Chapter 9

Using Microcomputer-Based Physiology Experiments in Investigative Labs in Introductory Biology

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Contents

Introduction....144
Materials....144
A/D board....145
Transducers....145
Console....145
The BioSensor software....146
Limitations of the BioSensor system....147
Methods....147
Biology 103....147
Biology 104....147
Biology 104 Activities....148
Results....149
Student opinion....149
Instructor opinion....149
Process skills test....151
Lecture scores....151
Future plans....152
Literature Cited....152

Introduction

Students at Clemson University take a two-semester lab science sequence as part of their general education requirement. Biology 103/104, four-credit courses in General Biology, fulfill that requirement for many students. In 1989 we began implementing investigative labs in Biology 103. That is, instead of giving students cookbook lab exercises with predictable results, we developed a program to have students design and perform their own experiments. This program has been very successful, and as full implementation in Biology 103 (approximately 60 lab sections) was reached in 1992 we began developing a program to expand investigative labs into the second semester (Biology 104).

One of the major content areas in Biology 104 is animal systems. We decided to interface physiology instruments with the computers we had already purchased for the 103 labs, and use those as the basis for student-designed investigations of human physiology in the 104 labs. Besides providing a variety of interesting techniques for students to use in their investigations, interfacing offers rapid feedback. Students obtain the results of their experiments quickly, so they are able to revise their hypotheses and collect further data in a short period of time.

Materials

The interfacing hardware and software used by the Clemson investigative lab project is called BioSensor. BioSensor consists of:

a) a Keithley/Metrabyte DAS–8PGA A/D board;
b) six transducers (ECG, heat transfer, temperature, pulse rate, finger ergograph, and knee reflex time) for collecting physiological data;
c) a control console to connect the computer to the transducers;
d) software that stores and analyzes the transducer data;
e) a program to do several measurements on voluntary reaction time.

The A/D Board

The Keithley/Metrabyte DAS–8PGA A/D board is compatible with IBMs or clones with 8086 processors. At Clemson we use it on IBM Model 25 computers purchased in 1990–1991. The board has 12-bit resolution (4,096 degrees of resolution between a zero and a full-scale deflection). It can sample 8 channels simultaneously, and can take a maximum of 40,000 samples/second. This is more than adequate for our applications. A very useful feature is that it has on-the-board amplification, allowing voltage ranges from +/– 10 V down to +/– 10 mv to be sampled with full-scale resolution. According to Keithley/Metrabyte, with the purchase of a µCDAS-8PGA board instead of the DAS-8PGA and with no changes to the software, the BioSensor system will work on IBM PS/2 computers with Microchannel Architecture. We have not had the opportunity to verify this.

The Transducers

Some of the transducers were purchased and some were constructed in-house:

a) The ECG transducers are simple brass plates with screw terminals for the attachment of wires. Their very weak output is amplified by a DAM-50 amplifier on the console (see below).
b) The heat transfer transducer is composed of a Melcor 127-element thermocouple array (thermoelectric ceramic module, catalog number CP1.0–127–05L) glued between two brass plates similar to the ECG plates. This unit produces a voltage when its two faces are at different temperatures. When it has achieved thermal equilibrium, the temperature difference between the faces is proportional to the heat transfer through the unit.
c) The thermocouple is an industrial model from Omega Corporation (integral handle type-K thermocouple probe (catalog number EI–1701–105–HPS–CASS–18U–12SMP)). Its output must be amplified by an Analog Devices AD-595 monolithic thermocouple amplifier with cold junction compensation. The amplifier was manufactured Pioneer Technology.
d) The pulse rate transducer is a pulse ear clip (part 1092–72) purchased from Vernier Software.
e) The finger ergograph (constructed in-house) is a pistol grip with a spring-loaded trigger. The back-and-forth movement of the trigger is read by a linear displacement transducer. The BioSensor software then uses the speed of movement and the known resistance of the spring to calculate work output and a measure of the rate of fatigue. It is possible to change the tension on the spring to change to work required to move the trigger.
f) The knee reflex transducer was also constructed in-house, and consists of two levers connected to a rotary potentiometer. A rubber hammer with a microswitch in the head records a blow to the knee, and the rotation of the potentiometer as the knee joint flexes records the response.

The Console

The console provides plug-in connections for all the transducers. It also has a DAM-50 Preamplifier from World Precision Instruments for amplifying, filtering and isolating microvolt ECG signals.

The BioSensor Software

The BioSensor software consists of assembly language routines provided with every purchase of a DAS-8PGA interfacing board, plus series of nine BASICA analysis and display programs written at Clemson. The assembly language routines avoid the 64K limit on BASIC's addressable memory and their speed of sampling does not depend on BASIC's processing speed. Another valuable attribute is that the sampling is a "background" activity—if sampling is not too fast, the computer can execute "foreground" commands such as plotting data while the sampling continues.

The software leads the user through a four-step process:

1. Setting up the experiment.
2. A real-time preview of the data.
3. Recording the data.
4. Analysis and display of the data.

Setting up the experiment. The student begins by choosing any combination of channels. The program displays hints to help the experiments succeed (e.g., amplifier settings for the ECG experiment and places to attach the clip for the pulse rate experiment). Depending on the combination of channels selected, the computer sets the interfacing board's gain and assigns a default sampling frequency and sampling duration. The student can change these, but the program will only permit settings within the capabilities of the computer.

Real-time preview. After sampling conditions are established, the program gives the students a chance to preview results as they're being recorded. The student selects a single channel that he/she wishes to see, and the computer will present one screen of output (usually 10–20 seconds). This allows the student to verify that connections are good and that the transducer is being used correctly. However, students may forego this preview if they wish.

Recording the data. When the students are ready for the full experiment, the program samples all selected channels at the specified frequency and duration. Then it asks which channel's data they wish to examine first.

Analysis and display. As the students request each channel's data, the complete data set for that channel is scanned to determine the largest and smallest value, and other analysis may be performed also. For example, to remove 60-cycle noise from ECG data, the user may elect to present each data point as a moving average of every point within 1/60 of a second of that point. This averages the effect of 60-cycle noise on that point to zero. For slowly-developing temperature and heat flux, the user may elect to present the data as a series of 1-second averages. In a finger ergograph exercise, the software computes work output in calories per second and presents the results as a series of one-second totals. It also computes total work output, peak work output, and time to 50% fatigue.

Then the results are plotted. A movable cursor allows students to pinpoint exact x and y coordinates, measure the horizontal and vertical distance between two points, or determine the average y value between two points. A statistical program allows evaluation of the significance of a difference between two treatments using a chi-square median test.

Any screen may be printed.

Disk storage and retrieval. If desired, students can store or retrieve data from a data disk.

Voluntary reaction time. BioSensor allows several kinds of voluntary reaction time experiments. In each of them, the computer gives the user a stimulus and the user responds by pressing the spacebar. The program lists and averages the reaction times. If desired, the results may be exported to a statistical program that will use a chi-square median test to determine if there is a significant difference between two treatments.

The possible stimuli are:

a) An “X” appears in the middle of the screen;
b) A letter appears in the middle of the screen, but the user should respond only if the letter is on a random list of letters given to the user at the start of the experiment. This list can be 1–10 letters long;
c) A period appears somewhere on the screen. The period can be high-contrast (white on a blue background) or low-contrast (black on a blue background), and can appear in screen areas ranging from the whole screen down to the middle 3% of the screen;
d) A tone sounds;
e) Either a high tone or a low tone sounds, and the user should respond only if the *high* tone sounds.

Limitations of the BioSensor System

Maximum size of one data set: 32,758 observations
Fastest sampling speed: 4,000 observations/second
Slowest sampling speed: 1 observation/4,000 seconds

The BioSensor system has proved to be more than adequate for our needs in freshman biology at Clemson. For example, in a year of classroom use, we have never had to sample faster than 450 observations/second (in a knee reflex experiment), or slower than one observation every 10 seconds (in sampling the long-term temperature changes in some germinating bean seeds). Also, we have never come close to exceeding the 32,758 data point limit.

Methods

Biology 103

Since Biology 103 is a prerequisite for Biology 104, we can assume that students are somewhat familiar with experimental design, and with writing reports in a scientific format. Biology 103 students learn the elements of experimental design and data presentation through *Fish Farm*, a computer simulation. Working in teams, students perform experiments to determine the best culturing conditions for a new hybrid of fish. They then present their recommendations in a report. During the rest of the semester each team designs and carries out three wet lab experiments on two different topics. They have a choice of techniques and may investigate diffusion, osmosis, enzymes, photosynthesis, or cellular respiration. Teams present their proposals and results orally to the class, and each student writes a lab report for each investigation. A complete description of Biology 103 has been published in Volume 12 of the ABLE Proceedings (Dickey and Kosinski, 1991).

Biology 104

Investigative labs in Biology 104 build on the skills students have acquired in Biology 103. The first laboratory session in Biology 104 includes a review of hypothesis testing using the reaction time program in BioSensor, but for the most part students are already familiar with the rudiments of designing experiments and writing reports. Biology 104 offers an opportunity for students to master the application of these skills. In addition, statistical analysis of data is introduced.

The laboratory program covers human physiology in much greater depth than does the lecture course or the textbook. Therefore the laboratory manual includes the background information students will need to understand the biology of their experiments. In addition, a series of videotapes is being developed to explain the major concepts in each physiology unit. A second series of videotapes illustrates how to use the interfacing equipment.

Biology 104 Activities

Following the introductory week, the schedule proceeds through four cycles during which students investigate four different topics. Table 9.1 shows a sample schedule. The three interfacing units for student investigations are Motor Response (reaction time, knee reflex, and ergograph), Thermoregulation (thermocouple and heat transfer), and Cardiovascular (pulse and ECG, plus non-interfaced blood pressure measurements). For the final experiment, students are either taught techniques for field ecology, or have the choice of using pillbugs or Siamese fighting fish for behavior experiments. A unit on plants is under development and will replace one of the physiology experiments next year, since plant biology is also an important content area of Biology 104.

Table 9.1. Sample schedule for investigative interfacing labs.

Week	Laboratory Activities
1	Course Introduction Introduction to BioSensor Reaction time experiment (review of hypothesis testing)
2	Introduction to Motor Response Learn to use knee reflex transducer and finger ergograph Design experiment on motor response
3	Propose and perform experiment on motor response
4	Oral reports on results; collect additional data if needed
5	Introduction to Thermoregulation Learn to use thermocouple and heat transfer transducers Design experiment on thermoregulation
6	Propose and perform experiment on thermoregulation
7	Oral reports on results; collect additional data if needed
8	Introduction to Cardiovascular Physiology Learn to use pulse and ECG transducers and measure blood pressure Design experiment on cardiovascular physiology
9	Propose and perform experiment on cardiovascular physiology
10	Oral reports on results; collect additional data if needed
11	Introduction to techniques in field ecology or animal behavior Design experiment
12	Propose and perform experiment on ecology or behavior
13	Oral reports on results

In each cycle, students learn experimental techniques by performing brief introductory exercises. Each team then designs an experiment using their choice of technique (or combination of techniques), presents their proposed experiment to the class, collects data, and presents the results to the class. Each individual student writes his or her own lab report, which constitutes the bulk of the lab grade (50 points per report). The rest of the points are awarded for the written proposals (10 points each) and for oral presentation of the proposals (5 points each) and results (10 points each).

Results

Spring 1995 was the first semester of implementation of our investigative lab program in our second-semester general biology course. We collected data on student opinion, instructor opinion, student scores on a science process skills test, and scores in the lecture course.

Student Opinion

Students liked certain aspects of the program and disliked others. They enjoyed investigating these topics more than they did the Biology 103 topics, since they were experimenting on themselves. In order for teams to have enough subjects, students participated in each others' experiments. Thus students gained a greater understanding of all six investigations in the class than they would just by listening to the proposal and results presentations of other teams. Instructors were also pressed into service as subjects, resulting in lively interactions in the laboratory. When experiments were being performed, it was not unusual to encounter students or instructors in the hall doing calisthenics or staring at "Baker-Miller pink," a color psychological research has shown to be restful. Some sample investigations are listed in Table 9.2.

Students also liked being part of the development of a new laboratory curriculum, and tended to be forgiving when things didn't work as planned.

On the other hand, students disliked the fact that laboratories were not coordinated with lecture. They felt that it was strange that they were monitoring their ECGs in lab at the same time that lecture was teaching about plants. They also were annoyed at perceived slowness of the BioSensor software. After the semester was over, we were able to compile the software and greatly increase its speed, so perhaps this second objection will not be a factor in the future.

Instructor Opinion

The 12 sections of investigative labs were taught by three lecturers who had had no previous role in the project. Instructor opinion was very positive. Instructors believed that over the semester, students had improved their ability to design experiments, use statistics, write reports, and give oral presentations. They believed the semester had been an overall success, and offered many suggestions for improvements in the hardware, software and activities for the next implementation.

Table 9.2. Sample investigations

Transducer or Test	Independent variable	Outcome
Reaction time	Caffeine	No significance
	Screen contrast	Significantly longer with low contrast
	Physical distraction	Significantly longer when distracted
	Hand vs. foot	Significantly longer for foot (using paired difference test)
Ergograph	Male vs. female	Time to 50% fatigue and work output significantly greater for males
	Dominant vs. weaker hand	Time to 50% fatigue and work output significantly greater for dominant hand
	Rested vs. fatigued muscles	Time to 50% fatigue and work output significantly greater for rested muscle
Thermocouple	Breath mints	No significant effect on exhaled breath
	Drinking hot beverage	No significant effect on temperature measured in crook of arm
	Different materials used as insulators	Polyester significantly better than other materials
Thermocouple/ Heat transfer	Submerge hands in hot and cold water	Significant difference in forearm temperature; no significant difference in forearm heat transfer
Heat transfer	Biceps curls	Heat transfer from biceps not significantly different
	Drinking cold water after exercising	Significantly higher heat transfer
Blood pressure	Body position	Standing significantly higher than squatting or sitting
	Caffeine	Significant increase
Blood pressure/ Pulse	Surprise	Surprise caused significant increase in pulse rate and blood pressure
Pulse	Soft music	Significantly lower pulse rate
	Video of childbirth (*Miracle of Life*)	Significantly lower pulse rate
	Gaze at Baker-Miller pink	Significant decrease in pulse rate

The Process Skills Test

We wrote an in-house process skills test or 20 multiple-choice questions that assessed the students' ability to compose hypotheses, interpret tables and graphs, design experiments, predict experimental outcomes, and troubleshoot defective experiments. The subject matter was first-semester topics such as diffusion, enzyme kinetics, photosynthesis and respiration, not physiology, interfacing or any other second-semester topic. The exam was administered as a pretest and a posttest to six investigative and six traditional laboratory sections that were paired with the investigative laboratory sections meeting at the same time. Investigative and traditional sections had different instructors. The results are shown in Table 9.3.

Table 9.3. Pretest, posttest and gain of investigative and traditional students on a science process skills test.

	Investigative	Traditional
n	125	111
Pretest	58.4%	56.4%
Posttest	62.3%	57.2%
Gain	3.83%	0.86%
Gain	> 0**	= 0

The results showed that scores of investigative and traditional students were not significantly different at the $p = 0.05$ level on the pretest, and *were* significantly different at the $p = 0.05$ level on the posttest. Despite this, the gain from pretest to posttest was not significantly different in traditional and investigative students because of the slightly higher pretest scores of the investigative students. However, gain of the investigative students was significantly greater than 0 at the $p = 0.01$ level, while the gain of the traditional students was not significantly different from 0.

While the gains of both treatments were disappointingly small, there is at least some indication that investigative labs are improving the process skills of the students.

Lecture Course Scores

Some students in investigative labs feel that their lecture course scores suffer because they are not getting the content review included in traditional labs. Faculty who do not support investigative labs make the same assertion. To determine if there was any validity to these fears, we examined the final *lecture* course scores of investigative and traditional students in lab sections that met at the same time. The survey included 308 students taught by six lecturers. The number of students per lecturer ranged from 33 to 76.

Table 9.4. Final lecture scores of traditional and investigative students.

	Investigative	Traditional
n	152	156
Score	74.8%	75.0%

These scores were not significantly different. Therefore, there is no evidence that participation in investigative labs is detrimental to student performance in content-oriented lecture courses. This is the same result we obtained when we evaluated the effect of the first-semester investigative lab course.

Future Plans

In the spring 1995 semester, we implemented the investigative format in 25% of the lab sections of our second-semester course. When this course is offered again in spring of 1996, we will introduce the investigative format into half of all sections and do a larger test of its effect. We may use the investigative format in all sections by spring of 1997.

In the next implementation, we will introduce each of the transducers with videotapes, which should make the students more independent of the instructor. We will also make changes in the software to increase its speed and ease of use.

Literature Cited

Dickey, J. L. and R. J. Kosinski. 1991. A practical plan for implementing investigative laboratories. Pages 137–149, in Tested studies for laboratory teaching. Volume 12. (C. A. Goldman, Editor). Proceedings of the 12th Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 218 pages.