm; no substrate, 0 mm.	Belthoff/22 Fall 1989	Cindy Galloway, J. R. Foster, Larry Nazry, Kelly Franz
The effect of different substrates on the production of CO2 by yeast CO2 production after 25 minutes (ave of 2 reps). Glucose 4.8 mm, fructose 4.65 mm, Sweet&Low 3.45 mm, saccharin 0 mm, water 0 mm. Concentrations of substrates used are not given.	Belthoff/5 Spring 1989	Ryan Horne, Scott Neal, Flynn Maffett
Comparing the measurement of carbon dioxide evolution during alcoholic fermentation of corn Made mashes of corn, barley and oats by boiling the grains in distilled water. Then used mashes as substrate for yeast fermentation. No CO2 evolution was seen, except in control vial where sugar was used as a substrate.	Berry/10 Fall 1989	Elliot Strickland, Trent Hackle, Alison Turbeville, Kevin Mims
The rate of alcoholic fermentaion in disaccharides and monosaccharides CO2 evolved after 45 minutes (ave of 4 reps, data given for 5 min intervals). Lactose 5.5 mm, glucose 9.3 mm, fructose 1.6 mm, sucrose 9.6 mm. Concentrations of sugars not given.	Berry/10 Fall 1989	Jay Crump, Allison Jakubecy, Wilken Benjamin
The effects of different sugars during alcoholic fermentation CO2 evolved after 45 minutes (ave of 2 reps, data given for every 5 min). Sweet-n-Low 27.5 mm, glucose 35.5 mm, Karo 13 mm, molasses 38.5 mm.	Berry/8 Spring 1989	Bart Welch, Seth Nagy, Lisa Norman, Dick Landgren

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
Concentrations of solutions not given.		
The effect of Temperature and Source on the Rate of Alcoholic Fermentation Tested five sources of sugars (maltose, sucrose, glucose, ribose, fructose) at three different temperatures (5, 22, 37). At 5 degrees C, sucrose and ribose showed the most CO_2 at 30mm. At22, glucose gave most at 75mm. And at 37 ribose was the most productive at 400mm.	Brignola/2 Spring 1990	Nell Grinter, James Addison, Derik von Recum
The Effect of Temperature and pH on Fermentation Carried out fermentation at pH values of 2, 4, 6, 7, 8, 10, 12 in temperature baths set at 5, 37, 45, 55 degrees C. Glucose was used as the source. The highest rate was obtained with 45 degrees C at pH 7 (distance was past measurable within 5min.). Overall pH extremes showed very little as did temperature extremes. Experiment well done.	Brignola/2 Spring 1990	Leslie Sell, Lee Kendall, Jane Banks
The Effect of Different Sugar Solutions on the Amount of CO2 Produced by Alcoholic CO_2 evolved after 40 minutes (data recorded every 5 minutes). Glucose, 4 mm; sucrose, 24 mm; fructose, 13 mm; maltose 0 mm. Concentrations of sugars not given.	Brignola/6 Fall 1989	Kelley Huskamp, Keith Franklin, Colleen Dorney
How pH Can Effect the Rate of Fermentation Tested pH values of 2, 4, 7, 10, 12 with one substrate, glucose. Found that pH 7 allowed the highest rate of fermentation (21mm). pH 4 showed slight change (2mm) with all others showing no change in the 30min. experiment.	Brignola/8 Spring 1990	Joaane Coackley, Cristina Jepson, Gregg Hughes
How Temperature Effects the Source of Alcoholic Fermentation Tested sources of substrate : maltose, glucose, sucrose, and fructose on the rate of alcoholic fermentation. Also tested the effect that temperature had on each substrate. Several replicates were done at 5, 37, and 60 degrees C. Results show that in all temperatures that glucose was preferred substrate and the higher the temperature the greater the rate of fermentation.	Brignola/8 Spring 1990	Elisa Mason, Greg Adams, Nancy Gauvreau, Mark Fleming

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
How Sugars Effect the Rate of Alcoholic Fermentation Investigated the role of different sources of sugars (50%) and their effect on this rate. Used fructose, sucrose, glucose, lactose, maltose, and ribose and measured the rate by amount of CO_2 given off. Through repetition found fructose and glucose were most efficient.	Brignola/8 Spring 1990	Nancy Gauvreau, Mark Fleming, Elisa Mason, Greg Adams
the effect of varying concentrations of sugar on carbon dioxide produced in alcoholic CO_2 evolved after 30 minutes using varying amount of sugar (ave of 2 reps). 1.5 ml: 0 mm; 2.5 ml: 0.8 mm; 3.5 ml: 5 mm; 4.5 ml: 0 mm; 5.0 ml: 1.5 mm. There must have been some problem to get such low CO_2 production.	Cummings/46 Fall 1989	Amy Rogers, Ashley Craig, Tracy Smart
the effect of increasing temperature on the rate of alcoholic fermentation CO_2 evolved after 30 minutes. 5 °C: 0 mm; 19 °C: 4 mm; 53 °C: 0 mm; 100 °C: 0 mm. These results aren't very good but Whatley has a couple of useful references.	Cummings/46 Fall 1989	Jennifer Whatley, Marjorie Clark
The effect of substrate concentration on the rate of alcoholic fermentation many concentrations of corn syrup solution used no CO_2 formed at any concentration	Cummings/9 Spring 1990	Tina Seawright, Taylor Laney
The effects of substrate concentration on the rate of alcoholic fermentation a 50:50 mix of corn syrup:water gave best results, with reduction in CO_2 production as concentration increased or decreased	Cummings/9 Spring 1990	Tina Seawright, Taylor Laney
The effect of varying sugar substrates on alcohol fermentation CO_2 evolved after 50 minutes using different substrates, average of 2 reps. Maple syrup 46 mm, corn syrup 16 mm (syrups both diluted 1:1), 2% potato starch 2 mm, 2% gucose 12 mm.	Dickey/6 Spring 1989	Patricia King, Shannon Broome, Kathy Maples
The effect of different sugar substrates on the rate of alcoholic fermentation CO_2 evolved after 30 minutes using different substrates, ave of 3 reps. Honey 15.7 mm, molasses 18.0 mm, sorghum syrup 23.1 mm, granulated	Dickey/6 Spring 1989	Teresa Stills, Brian Powell, Austin Smith

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
sugar 48.0 mm, brown sugar 43.1 mm, Sweet-n-Low 38.5 mm. Liquids were diluted 1:1, 10% solutions were made of powdered sugars and sweeteners.		
Fermentation rates of chocolate syrup, nutrasweet, sugar, and Kero syrup Diffiicut to analyze the results. Kero showed the same rate of fermentation as Nutraseet solutions. The group felt a lot of experimental error was involved in their study.	Holden/53 Fall 1990	D.Helms, R.Miller, M.Shumpert
How does pH affect fermentation? Basic solutions were more conducive to fermentation than acidis solutions. Neutral solutions seemed to show most consistent fermentation rates.	Holden/53 Fall 1990	J.Marsella, J.Mundy, A.Castro
Fermentation rate of different juices This group was interested in the fermentation rates of different juices used to make alcoholic beverages. They found potato juice was the poorest fermentater, while apple juice was the best.	Holden/53 Fall 1990	J.Pickett, S.Stone,M.Heckle
Fermentation rate of mono-,di-,and polysaccharides The monosaccharides produced the most and polysaccharides the least carbon dioxide. One of the papers discusses this very nicely.	Holden/53 Fall 1990	A.Castro, J.Mundy, J.Marsella
Comparisons and Explainations of the Rates of Alcoholic Fermentation in Corn, Potatoes, and Study of liquor substrates with respect to fermentation rate. Corn did very well, molasses did little, potatoes did nothing in spite of the addtion of amylase.	Knaub/18 Fall 1990	laura dobson; Jeff Brown, Brian Goodlett
Determination of Fermentation rates in Acidic Fruits This is a study of ph and fermentation using natural juices as substrates. Lemon and limes pH 2.6-2.65 did little. Oragnes and tangerines pH 4.00-3.85 did well. Pinaples were excelledt at 3.40. Good reports, excellent references	Knaub/18 Fall 1990	Johnny Shaw, Perry Hooper, Peter Kennedy, Brice McKoy

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
Alcoholic Fermentation of Fruit Good survey of fruit substrates for fermentation. Apples and Bananas did best. Oranges were supposed to be an negative control but fermented well. Good reports, excellent references.	Knaub/18 Fall 1990	Johnny Shaw, Perry Hooper, Peter Keddedy, Brice Mckoy
Comparison of Fermentation in Natural and Prepared Juice Natural juices : apple, orange, and grape and their prepared forms were compared. Prepared juices were superior except in the case of grapes.	Knaub/49 Fall 1990	Michelle Chapman, Melissa Schaeffer, Ann Love, Sunshine Lovett
The Effect of Temperature on the Fermentation Rate of Sucrose and Sweet One The two substances, one natural and one artifical, that gave the highest rate of fermentation (sucrose and Sweet one) were chosen. 12.5 ml of water was added to 12.5 g of substance and 2.5 ml of this solution was added to 2.5 ml of yeast. After 15 minutes, the water drop was recorded at different temperatures. Results are; 0C-2.6 mm, 22C-1.3 mm, 42C-4.3 mm, 62C-0 mm, 100C- 0 mm for Sweet one. Results for sucrose are;0C-1 mm, 22C-10 mm, 42C-10 mm, 63C-.3 mm, and 100C-0mm.	Reap/4 Spring 1990	Amanda Albea, Camille Canady, Audrey Johnson, Wendi Stephenson
This experiment measures the carbon dioxide produced during fermentation using two types of Different volumes of juice (2,4 , 8, and 10 ml) to 5 ml yeast were used Water drop was recorded every 5 minutes for 25 minutes. Motts unsweetened and Welch's sweetened juices were chosen. Unsweetened apple juice produced more CO_2 than sweetened.	Reap/4 Spring 1990	Carey Bush
The effects of carbon dioxide evolution of various sweetened and unsweetened fruit juices in the Chose sweetened and unsweetened juices (apple, plum, pear, grape grapefruit, berries, and control-sucrose) and measured production of CO_2. Five ml of yeast and 5 ml of jucie was used. At 5 minute intervals, the drop in water line was recorded. Unsweetened juices (apple, plum and grape) had higher CO_2 evolution.	Reap/4 Spring 1990	Ashely Burdette, Carey Bush, Lori Lacy

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
The natural sugar with the fastest fermentation rate and a comparision of fermentation rates of Natural sugars (sucrose, glucose, maltose and ribose) and artificial sweeteners,Nutrasweet-Equal, sweet and low, and sweet one were used. Solutions used in the fermentation were made by mixing 12.5 ml of water with 12.5 g of sugar/sweetener. Then, 2.5 ml of solution was mixed wiht 2.5 ml of yeast. Karo was used as a control. Water drop was recored after 25 minutes and three trials were done. Sucrose had the greatest amount of C02 produced of the natural sugars (water drop-23 mm), followed by glucose (9.7 mm), and maltose (3 mm). Ribose had no drop. For the artifical sweeteners, Equal had a water drop of 10.7 mm, and Sweet and low was 3.7 mm and 14mm for Sweet one, which was overall the highest CO2 producer.	Reap/4 Spring 1990	Audrey Johnson, Camille Canaday, Wendi Stephenson and Amanda Albea.
The effect of varying temperatures on the amount of carbon dioxide produced in alcoholic CO2 produced after 60 minutes, average of 2 reps. 15 °C: 0 mm; 25 °C: 1.5 mm; 35 °C: 7 mm; 40 °C: 7 mm; 45 °C: 14 mm; 60 °C: 0 mm. Very little CO2 produced until about 30 minutes into the experiment. There wasn't much total CO2 production, but the shape of the curve is great.	Reap/42 Fall 1989	Robert Satcher, Amy Cavanaugh, Maggie Taylor
The effect of temperature on the amount of carbon dioxide given off during alcoholic CO2 produced after 2 hours, average of 2 reps. 6 °C: 0 mm; 14 °C: 21.5 mm; 26.5 °C: 27 mm; 42 °C: 10 mm; 69.5 °C: 0 mm. Very nice! Bauld lists a couple of references on fermentation.	Reap/42 Fall 1989	Heather Ashley, Janet Bauld, Chad Mason
Alcoholic fermentation in six different types of yeasts Got different types of brewer's yeasts, but used suspensions which were too dilute so they didn't get any results.	Reap/42 Fall 1989	Angie West, R. Brian Rivers, Tammy Roscoe
How different sugars affect the rate of alcoholic fermentation Fructose, glucose, sucrose, maltose, lactose and ribose were used.50% sugar solutions were used and after 35 min only fructose and sucrose fermented	REAP/6 Spring 1990	Amy Huffman, Dan Kristensen, Matt Rainsford

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
Finding which sugares are most conducive to the process of alcoholic fermentation Fructose, sucrose, maltose,and ribose were chosen. Fifty percent sugar solutions were made. Sucrose, glucose, and fructose, showed the best fermentation, respectively. Maltose and ribose did not ferment in the time alloted -50 minutes.	Reap/6 Spring 1990	Amy Huffman, Matthew Rainsford
The effects of different temperatures on CO2 production from fermentation Four temperatures were chosen and water baths and ice baths were first brought to the desired temperatures. After 25 minutes water drop was recorded for the temperatures and three trials were done. The amount of drop for each temperature was as follows; 3C-0 cm, 21C-.23 cm, 37C-.35 cm, 85-100C-.13cm. A nice bell shaped curve was obtained.	Reap/6 Spring 1990	William Royall, Meg Kinder, Stacie Gantt
The effects of different temperatures on CO2 production from fermentation Yeast and sucrose solutions were allowed to heat up to the appropriate temperatures for 25 minutes before they were mixed together to start the fermentation. Water drop at each temp was recorded as follows; 0C-0 cm, 23C-1.16 cm, 41C-7.1 cm, 50C-6.43 cm, 61C-.7 cm, 85-100C-.05 cm. A beautiful bell-shape curve was obtained.	Reap/6 Spring 1990	William Royall, Meg Kinder
Effect of pH on fermentatioon of different substrates using artificial sweetners and Measured pH of 2 different groups' ferm. exp. Results from different groups were difficult to compare but general trend was higher pH 6.1 (52mm) produced less CO2 than low pH (140mm)	sigmon 22 Fall 1990	Chris Leming
Rate of alcoholic fermentation using artificial sweetners versus sugar Using 1 packet each of Twin, Sweetnlow,Equal, and sugar found that Equal and sugar produced 75mm, Twin 60mm, and Sweetnlow 50mm of CO2.	sigmon 22 Fall 1990	Stefanie Genereo, Marcy Johnson, Tess Rodgers
Rate of Alcoholic fermentation of choc. syrup, corn syrup, honey, and maple syrup Maple and corn syrup produced most CO2 (38 mm), choc syrup and honey (32mmm). Used 2.5 ml of sugar solution	sigmon 22 Fall 1990	Stefanie Genereo, Marcy Johnson, Tess Rodgers

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
Effect of Karo syrup, Pepsi, choc. milk, whole milk, and ginger ale on CO_2 production of Whole milk did not produce CO_2, ginger ale very little, Pepsi, choc. milk, and karo syrup fermented at about the same rate.	sigmon 22 Fall 1990	Sidney Poole, Alexa Facusse
Effect of presence of CO_2 in carbonated drinks on fermentation Open and carbonated Pepsi fermented at same rate(50mm), seltzer soda (they were supposed to use club soda w/o sugar) and karo syrup produced about 40 mm. Honey produced 0mm.	sigmon 22 Fall 1990	Sidney Poole, Alexa Facusse
Effect of different amounts of substrate on fermentation at 64 degrees C? Used 2.5, 3.5, 4.5, 5.5 ml of corn syrup. Good results with all except 3.5 - no fermentation. 5.5 ml produced more CO_2 than vial could hold in 15 min.	sigmon 46 Fall 1990	Dawn Bowden, Angela Roberts, Jennifer Whitesides
Effect of different amounts of substrate on fermentation Used 2.5 and 3.5 ml of corn syrup and cane sugar solution. Corn syrup 2.5 (6mm) and 3.5 (9mm) of CO_2. Sugar 2.5 (3mm) and 3.5 (5mm).	sigmon 46 Fall 1990	Brent Stone, Brian Myslinski
Effect of temp (0, 21, 57, 100 degrees C) on fermentation Used orange juice as substrate. Produced very nice graph over 50 min period. No CO_2 at 0, 18 mm at 20 degrees, 38 mm at 57. Could not used 100 degrees - vial started to melt.	sigmon 46 Fall 1990	Elizabeth Larson, David Owens, Jeannie Hamby
How is fermentation affected by pH of different juices? 2 ml of yeast suspension and 2 ml of oj (pH 4.0), apple juice (3.8), and white grape juice (3.3). CO_2 produced - oj 30mm, apple 28.5mm, grape 25mm. Higher pH, more CO_2 produced.	sigmon 46 Fall 1990	Elizabeth Larson, Jeannie Hamby, David Owens
Effects of different amounts of substrate on fermentation Using 2.5, 3.5, 4.5, 5.5 ml of corn syrup, results given after 25 min. 20mm, 23mm, 28mm, and 14mm respectively.	sigmon 46 Fall 1990	Dawn Bowden, Angela Roberts, and Jennifer Whitesides

Investigations of fermentation

Experiment	Instructor/sec Semester	Students
Effect of different sugar solutions (brown sugar, maple syrup, corn syrup, and cane sugar) on Brown sugar produced least CO_2 6mm, others app. same 12-14 mm. Amounts of sugars used??	sigmon 46 Fall 1990	Brent Stone, Brian Myslinski
The Effect of Temperature on the Amount of Carbon Dioxide Given Off During Alcoholic CO_2 produced after 10 minutes (ave of 3 reps). 18 °C: 0 mm; 30 °C: 0 mm; 41 °C: 7 mm; 52 °C: 37 mm; 66 °C: 0 mm.	Tauber/26 Fall 1989	Joel Smith, Melinda Darby, Christine Peterson
The Effects of VArying Amounts of Substrate on the Rate of Alcoholic Fermentation CO_2 evolved after 30 minutes, ave of 2 reps. 1.5 ml sugar: 0 mm; 2 ml sugar: 19.5 mm; 2.5 ml sugar: 17 mm; 3 ml sugar: 22 mm; 5 ml sugar: 3 mm (??)	Tauber/26 Fall 1989	Lyn Pusser, Monica Hanna
The Effect of Changing the Substrate Concentration on the Amount of Product CO_2 evolved after 30 minutes, ave of 3 reps. 1.5 ml sugar: 9 mm. 2.5 ml sugar: 10.6 mm; 5.0 ml sugar: 10.6 mm; 7.5 ml sugar: 10 mm.	Williams/49 Fall 1989	Jamey Meekins, Corey Holcombe, Joseph Allison
The effects of various sources of sugar when given to yeast on the process of alcoholic CO_2 evolved after 30 minutes. Orange juice, 45 mm; grape juice, 9 mm; milk, 0 mm; corn syrup, 2 mm.	woodroffe/7 Spring 1989	Jeff Underhill, Karen Ann Jenkins
The effects of different sugars and temperatures on alcoholic fermentation CO_2 evolved after 30 minutes. Used different substrates at different temperatures. 0 °C: no fermentation. 30 °C: apple juice 17 mm, pineapple juice 13 mm, orange juice 15 mm. 37 °C: apple 16 mm, pineapple 9 mm, orange 13 mm. Also tried castor oil and got no fermentation.	woodroffe/7 Spring 1989	Sammy Cole, James Hill, Mark Taylor

Investigations using photosynthesis in Elodea

Experiment	Instructor/sec Semester	Students
The Effect of Different Concentrations of Sodium Bicarbonate on the Photosynthetic Rate of Elodea Used 1 L of .5%, .7% and 1% Na_2CO_3. The most oxygen was produced with the 1% solution. The biggest weakness of this experiment is the fact that they did not record O_2 produced during frequent enough time intervals.	Bebek/38 Fall 1990	Kathy Kall, Elizabeth Gray, Bryan Slattery
The effect of temperature and ph on the photosynthetic rate of elodea. O_2 evolved after 30 minutes (no replication): 11 °C: 0; 22 °C: 3 mm; 35 °C: 18 mm. Then used 35 °C to test different pH (O_2 evolved after 30 min): pH 4: 37 mm; pH 6: 65 mm; pH 8: 29 mm; pH 10: 28 mm.	Belthoff/22 Fall 1989	Kathryn Falls, Synita McClary, Amelia Howard
The effect of sodium bicarbonate on the photosynthetic rate of elodea 2 reps, average O_2 evolved in 40 minutes at: 0% $NaHCO_3$: 0 mm; 0.1% $NaHCO_3$: 25.5 mm; 1.0% $NaHCO_3$: 55 mm; 5.0% $NaHCO_3$: 10.5 mm.	Belthoff/5 Spring 1989	Karen Wais, Stacy Holloman, Crosby Broadwater
What will be the effect of varying amounts of sucrose on Elodea photosynthetic rate? Data is recorded in inches, ave. of 2 reps except at 0.1 M. distilled water: 0 in.; 0.1 M sucrose: 0.8125 in.; 0.3 M sucrose: 0.8125 in.; 0.5 M sucrose: 0.8 in.	Belthoff/5 Spring 1989	Robert Carter, Al Fleming, James Coley
The effect of temperature on the photosynthetic rate in Elodea O_2 evolved after 30 minutes at: 10° C (4.5 mm), 20° C (28 mm), 30° C (4 mm), 50° C (8 mm). Measurements were taken every 5 minutes (see Thompson)	Belthoff/5 Spring 1989	Carol Thompson, Melanie Strickland, Craig Yardley
The effect of different pH levels of photosynthesis of the Elodea plant O_2 evolved after 10 minutes, average of 2 reps. pH 4: 4 mm; pH 7: 8.75 mm; pH 10: 0 mm.	Berry/10 Fall 1989	Jeff Butler, Jennifer Thompson, Dana Marks
The effects of changes in temperature on the photosynthetic rate in Elodea O_2 evolved, average of 2 reps. 20 °C: 7.5 mm; 40 °C: 9.5 mm; 60 °C: 4.5 mm.	Berry/8 Spring 1989	Brian Brewer, Dale Pullen

Investigations using photosynthesis in Elodea

Experiment	Instructor/sec Semester	Students
How Carbon Dioxide Concentration Effects Rate of Photosynthesis Elodea was placed in four concentrations of sodium bicarb. (0.01%, 0.1%, 1.0%, 10.0%) and the amount of CO_2 was determined. It was found that 0.1% sol'n allowed a greater rate than the rest (13.25mm). All others were significantly lower. Also tested water and found no CO_2 evolved.	Brignola/2 Spring 1990	Myra Bickley, Jim Nichols, Brad Sease
The Effect of Concentration of CO2 on Photosynthetic Rate in Elodea Allowed photosynthesis to take place in 0.01, 0.05, 0.1, 0.5, 1.0, 5.0% solutions of sodium bicarbonate. Performed two experiments. One tested the rate with one set of plants and emmersed them in increasing conc. allowing 5min. to equilabrate between runs. The second was a decreasing expreiment from high to low. In both cases found that 5.0% showed the most O_2 production. Replicates were not done.	Brignola/2 Spring 1990	Myra Bickley, Jim Nichols, Brad Sease
The Effects of Different Solutions on the Photosynthetic Rate in Elodea Measured O_2 evolved after 10 minutes in distilled water (0 mm), 1% salt water (6 mm), 1% sucrose (5 mm) and 0.1% $NaHCO_3$ (6.5 mm).	Brignola/6 Fall 1989	Mark Golla, Paige Steen, Lee Buford
Measuring the Photosynthetic Rate of Elodea Used one setup for each concentration, no replication. O_2 evolved in 20 minutes. 0.1% $NaHCO_3$: 7 mm; 0.5% $NaHCO_3$: 7 mm; 1.0% $NaHCO_3$: 10 mm; distilled water: 0 mm.	Brignola/6 Fall 1989	Christie Adams, Jamie Lipscomb, Adam Pratt
The Effect of Different Amounts of CO2 on Photosynthesis Used 0, 0.1, 1.0, 5.0, 10.0% solutions to examine the effect of increasing CO_2 on the rate of photosynthesis. Through two trials demonstrated that the greater the % CO_2 the greater the rate of photosynthesis (0mm, 4.25mm, 6.25mm, 7.0mm, 7.25mm, for 0, 0.1, 1.0, 5.0, 10.0%, respectively).	Brignola/8 Spring 1990	Susan Taylor, Jennifer Buckley, Chris Hill
THe effect of pH on Photosynthesis Exposed Elodea to pH values of 2, 4, 6, 7, 8, 10, 12 for a total of 20min. Found that pH 12 allowed the	Brignola/8 Spring 1990	Tim Williams, Wayne Hinds

Investigations of mitochondrial activity

Experiment	Instructor/sec Semester	Students
The Effect of Succinate on Mitochondrial Activity In this experiment they varied the amount of Succinate in the reaction. The students conclusion that the more substrate the faster the reaction will proceed. However no replicates were done and graph is hard to interprate in this manner	Brignola/2 Spring 1990	Wanda Jordan, Kesha Venning
The Effect of Different Temperatures on Mitochondrial Activity % transmittance after 15 minutes (average of 2 reps, 3 at room temp). 0 °C: 0%; 25 °C: 77%; 60 °C: 0%; 100 °C: 75%.	Droge/30 Fall 1989	Shana Cloer, Stephanie Dean, John Andrew Monin
Rate of aerobic respiration when using varying amounts of substrate Using .1, .2,.3,.04, and .05 ml of succinate did not get good correlatioon of amount of substrate with transmittance. Four people per group caused too much confusion while measuring and reading Spec 20.	sigmon 22 Fall 1990	Tyler Brewington, Tara Daniels, Marci MacVean, Chris Leming
The effects of the concentration level of substrate on enzyme activity % transmittance after 12 minutes, varying amount of substrate. 1.5 ml substrate: 10%; 1.0 ml: 31%; 0.05 ml: 25%; 0.005 ml: 48%.	Williams/53 Fall 1989	Michael Masters, Jay Vermeulen, Scott Herrington
The transmitance of light using pinto bean, lima juice, and pH's of 2,4, & 6 I can't tell what they did...	Williams/53 Fall 1989	Rhett Sanders, David labinet

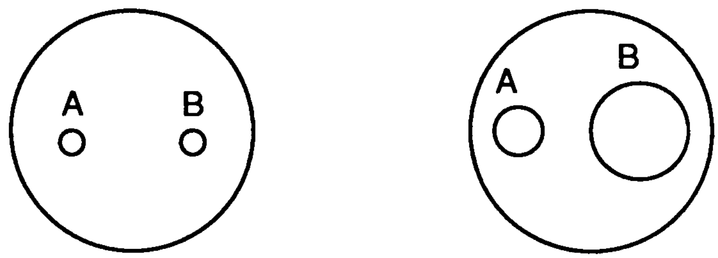
Appendix 5

Process Skills and Nature of Science Test
Used in Fall 1989

Test of Scientific Problem Solving **Biology 105**

Please select the **best** answer to each of the following questions. We do not expect you to be able to answer every question, but please do your best.

1. Agar is a jellylike substance which allows molecules to diffuse through it. The rate of movement depends on several factors, including molecular size (heavy molecules move more slowly). Samples of molecule A and molecule B are placed as shown in the left drawing, and after 30 minutes the molecules have diffused outward to produce the pattern in the right drawing.



The best conclusion from these observations would be that

1. molecule A is not as heavy as molecule B.
2. molecule B is not as heavy as molecule A.
3. no conclusion about molecular size is possible because the experiment has gone on too long.
4. no conclusion about molecular size is possible because the experiment has not been allowed to go on long enough.

2. We could not see molecules A and B even with the most powerful microscopes. Nevertheless, the simple apparatus above can allow us to directly measure

1. the molecular weight of the slower molecule.
2. the rate at which molecules B and A are colliding.
3. which is heavier, molecule B or molecule A.
4. which is heaviest, molecule B, molecule A, or an agar molecule.

3. The experiment in problem #1 was done at room temperature (25° C). Several more experiments are then performed by placing the agar plates in chambers at different temperatures. If the results shown for 25° in the tables below are correct, and if all molecules diffuse faster at higher temperatures, which of these tables shows the pattern of results you would expect? The numbers under "A" and "B" show the distances in cm which each molecule moved.

	1)		2)		3)		4)	
Temp.	A	B	A	B	A	B	A	B
5°	1.0	2.5	2.4	6.5	0.7	8.0	0.1	4.9
15°	1.5	3.8	2.2	5.8	1.4	7.2	0.9	5.0
25°	2.0	5.0	2.0	5.0	2.0	5.0	2.0	5.0
35°	2.8	7.0	1.9	4.6	3.2	4.6	8.2	5.1

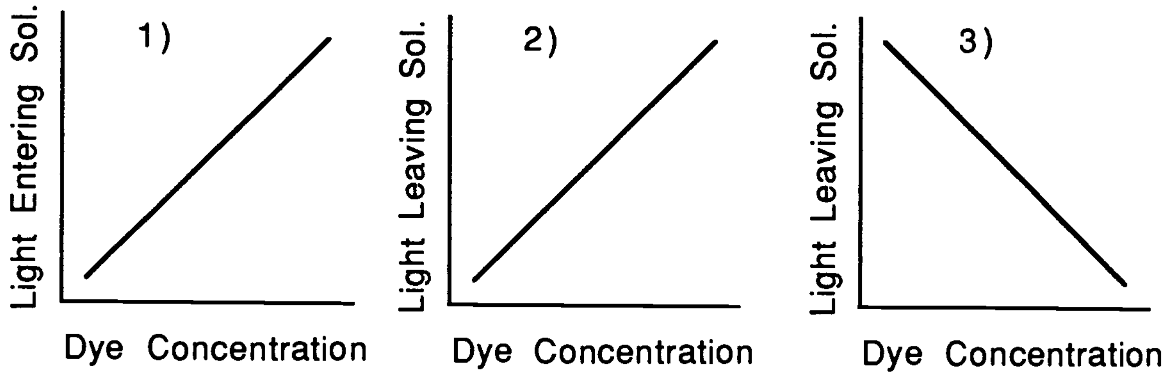
4. In the experiment in problem 3, the **dependent** variable(s) was (were)

1. the size of molecules A and B.
2. the temperatures.
3. the distance moved by the molecules.
4. **All** of these were dependent variables.

5. Science students are always told to take replicate (multiple) observations under each set of experimental conditions. The situation where repeated observations would be **most** effective at improving accuracy would be if a student were

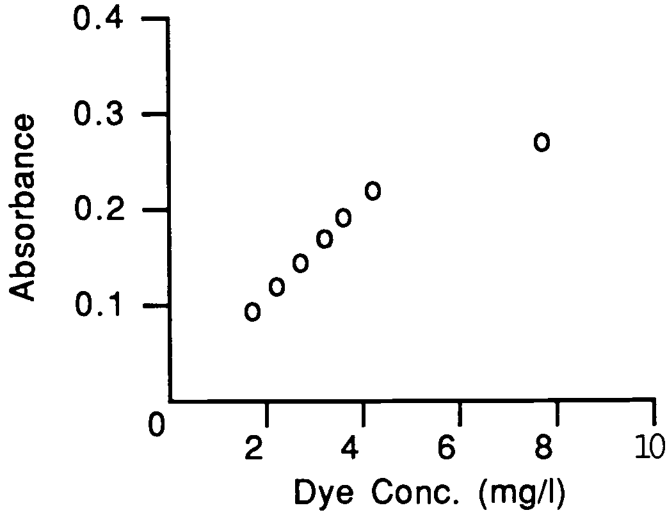
1. measuring the size of red blood cells. They differ slightly from one another, and with each measurement the student makes small, random measurement errors.
2. trying to estimate the number of plants per acre in a desert area by counting them on an aerial photograph. However, the student is computing the plant density from an incorrect formula.
3. observing pigeon behavior. But he cannot tell the difference between male and female pigeons, even though this is important to the study.
4. attempting to prove that another student who had done the same experiment the year before had not analyzed his data correctly.

6. In a technique called spectrophotometry, the concentration of a colored substance in a solution can be measured by determining how much light the substance absorbs when a beam of light is passed through the solution. The more light the solution absorbs, the higher the concentration of the colored substance. If we were measuring the concentration of a dye in a solution with spectrophotometry, which of the following relationships would be valid? ("Sol." means "solution.")



4. **None** of these relationships are valid.

7. If we want to use spectrophotometry to measure the **absolute** concentration of a colored substance (that is, an actual concentration in mg/l or some other units), we must use a "standard curve," or a plot of the light absorbance against a series of known concentrations of the substance. For example, a standard curve for the dye above would be:



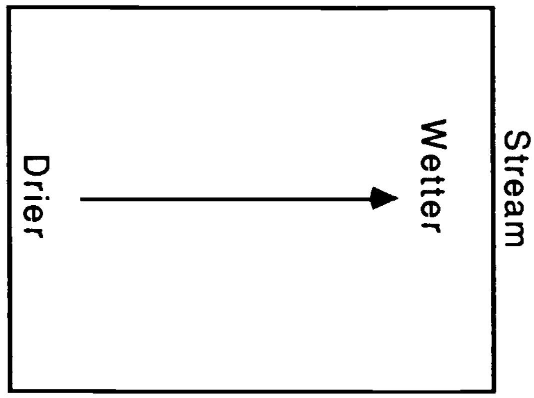
where each circle represents an experimental measurement done by a student team. Using the standard curve above, you would have the greatest confidence that a solution with an absorbance of ... had a dye concentration of ... mg/l.

1. 0.03 ... 0.8
2. 0.20 ... 4.0
3. 0.25 ... 6.0
4. 0.35 ... 10.0

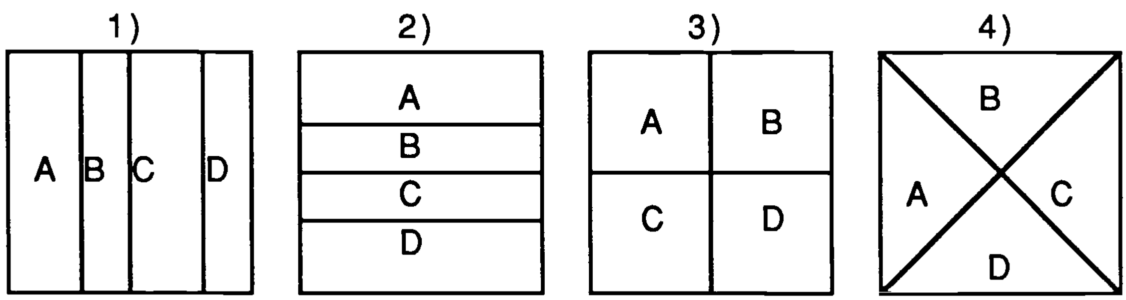
8. If a standard curve is done correctly, the absorbance should be directly proportional to the concentration of the colored substance. If this is true, the point on the standard curve which is most probably in error is the one for a dye concentration of ... because ...

1. 2 mg/l ... its absorbance is too high.
2. 4 mg/l ... its absorbance is too low.
3. 8 mg/l ... its absorbance is too high.
4. 8 mg/l ... its absorbance is too low.

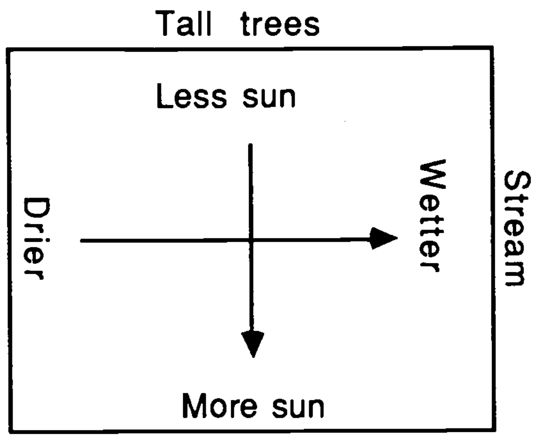
9. An agricultural scientist is testing four crop varieties (A, B, C and D) for yield. She is performing her experiment in three different regions of a state, and in one region the experimental field has a gradient from moist soil near a stream to dry soil at the other end of the field. The moisture gradient runs as shown below:



This difference will probably affect the yields of all varieties, but she does not want the moisture differences to bias her comparison of the yields. Which of the following planting arrangements would be best for this experiment?



10. In another region of the state, there are two soil gradients in the field. First, closer to a stream the soil gets wetter. Second, due to tall trees at one end of the field, the crop there is shaded more hours per day than the crop at the other end. These two gradients run at right angles to one another:



The scientist believes that the moisture gradient will produce more of an effect on the crop than the light gradient. Which of the following planting arrangements would be best in this new situation?

1)

A	B	C	D

2)

A	B
C	D

3)

B	A	D	C
A	B	C	D
A	C	B	D
A	B	D	C

4)

A	C	D	B
C	B	A	D
D	A	B	C
B	D	C	A

11. Which of the following would **not** be one of the controlled variables in this crop trial?

1. the number of seeds planted per acre.
2. the crop varieties used.
3. the soil moisture.
4. the amount of fertilizer applied.

12. Yield experiments like the one above are run in three separate regions of the the state, and the results are reported (in kilograms per hectare) in the following table:

Variety	Reg. 1	Reg. 2	Reg. 3	Average
A	65	70	85	73
B	33	68	80	60
C	35	90	95	73
D	68	75	65	71

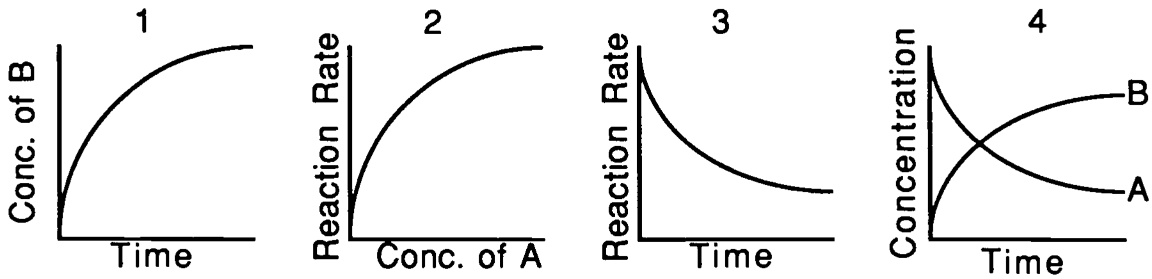
Assuming that farmers desire the highest possible yields, which of the following recommendations is the one which is most supported by the data above?

1. Farmers in region 1 should use variety D; in other regions farmers should use variety C.
2. Farmers who desire reliability rather than high yields should use variety A.
3. Variety C shows the highest yields in two out of three regions, but it is also requires more work from the farmer.
4. Variety A's good showing in region 3 was probably due to unusually good weather during the growing season.

13. Farmers are ultimately interested in profits rather than just yields, and the scientist's recommendation was based solely on yields. Which of the following economic considerations might cause a knowledgable farmer to adopt a different variety than the one recommended by the scientist?

1. The prices for all varieties of this crop have been dropping lately, and many producers have gone out of business.
2. There is hope that new markets overseas may soon open up for all varieties of this crop.
3. The varieties require different amount of insecticide, and insecticide prices are increasing rapidly.
4. On working farms, all the yields shown in problem 13 will probably be at least 10% lower.

14. Enzymes are proteins which speed up the rate of chemical reactions. A certain enzyme speeds the reaction by which compound A is converted to compound B. If increasing amounts of A are added to a small amount of enzyme, the reaction rate will increase until all of the enzyme is occupied by A. After that, the reaction rate cannot increase any further no matter how much more A is added. Which of the following graphs depicts this situation?



15. A student team puts a mixture of enzyme and A in a series of test tubes, and then subjects the tubes to different temperatures. It seems that the amount of B in the tubes after one minute increases up to 37°. However, their instructor suggests that perhaps increasing temperature is causing the enzyme itself to decompose and give a false reading to the chemical test which is detecting B. The students could answer this criticism by performing the experiment on a test tube which contained

1. enzyme and B rather than enzyme and A.
2. equal amounts of A and B but no enzyme.
3. A and no enzyme.
4. enzyme only.

16. Photosynthesis is often demonstrated with an aquatic plant called *Elodea*. Oxygen gas enters spaces inside the stem during photosynthesis. If the stem of an *Elodea* plant is cut, the oxygen gas leaves the spaces as a stream of bubbles. Students can measure the volume of the oxygen in order to estimate the rate of photosynthesis. Some students investigated the effect of light intensity on *Elodea* photosynthesis. They varied light intensity by moving a sunlamp closer and closer to the plant. They left the room lights on and the window shades up while they did this. They expected the rate of gas evolution to increase as the sunlamp got closer.

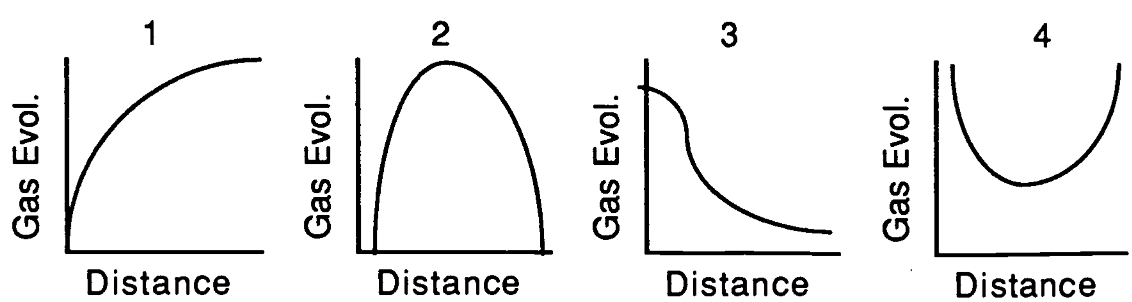
    How is the rate of photosynthesis being measured with this method?

    1. By the distance of the lamp from the*Elodea*.
    2. By the gas which comes out of the cut stem.
    3. By the gas which enters the internal spaces in the stem.
    4. By the growth of the plant.

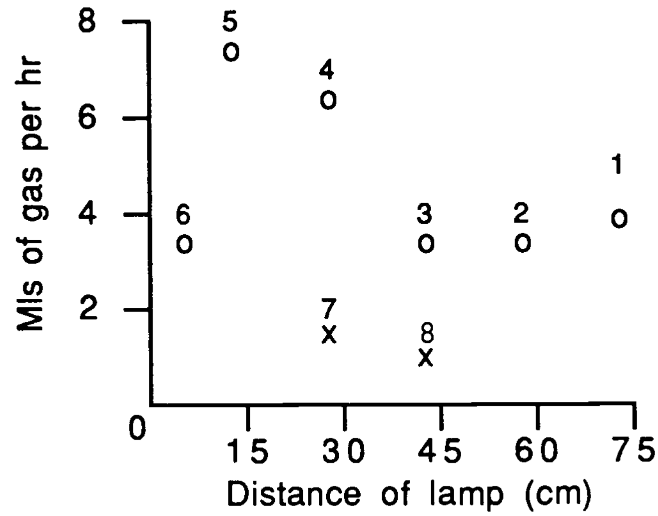
17. What is the apparent hypothesis of the study in question 16?

    1. The photosynthetic rate of *Elodea* will decline as the distance from the lamp increases.
    2. *Elodea* photosynthesizes best in a 0.2% bicarbonate solution.
    3. While the light is on, the starch content of *Elodea* leaves will increase.
    4. The gas coming from the cut stem of *Elodea* will have more oxygen in it than air does.

18. Which graph below depicts the expected response of *Elodea* gas evolution rate to lamp distance?



19. Some students do this experiment and submit the graph below to their laboratory instructor:



In this graph, the o's and x's are the data points, and the small numbers above them show the order in which the measurements were done. The x's show duplicate readings at 30 and 45 cm. All experiments were done in a 0.2% bicarbonate solution.

The students who did the study are puzzled by their data. The first problem is that there is no real increase in photosynthesis as the lamp distance is moved from 75 cm to 45 cm, even though physics tells us that the light intensity increased 278% as the lamp moved through that distance. The following explanations were advanced by other students in the class. Which is the most convincing to you?

1. There is so little light at distances greater than 45 cm that the plant is not photosynthesizing at all.
2. *Elodea* photosynthesizes better in dim light and is inhibited by brighter light.
3. The light from the sunlamp is **not** varying with distance.
4. The *Elodea* is using the the overhead room lights and light from the window to photosynthesize.

20. The students' next question concerns the fact that the 7 cm reading is so low, and that the duplicate readings at 30 and 45 cm were so much less than they were before. This time they read their laboratory manual and find the following statements about *Elodea.* Which one is the most likely to be the solution to the problem?

    1. If the *Elodea* warms up during the experiment, the apparent rate of photosynthesis will increase.
    2. Often the cut ends of the *Elodea* stems become plugged over time, and the rate of gas evolution is reduced.
    3. Use only the fresh, robust pieces of *Elodea* because the pale, thin pieces do not evolve gas rapidly.
    4. *Elodea* photosynthesizes better in a bicarbonate solution than in distilled water.

21. The students have read in their laboratory manual that *Elodea* has a higher rate of gas evolution in 0.2% bicarbonate solution than in distilled water. This statement gives them the idea that it might be interesting to investigate the effect of bicarbonate on photosynthesis of *Elodea*. Which of the following is the best hypothesis to test?

    1. The rate of gas evolution of *Elodea* will remain the same in distilled water, 0.1%, 0.2%, 0.5% and 1% bicarbonate solution.
    2. The rate of gas evolution from *Elodea* will increase if it is put into bicarbonate solution.
    3. The rate of photosynthesis of *Elodea* will decline if the surrounding solution is not right for it.
    4. Bicarbonate helps *Elodea* photosynthesize.

22. If the students do the bicarbonate experiment mentioned above, what will the **independent** variable be?

    1. the amount of the *Elodea*.
    2. the distance between the lamp and the *Elodea*.
    3. the rate of oxygen evolution from the *Elodea* stem.
    4. the bicarbonate concentration in the solution surrounding the *Elodea*.

23. A microbiologist is attempting to find and culture a bacterial strain which will manufacture large amounts of an antibiotic. There are several bacterial strains which **may** be antibiotic producers and many different culturing methods which might be used to maximize production of the antibiotic. The first step in solving this complex problem should be to

1. find the culturing conditions under which the majority of the bacterial strains will grow.
2. determine which strain is most easily available.
3. test all the bacterial strains for ability to produce the antibiotic.
4. determine which bacterial strain reproduces most rapidly.

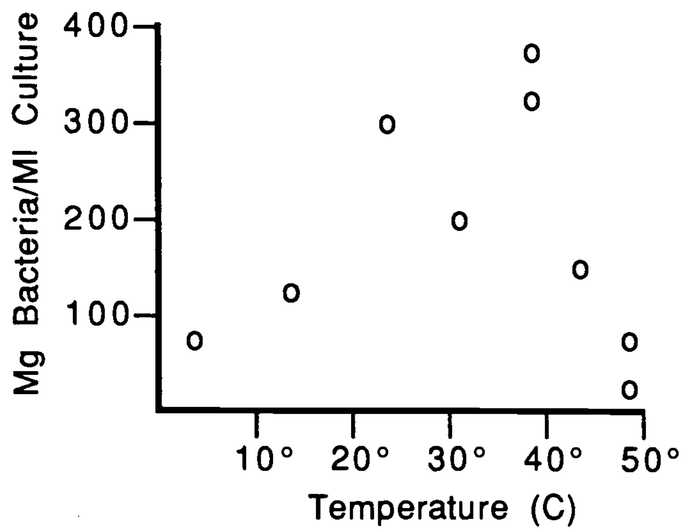
24. The microbiologist decides to find the best culturing conditions for a selected strain (with respect to temperature, pH and nutrients). But the time allotted for the antibiotic study is short. The quickest way to find the optimal culturing conditions would be to

1. select several temperature, pH and nutrient levels and test the growth of the bacterium at every possible combination of these conditions.
2. hold pH and nutrients constant and vary temperature until the optimal temperature is discovered. Then bring temperature to the optimal value and hold nutrients constant and vary pH. Then bring temperature and pH to the optimum and vary nutrients.
3. vary temperature, pH and nutrients randomly and simultaneously, and record growth. After a large number of these trials, the optimal conditions are the conditions which produced the greatest growth.
4. find a bacterial strain with a high reproductive rate, and then implant genes for antibiotic production into it.

25. Given that the purpose of the experiment was to find a strain which would produce antibiotic and then maximize its production, which of the following is the best way for the microbiologist to present his final data?

1. A bar graph of maximum antibiotic production (y-axis) vs. strain (x axis) with optimum culturing conditions noted in the caption.
2. A line graph of temperature, pH and nutrients (y-axis) vs. growth (x axis) for the most productive strain, with antibiotic production noted in the caption.
3. A table showing growth rates of the most productive strain with temperature, pH and nutrients as column headings. The conditions which caused maximum antibiotic production would be noted in the caption.
4. A pie chart showing the percentage of total antibiotic production attributed to the different strains, with the total antibiotic production given in the caption.

26. The 24-hour growth of the most productive strain as a function of temperature is shown below. Each circle indicates an experimental measurement.



The microbiologist is concerned about the unexpected result that both the 25° growth and the 40° growth are higher than the 30° growth. What should the microbiologist do?

1. Accept the fact that the strain responds to temperature in a more complex fashion than he had anticipated.
2. Drop the 40° points, which are probably due to error.
3. Do another growth experiment at 30°.
4. Drop the 30° point, which is probably due to error.

For questions 27-35, please indicate your disagreement (1) or agreement (3) with the statement. If you are uncertain, put 2 for that question.

27. Any organized, systematic body of knowledge is scientific.
    1. Disagree. 2. Uncertain. 3. Agree.

28. All the investigators who repeat an experiment might not obtain exactly the same results, even if they all perform it correctly.
    1. Disagree. 2. Uncertain. 3. Agree.

29. Science depends on orderly, systematic work, so unplanned observations and accidental findings should be excluded from scientific data.
    1. Disagree. 2. Uncertain. 3. Agree.

30. Science is objective and rational, and is not influenced by the cultural experiences of the scientist.
    1. Disagree. 2. Uncertain. 3. Agree.

31. The scientific approach can be used to solve any problem.
    1. Disagree. 2. Uncertain. 3. Agree.

32. Once it has been widely accepted, scientific truth cannot be challenged by new data.
    1. Disagree. 2. Uncertain. 3. Agree.

33. Scientific methods can be used successfully by non-scientists.
    1. Disagree. 2. Uncertain. 3. Agree.

34. I understand the general methods by which scientists work.
    1. Disagree. 2. Uncertain. 3. Agree.

35. I think that training in scientific methods is useful for all educated people.
    1. Disagree. 2. Uncertain. 3. Agree.

Appendix 6

Student Opinion Data
Spring 1989 - Fall 1990

Results of Student Opinionnaire
Investigative Lab Students

The results below are shown as percentages of **the investigative students** who answered that they agreed, were neutral about, or disagreed with the statement to the left of the percentages. The first line shows the results from Spring 1989 (67 students); the second line shows results from Fall 1989 (247 students); the third line shows Spring 1990 (115 students); the fourth line shows Fall 1990 (238 students). A line with a "-----" means that that question was not asked that semester.

	Agree	Neutral	Disagree
I enjoyed having the freedom to design experiments.	73.1	11.9	13.5
	49.2	26.4	24.4
	73.9	17.4	8.6
	68.1	18.7	13.3
I enjoyed designing and doing wetlab experiments.	-----	-----	-----
	39.7	23.3	37.0
	60.9	22.6	16.5
	55.2	28.0	16.8
I think I learned about science by designing and doing the wetlab experiments.	-----	-----	-----
	-----	-----	-----
	-----	-----	-----
	68.5	13.7	17.8
I enjoyed using the FISHFARM computer simulation.	52.2	13.4	32.8
	35.7	18.1	46.2
	53.0	22.6	24.3
	63.5	16.2	20.3
I think I learned about science by doing the FISHFARM computer simulations.	-----	-----	-----
	-----	-----	-----
	-----	-----	-----
	47.7	22.4	29.9
The videotapes were helpful in designing and doing experiments.	76.2	14.9	9.0
	63.7	22.2	14.1
	71.3	18.3	10.4
	-----	-----	-----

	Agree	Neutral	Disagree
My lab instructor was helpful in designing and doing experiments.	94.0	3.0	3.0
	74.1	17.4	8.5
	94.8	3.5	1.7
	-----	-----	-----
The Wetlab Manual was helpful in designing and doing experiments.	79.1	7.5	13.5
	69.2	15.2	15.6
	80.9	13.0	6.1
	-----	-----	-----
Keeping a lab notebook was helpful in designing and doing experiments.	65.7	20.9	12.0
	62.3	25.7	12.0
	68.7	23.5	7.8
	64.8	24.3	10.8
The Aquaculture Handbook was helpful to me in using the FISHFARM program.	76.1	6.0	16.4
	76.6	16.1	7.2
	76.4	17.4	5.2
	-----	-----	-----
My team members were helpful in designing and doing experiments.	85.1	7.5	7.5
	75.8	14.1	10.0
	84.4	13.0	2.6
	-----	-----	-----
The Writing Guide was helpful in learning to use my lab notebook.	50.7	32.8	16.5
	56.9	24.8	18.3
	68.1	20.4	11.5
	72.9	17.4	9.8
The Writing Guide was helpful in writing lab reports.	86.6	6.0	7.5
	84.2	8.1	7.7
	84.4	11.3	4.3
	85.3	8.8	5.8

	Agree	Neutral	Disagree
My lab notebook was helpful in writing lab reports.	77.8	11.9	10.5
	84.2	8.1	7.7
	78.3	17.4	4.3
	80.3	10.9	8.8
Lab reports were a good way of evaluating my success in the investigative portion of Biology 105.	58.3	16.4	25.4
	36.2	27.2	36.5
	44.2	29.6	25.2
	45.5	24.5	29.9
My team members were helpful in designing and doing experiments.	85.0	7.5	7.5
	75.8	14.1	10.0
	84.4	13.0	2.6
	-----	-----	-----
The members of my lab team were important to my success in this course.	68.7	17.9	13.4
	57.4	25.9	16.6
	67.3	21.2	11.5
	-----	-----	-----
My lab instructor was important to my success in this course.	78.4	15.3	6.1
	67.2	20.6	12.1
	82.3	14.2	3.6
	69.6	21.5	8.9
I feel more confident than at the beginning of the course that I know how to analyze problems scientifically.	59.7	28.4	12.0
	53.4	31.6	14.7
	61.6	28.6	9.8
	61.0	28.0	11.0
I feel more confident than at the beginning of the course that I know how to design experiments.	65.7	22.4	12.0
	63.5	24.8	11.7
	66.3	23.9	9.8
	73.1	17.6	9.3

	Agree	Neutral	Disagree
I feel more confident than at the beginning of the course that I know how to analyze data.	64.1	23.9	12.0
	60.3	26.3	13.3
	67.9	21.4	10.7
	69.6	21.5	8.9
I feel more confident than at the beginning of the course that I know how to present my work to others, both orally and in writing.	64.1	25.4	10.5
	69.9	26.3	13.3
	71.7	21.2	7.1
	70.9	19.8	9.3
Biology 105 was what I expected a lab to be.	29.9	23.9	45.8
	19.4	20.6	59.9
	22.1	15.0	62.8
	23.6	22.4	54.0
I liked doing the investigative labs.	60.2	20.9	17.9
	38.8	19.0	42.1
I liked doing the labs (had only inves. labs).	48.7	29.2	22.1
I liked doing the traditional labs.	18.8	37.5	43.8
	50.4	23.0	26.6
	-----	-----	-----
	-----	-----	-----
I am more interested in biology than I was before I took this course.	32.8	32.8	34.3
	22.6	36.4	40.9
	31.0	35.4	33.6
	31.5	33.2	35.2
I think I would have learned more about science if I had been in a traditional section.	29.8	22.4	47.8
	44.1	29.9	25.9
	-----	-----	-----
	27.8	30.8	41.4
I think I would have gotten a better grade if I had been in a traditional section.	22.8	26.9	49.3
	44.6	26.3	29.1
	-----	-----	-----
	31.0	34.7	34.3

	Agree	Neutral	Disagree
I would rather take quizzes than write lab reports.	40.3	10.4	49.2
	60.6	17.1	22.4
	65.5	15.2	39.3
	35.4	24.1	40.6
I think I will be able to apply what I learned in Biology 105 to other courses.	44.8	35.8	19.4
	40.4	32.4	27.1
	45.4	28.2	26.4
	46.8	38.1	15.2
Biology 105 helped me with Biology 103 lecture content.	44.8	35.8	19.4
	52.5	22.1	25.4
	21.1	27.4	51.6
	17.0	23.2	51.5
This lab course required too much work outside of class.	64.2	14.9	20.9
	58.7	22.9	18.3
	63.7	23.0	13.3
	54.0	22.8	23.2
I would have been satisfied with a C in Biology 105 if I could have gotten it without studying or doing out-of-class work.	-----	-----	-----
	20.7	19.0	60.3
	22.1	16.8	61.1
	19.4	14.8	65.9
I would recommend this lab course to other students.	44.7	26.9	28.3
	29.9	29.9	40.1
	34.8	37.5	27.7
	-----	-----	-----
Overall, this is one of the best courses I have taken.	25.3	34.3	40.3
	16.8	28.4	54.8
	-----	-----	-----
	-----	-----	-----

Investigative vs. Traditional Student Opinionnaire Comparisons

In Spring of 1989, Fall of 1989 and Fall of 1990, both traditional and investigative labs were taught, and some questions were asked on both the traditional and investigative questionnaires. For each of these questions, a contingency table was created and chi-square analysis was performed on the numbers of students responding in each of five categories of agreement (ranging from strongly disagree to strongly agree). Statistical significance of the results is indicated below with "ns" for results not significant at the 0.05 level, "*" for significance between the 0.05 level and the 0.01 level, and "**" for significance at the 0.01 level or greater.

In Spring of 1989, all labs were taught by instructors who taught at least one investigative lab. In Fall of 1989, most traditional lab sections were taught by instructors who did not teach any investigative labs, but some were taught by instructors who also had in investigative section. Therefore, in Fall of 1989, there were two comparisons performed: between investigative lab students and traditional students who had the same instructor ("investigative instructor" or "II" below), and between investigative lab students and traditional students who had instructors who did not teach any investigative labs ("other instructors" or "OI" below). In Fall of 1990, no instructor taught both an investigative and a traditional section.

The number of students in each group are shown below:

Table 3. Numbers of students in investigative and traditional laboratories in several semesters.

	Spring 1989	Fall 1989	Fall 1990
Investigative	67	247	238
Traditional (inves. instructor)	90	149	----
Traditional (non-inves. instructor)	---	699	555

Note that although each statement is listed below with the results summarized as percent agreeing with, neutral about, or disagreeing with the statement, the chi-square analysis was performed on actual numbers of students in five categories of agreement.

I feel more confident than at the beginning of the course that I know how to analyze problems scientifically.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	ns	57.3	30.3	12.4	59.9	28.3	11.9
Fall '89, II	ns	46.6	38.6	14.6	53.4	31.5	14.9
Fall '89, OI	**	42.2	35.6	22.1	53.4	31.5	14.9
Fall '90	**	35.4	26.8	37.6	61.0	27.9	11.0

I feel more confident than at the beginning of the course that I know how to design experiments.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	ns	58.8	31.1	10.0	64.8	23.1	11.9
Fall '89, II	**	37.0	49.0	13.9	63.4	24.7	11.7
Fall '89, OI	**	35.3	38.5	26.0	63.4	24.7	11.7
Fall '90	**	23.6	40.0	36.3	73.1	17.6	9.2

I feel more confident than at the beginning of the course that I know how to analyze data.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	ns	58.8	31.1	10.0	64.1	23.8	11.9
Fall '89, II	ns	56.0	33.3	10.6	63.4	24.7	11.7
Fall '89, OI	**	46.6	35.5	17.7	63.4	24.7	11.7
Fall '90	**	39.6	37.9	22.4	69.6	21.5	8.8

I feel more confident than at the beginning of the course that I know how to present my work to others, both orally and in writing.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	ns	46.0	37.0	16.8	64.1	25.3	10.4
Fall '89, II	**	28.8	52.3	18.7	59.9	29.1	10.9
Fall '89, OI	**	35.1	42.1	22.7	59.9	29.1	10.9
Fall '90	**	24.5	43.2	32.1	70.8	19.8	9.2

Biology 105 was what I expected a biology lab course to be.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	**	55.5	21.1	23.3	29.8	23.8	46.2
Fall '89, II	**	49.3	22.2	28.3	19.4	20.6	59.9
Fall '89, OI	**	42.7	21.9	35.3	19.4	20.6	59.9
Fall '90	**	41.7	20.5	37.6	23.6	22.3	54.0

I am more interested in biology than I was before taking this course.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	ns	34.4	41.1	24.4	32.8	32.8	34.3
Fall '89, II	ns	32.2	37.5	30.2	22.6	36.4	40.8
Fall '89, OI	ns	27.2	32.8	39.8	22.6	36.4	40.8
Fall '90	*	20.5	35.1	44.3	31.5	33.1	35.2

For traditional sections: **I think I would have learned more about science if I had been in an "investigative" section.**
For investigative sections: **I think I would have learned more about science if I had been in a "traditional" section.**

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	*	20.2	40.4	39.3	31.7	23.8	44.4
Fall '89, II	**	13.4	40.9	45.6	44.1	29.9	25.9
Fall '89, OI	**	17.8	40.4	41.6	44.1	29.9	25.9
Fall '90	ns	20.1	37.5	42.2	27.7	30.7	41.4

For traditional sections: **I think I would have gotten a better grade if I had been in an "investigative" section.**
For investigative sections: **I think I would have gotten a better grade if I had been in a "traditional" section.**

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	ns	13.7	43.6	42.5	23.8	26.8	49.2
Fall '89, II	**	10.1	39.8	50.0	44.1	25.9	29.9
Fall '89, OI	**	18.7	44.3	36.9	44.1	25.9	29.9
Fall '90	*	24.9	39.5	35.5	30.9	34.7	34.3

I would rather take quizzes than write lab reports.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	**	69.6	9.0	21.3	49.2	10.4	40.3
Fall '89, II	ns	68.4	15.4	16.1	60.5	17.0	22.3
Fall '89, OI	*	51.3	17.1	31.5	60.5	17.0	22.3
Fall '90	**	49.6	15.8	34.5	35.4	24.0	40.5

This lab course required too much work outside of class.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	**	5.5	27.0	67.4	64.1	14.8	20.8
Fall '89, II	**	8.0	23.4	68.4	58.7	22.8	18.3
Fall '89, OI	**	11.1	24.9	63.8	58.7	22.8	18.3
Fall '90	**	11.2	25.9	62.7	54.0	22.7	23.2

I would have been satisfied with a C in Biology 105 if I could have gotten it without studying or doing work outside of class.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Fall '89, II	ns	21.4	16.1	62.4	20.6	19.0	60.3
Fall '89, OI	*	30.2	16.9	52.7	20.6	19.0	60.3
Fall '90	**	31.9	23.0	45.0	19.4	14.7	65.8

I think I will be able to apply what I learned in Biology 105 to other courses.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	ns	47.1	30.3	22.4	44.7	35.8	19.4
Fall '89, II	ns	40.9	42.9	16.1	40.4	32.3	27.1
Fall '89, OI	ns	36.8	34.3	28.7	40.4	32.3	27.1
Fall '90	**	32.0	31.7	36.0	46.7	38.0	15.1

Biology 105 helped me with Biology 103 lecture content.

		Traditional			Investigative		
		Agree	Neutral	Disagree	Agree	Neutral	Disagree
Spring '89	**	79.7	6.3	13.8	48.2	30.4	21.4
Fall '89, II	**	86.3	5.4	8.2	52.4	22.1	25.4
Fall '89	**	70.0	12.4	17.5	52.4	22.1	25.4
Fall '90	**	66.6	12.8	20.4	18.5	25.3	56.1

Appendix 7

Report on the July 1990 Investigative Lab Workshop
Dr. James Okey
University of Georgia

The University of Georgia

College of Education
Department of Instructional Technology

July 31, 1990

Bob Kosinski and Jean Dickey
330 Long Hall
College of Sciences
Clemson University
Clemson, SC 29634

Dear Bob and Jean:

Enclosed is the report of the evaluation of the Investigative Laboratories Workshop. Results from the questionnaire administered at the close of the Workshop are included as well as summaries of information gained from observations and interviews with participants.

I will emphasize again here the major conclusions from the evaluation --

- the participants were nearly unanimous in their intent to implement all or part of the investigative laboratories approach at their own institutions
- the participants had laudatory things to say about the instructors, the instruction, and the materials provided at the Clemson Workshop

By any measure, the Workshop was a real success in introducing college faculty to the use of an investigative approach for their introductory courses. Congratulations on conceiving and running a successful dissemination program. I'll be in touch with you later about follow up activities with the Workshop participants.

Best regards,

James R. Okey, PhD
Professor

enclosures

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Evaluation Report

Investigative Laboratories Workshop

Conducted at

Clemson University
June 25 - 29, 1990

Prepared by

James R. Okey
Professor of Instructional Technology
University of Georgia
July, 1990

Evaluation Overview

Thirty college professors from the U.S. and Canada participated in a 5-day conference held at Clemson University to learn how to conduct investigative laboratories in introductory biology classes. The activities during the workshop focused on the philosophy of an investigative approach to science, the instructional ingredients for implementing investigations, hands-on activities using the instructional materials and format developed at Clemson, and discussions of how implementation could be accomplished at other sites.

At the close of the workshop, participants completed a questionnaire giving their reactions to various aspects of the workshop. The questionnaire along with summaries of the participants' reactions is attached. Included as well, is a summary of reactions obtained from observations of and interviews with workshop participants.

Results from the Questionnaire *

Institutional Description

Type of institution	Public	15
	Private	13
Program type	2-year	4
	4-year	11
	University	13
No. of biology faculty	1-3	2
	4-6	6
	7-10	4
	> 10	16
Size of program	majors	range from 2 - 800, M = 180
	non-majors	range from 0 - 1500, M = 470

		No. of Programs	
		Majors	Non-majors
No. in Program	0 - 50	9	3
	51 - 100	5	2
	101 - 200	5	4
	201 - 400	5	9
	> 400	3	10

* 28 of the 30 participants provided completed questionnaires which are the source of the following information.

Perceptions of the Program

(Numbers are percentages of respondents choosing the option.)

Strongly disagree = SD Disagree = D Undecided = D Agree = A Strongly agree = SA

Statement	SD	D	U	A	SA
1. The investigative laboratories program could be implemented in my institution.			4	36	60
2. Science process skills are an important part of science learning.				4	96
3. Workshop facilities (labs, equipment, computers, etc.) were appropriate in this institute.			4	14	82
4. Workshop activities gave me enough background to learn how to use investigative laboratories.			7	28	65
5. There was an appropriate mix of hearing about/discussing and doing in the workshop.				25	75
6. There was an appropriate mix of small group and large group activity in the workshop.		4	4	28	64
7. Workshop activities helped me learn what I needed to know to implement this program.			4	39	57
8. Materials provided at the workshop (lab manual, videos, computer programs) will help me implement the program.				7	93
9. Logistics for registration, meals, transportation, and rooms were handled well.				7	93
10. Simulated investigations are a valuable adjunct to conducting actual investigations.				50	50

11. The wetlab methods modules provide sufficient background to the investigative laboratory problems.

SD	D	U	A	SA
	4	7	39	50

12. I plan to implement the idea of investigative laboratories in my institution.

SD	D	U	A	SA
			36	64

Summary of the Perception Items

Responses to the perception items show --

- an overwhelming endorsement of the importance of processes in science instruction (#2)
- strong support for the facilities and logistics surrounding the workshop (#3, 9)
- endorsement of the methods used to conduct the workshop (#4, 5, 6, 7)
- a positive reaction to the simulation and methods modules (#10, 11)
- near unanimous support for the value of the materials in aiding implementation (#8)
- indications that all or part of the ideas can be implemented at other institutions (#1, 12)

Open-ended Questions

(Results from each question are summarized and then briefly discussed.)

13. Briefly, how do you plan to use the investigative laboratory materials at your institution?

- Use all (or most) of the materials (4)
- Incorporate ideas into existing labs (8)
- Use a few of the labs now (from 1 to 4), perhaps more later (6)
- Convert existing labs to a more investigative approach (5)
- Use ideas and specific labs in a new course (3)
- Use investigative labs in a revamped majors course (4)
- Use Fish Farm as a project, independent study, or in regular course (3)

Wide ranges of implementation plans are evident in the responses. Everyone will use some aspects of the labs or Fish Farm. Some will use all or most of the materials. Even when the materials themselves are not to be used, the investigative approach will be implemented. A number of the participants see the materials as usable in majors courses, not just for non-majors.

14. What modifications to the laboratory program will be needed to implement it at your institution?

- Essentially no changes, use as is (4)
- Modify existing labs to make them more investigative using these ideas (2)
- Fish Farm use -- as is, as independent study, can't use, get more computers
- Need more facilities -- computers, video, lab equipment (4)
- "Labs aren't high tech enough for our students"
- Put videos on reserve or use with whole class because of limited equipment
- Reduce the number of modules for our program (3)

A few participants will use the program virtually as is, but a variety of considerations will cause others to make modifications. They include equipment problems for Fish Farm or the videos and, in a small number of cases, the lab equipment itself.

15. Problems related to implementation of investigative laboratories include colleague support, lab facilities and equipment, computers, length of school term, elimination of content from lab, appropriatness for majors and non-majors, and use of TA's. Which of these are problems for you?

- The number of participants citing each problem are --

colleague support	13
lab facilities and equipment	14
computers	22
length of school term	6
elimination of content from lab	11
appropriatness for majors/non-majors	3
use of TA's	11

Virtually every participant cited some difficulties from among the above set. Almost nothing was cited beyond the list presented -- probably because the list was generated based on discussions with participants during the week. Citing problems should not be interpreted as a failure of the program; rather it is a recognition that every institution is different and different procedures are needed to implement and alter courses.

16. How well did this workshop help you achieve your objectives?

- gave me excellent ideas on the investigative approach and process skills (10)
- "Very well" (4)
- gave me new ideas and the tools to use them in my instruction (7)
- "Gave me everything I expected"
- "As well as could possibly be expected"

The participants were nearly unanimous in their views that this workshop gave them the tools to use investigative laboratories and process skills in their own instruction. They state that they are "enthused" and "satisfied" with what they have acquired.

17. **What were the best things about this workshop?**

- helpfullness, enthusiasm, organization, and leadership of the Clemson staff (14)
- interactions with colleagues with similar responsibilities and interests (13)
- access to materials (labs, videos, Fish Farm, manuals, facilities) (8)
- opportunity for hands-on activities with materials (5)
- "There is hardly a thing that was not good"

The enthusiasm for the Clemson staff is evident throughout the written comments from participants. They liked the open sharing of all aspects of the investigative laboratories approach. Beyond these interactions, they strongly valued the opportunity to talk with colleagues of like mind who held similar positions in other institutions.

18. **What could have been changed about the investigative laboratories workshop to make it more valuable to you?**

- "Nothing" (7)
- use more small group discussions throughout the workshop (6)
- more work with the writing component (2)
- more time with wet labs (2)
- work with more advanced tasks suitable for majors (2)
- "We should have been forced to design some of our own experiments"

The most predominant suggestion for change is "none". Participants liked what was planned for the workshop. Some reorganization of activities to allow for more frequent small group interaction was suggested by a number of people.

19. **What is your overall reaction to the content of the workshop, the instruction provided, the instructors, and the facilities?**

- excellent, extremely valuable, first rate, super, top notch, great (15)
- well organized workshop (3)
- "overall a supreme performance"
- "I'd like to put the entire workshop into my suitcase and take it all home"
- "Workshop has been very valuable to my professional growth"

Participants were extremely enthusiastic about the experience at Clemson. They liked the content and organization of the workshop. "Few workshops compare with this one." says one respondent.

20. What are your reactions to the use of FISHFARM as a means of conducting investigations?

- liked it, excellent, brilliant, wonderful, positive, good, love it (14)
- I'll try and use it (5)

Reactions to FISHFARM are highly positive. Some modifications in its use may be dictated by facilities and time available, but participants see this simulation as another good way to provide experience with the methods of science.

21. What are your reactions to the Wetlabs as a component of an investigative biology course?

- extremely positive, wonderful, good, excellent, valuable, very good (11)
- essential to the operation of investigative biology (5)
- "Integral to lab instruction"

Positive reactions to the Wetlabs were noted by nearly all the participants. They see them as an essential component of an investigative course. "These are the type of exercises students like."

Interview and Observation Summary

Observations and interviews were held during 3 of the Workshop days. During group presentations notes of participants questions and comments were made. While participants were carrying out activities individually or in small groups of 2 or 3, they were observed and questions were asked related to their activities or plans that they might have for using the investigative laboratories approach at their home institutions. The questions used with the participants were along the following lines --

- Can this program (or some parts of it) be used in your environment?
- Are you learning enough here to allow you to try out these ideas?
- What else, if anything, do you need to find out?
- Is it effective to have you play a student role to learn about the program?
- What would you do to help participants learn about this program and plan for its adoption or adaptation?

It was evident immediately that participants were intensely interested in the details of how implementation could take place. They asked many questions in the large group sessions and took notes concerning details of implementation -- establishment of lab groups, time allotments for lab, in and out-of-class activity, role of lab TA's, effects on students after they had experienced investigative science, exam procedures, training of TA's, and differences between courses for majors and non-majors.

During discussions and interviews with the participants individually or in their small lab groups, the concerns for implementation were paramount. Problems of implementation were readily discussed -- not that any particular problem was a barrier to implementation -- rather that the problem would have to be addressed at the home institution in some way. Thus the notion of implementing an investigative laboratory approach was not whether it would be done, but how, and to what degree.

The problems identified by a wide range of participants quickly fell into a few categories that are listed below --

✔ convincing colleagues of the value of an investigative approach. The role of the lab as a place to learn science processes is not firmly entrenched in college science courses.

✔ displacement of content from the lab course. Support of the lecture content is a tradition in Freshman laboratory science that is not easy to change.

✔ availability of computers to run the simulation, VCRs to show the video procedures, and lab materials to conduct the methods modules and planned experiments. Of highest concern here is the lack of the appropriate computer equipment. Many schools have access to only a few computers at any one time.

✔ fitting materials into a quarter school term. A number of schools do not have 16 week semester systems so an alteration of what is done at Clemson must be considered.

✔ appropriatness of an investigative approach for majors/non-majors courses. Some thought the investigative approach appropriate for non-majors, others thought it was right for all students, and some wanted to use the materials in Sophomore or other upper-division biology classes.

✔ availability of TAs for conducting investigative laboratories. The concerns here center on whether there are TAs and how they should be trained for leading investigative labs.

From observing a wide variety of the participants, it was not evident that many of them got much beyond the methods modules and into planning and conducting investigations of their own design. One participant wondered aloud if many participants weren't misinterpreting the role of the methods modules -- i.e., that they were means to an end, not the end itself. The goal was to get to the point where new investigations based on the techniques from the methods modules. Associated with this observation is the role that the writing portion of the lab played in the workshop. Several participants noted the value of the writing guidelines and voiced a desire to have used them. It may be that some participants will be attempting to implement portions of the investigative laboratories approach without themselves experiencing it during the workshop.

Overall Results and Summary

The results of the Investigative Laboratories Workshop can be succincltly summarized --

- virtually every participant plans to implement some aspects of the investigative approach at their own institution.

- participants strongly supported the notion that the workshop provided them with the experience and materials needed to implement investigative laboratories.

Followup activities during the coming academic year will be used to find out what the participants actually do, what problems them encounter, and what successes they have in altering the content and purpose of their introductory biology laboratory programs.

Appendix 8

Investigative Wetlab Manual/FISHFARM Manual/Writing Guide
Methods Module Videotapes
FISHFARM Computer Simulation

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Office of Educational Research and Improvement (OERI)
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