A comparison, for teaching purposes, of three data-acquisition systems for the Macintosh

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Swanson, Harold D. A comparison, for teaching purposes, of three data-acquisition systems for the Macintosh. Am. J. Physiol. 258 (Adv. Physiol. Educ. 3): S17-S23, 1990.—Three commercial products for data acquisition with the Macintosh computer, known by the trade names of LabVIEW, Analog Connection WorkBench, and MacLab were reviewed and compared, on the basis of actual trials, for their suitability in physiological and biological teaching laboratories. MacLab scored highest for ease of use but low for power and versatility. LabVIEW is the most powerful but requires extensive training. Analog Connection WorkBench offers a combination of versatility and ease of use.

As the first phase of studying how computers might be used for data acquisition in teaching laboratories of the Biology Department of Drake University (and as a necessary prelude to purchasing a system for doing that), I conducted a "hands-on" comparison of two systems that seemed especially suited for this purpose, coupled with a more limited comparison of a third system.

Each of the three systems proved to have many virtues, but they differed in several important respects and in how suitable we judged them to be for our department and program. One widely advertised and much acclaimed system, LabVIEW software and accompanying hardware from National Instruments, was judged the most versatile and powerful but far too difficult to learn to fit our needs. A less well-known system, Analog Connection WorkBench software and accompanying hardware from Strawberry Tree Computers, was judged easy to learn and use and powerful enough for all our anticipated uses; it was the one chosen for purchase. The system seen in less detail, MacLab hardware and software from World Precision Instruments, was judged to be the one best preadapted for routine physiological recording and to have the easiest instruction manual to use. But it is so much less powerful and flexible than the other two programs that we judged it less suitable for our immediate project of investigating the whole range of possible applications of computers to teaching laboratories.

The conditions and results of the comparison are presented here in some detail, in the hope they might aid other departments in judging which of the systems is most likely to fit their particular uses.

Background

Data from instruments can be read directly into computers to be stored, processed, and graphed. Signals from the computer can be used to control the experimental procedures and measuring instruments. Both these functions of computers have become increasingly important in research and testing laboratories, usually with expensive computers dedicated to specific tasks (4, 5). Such technology, however, is rare in physiological and other biological teaching laboratories, both because of expense and because of the difficulty of making appropriate hardware connections and writing the necessary programs.

All these barriers to the use of computers in teaching laboratories—for controlling instruments and acquiring data from them—are now becoming much less formidable. Powerful and versatile systems are now available for these purposes, using the same relatively inexpensive microcomputers used for other purposes. Several of these systems are advertised as being user friendly, requiring little electronic knowledge and no familiarity with programming languages (2, 3, 7). Most of these systems present menus for choices about their operation.

The Contestants

The claim to be user friendly is made with special strength by the two systems for the Macintosh that were the primary subjects of my comparison. With both of them, the details of operation are programmed by means of icons, similar to those familiar to users of the Macintosh. These icons can be combined in flowcharts to create unique programs. In addition, many choices are presented in menus. The two systems include much the same sorts of hardware and software. The hardware consists of a board inserted in the computer and fastened by a cable to an external connection block, which has screw-terminals accepting wires from any external source. The software includes "drivers" for the board (invisible to the unsophisticated user) and the iconic programming language.

The better known system is from National Instruments of Austin, TX; the programming language is called
LabVIEW. It may be used either with one of the National Instruments boards or with boards supplied by certain other companies (8). (I will, somewhat inaccurately, refer to the whole package tested, both hardware and software, as Labview.)

Less well publicized is the system supplied by Strawberry Tree of Sunnyvale, CA, whose software is called Analog Connection WorkBench. It supports only the boards from Strawberry Tree. (I will call the whole system Workbench.)

These systems were compared directly with each other and less directly with MacLab from World Precision Instruments (WPI) of New Haven, CN. This was seen in a demonstration by a WPI representative, in a "demo-disk," and in a colleague's laboratory. MacLab is menu driven; yet it cannot be programmed in the sense the other systems can be (although many options are presented) and does not have much capability of controlling instruments (although this is promised for the future). It is mentioned in this comparative study because, in conspicuous contrast to the two systems being primarily considered, it was designed specifically to fit the needs and expectations of physiologists and biologists and is accompanied by instructions biologists have little trouble reading.

**BASIS OF COMPARISON**

The three systems were compared on the basis of versatility, suitability, and feasibility; they showed differences with regard to all three.

Versatility was judged with respect to possible uses in the Drake Biology Department, on the basis of trials of a few of the possible applications, and of information in the instruction manuals supplied with the various systems. Our student laboratories include a variety of measuring instruments, all of which generate data that might usefully be analyzed with the computer. Most obviously, the laboratories in physiology, cell biology, and occasionally in general biology measure quantities that change in minutes or fractions of a second, including both biopotentials and physiological actions detected by transducers. In these and other areas of study, various instruments need to be turned on and off or triggered to perform particular operations, all at particular times and under particular circumstances. The need for power and versatility in student laboratories is increasing for our department as we increasingly involve undergraduate students in research activities.

Suitability was judged by comparing the capabilities of the hardware and software (according to specifications and descriptions supplied by the manufacturers) with what were assumed to be the most difficult uses to which we might expect to put them, and by testing a few of these challenging applications. The three areas of greatest concern were frequency response (how fast changing a signal could be faithfully recorded), sensitivity (how small a voltage change could be detected), and data manipulation (how many of the desired analyses of data and comparisons between sets of data could be performed and how easily). Feasibility was a judgment of how user friendly the systems really are—whether it will be practical to try to use them for our purposes. This judgement was based on my personal experience in the comparison project. Answers to questions of feasibility of such systems are very much a function of the individual people who would actually use them. Can I, as the department member first involved in trying to use the systems, succeed in doing so in the time available? Can I expect other members of the department, with a little bit of help from me, to develop and apply the necessary skill to use the system in their laboratories? Will our students be able to do some of their own programming for their own projects?

My personal capabilities for learning to use such systems are probably not unusual among physiologists and biologists. I have long used, and occasionally tinkered with, a variety of instruments including physiological recorders. Many years ago I took two courses in physics and one in electronics, and I have taken (but not used) three courses in simple computer programming. Just by using manuals and occasionally asking questions of the experts, I have taught myself to do what I wanted to do with the Statistical Package for the Social Sciences, and with Microsoft EXCEL, as well as learning to use three word processing programs on three different computers. Thus if I can use these data-acquisition systems, most biologists can. If I cannot do so without extensive training, many others cannot either!

Just on the basis of catalog descriptions and of the reviews that were available (8, 9), it seemed fairly evident that the three systems constitute a progressive series in both power and ease of use, with MacLab the least powerful and easiest to use and Labview the most powerful and the most difficult to use. But catalogs and reviews can be misleading. Some reviews in trade magazines are even written by representatives of the company promoting the product (1) or are based heavily on the specifications furnished by various suppliers. Even the objective reviews of new technology, generally written by engineers, may not be realistic about the suitability of a product for the final user.

The purposes of this comparison project were, first, to determine whether the published comparative descriptions of these three systems are correct, and second, to assess how critical are the differences among these systems in power and ease of use. The conclusion was that the comparative series is correct and that the differences can be critical.

**CONDITIONS OF THE TEST**

Representatives of Strawberry Tree and of National Instruments allowed me to borrow hardware, software, and manuals for 2 mo in the summer of 1989. The two systems were installed in a Macintosh II computer with a 20 M hard disk, furnished by a grant from Drake University Computer Intensive University Project. I worked principally from the manuals but made a few telephone calls for programming advice from representatives of the two companies. (Both Strawberry Tree and National Instruments supplied competent, quick, courteous, and imaginative advice by telephone.) The MacLab system was demonstrated to several faculty members a couple of months before the comparative study began; a demonstration disk and a manual con-
continue to be available for reference, and a colleague in a neighboring department has just begun working with MacLab.

The two systems, Labview and Workbench, were compared by setting up each one to accomplish two tasks. The first task was to receive an electrocardiograph signal, display it in real time, and record it for more detailed computer analysis. The second task was to supply power to a force transducer, receive, display, and record the signal, and facilitate zeroing and calibration. The capabilities required by these two tasks are basic for physiological teaching laboratories and resemble the capabilities of popular physiological recorders (plus the ability to record data in a form suitable for direct analysis using the computer). In addition, the capabilities tested broadly overlap those of MacLab, making that further comparison possible.

It was originally intended that Labview and Workbench would be studied in an evenhanded way, but there came to be two exceptions to that policy. First, Labview was installed and demonstrated by a company representative, who used it to program a “virtual instrument” (a software program controlling acquisition and use of data) for displaying and recording electrocardiograms (ECGs). (I later modified this virtual instrument for use with the force transducer.) Workbench, however, was shipped to me, and I installed it and started using it on my own. The second exception was that I spent about twice as much time during the trial period working with Labview as with Workbench.

COMPARATIVE DESCRIPTIONS

Hardware. The differences in hardware between Labview and Workbench are not critical, but the MacLab hardware is significantly different from the others.

The particular National Instruments (Labview) and Strawberry Tree (Workbench) data acquisition boards that were compared are very similar in capabilities. Both provide for eight channels of analog input (recording of quantitative electrical signals), and two channels of analog output [controllable direct current (DC) voltage up to ~10 V]. Each also offers eight channels of digital output or input (pulses that trip switches or signal the state of switches). The one important difference between the two is that the Labview board (NB-MIO-16L-25) is described as having a maximum sampling rate of 40 kHz on a single channel, whereas the Workbench board (ACM2-12) can sample at a rate of only 10 kHz. This difference is critical for recording the shape of a nerve impulse. (Workbench promises a new board soon, capable of more than 40 kHz.) (For recording on multiple channels simultaneously, the sampling frequencies possible may be reduced by as much as a factor of five.)

Either board is connected by cable to an external panel with screw-terminals for wires to and from laboratory instruments. The Labview connection panel is a little easier to connect wires to but is not as well labeled as the Workbench panel; labels facilitate using the right terminal. The Workbench panel offers 5, 12, and 6.9-V fixed power sources, the Labview panel only 5 V. The 5-V source is intended for use with the digital signaling system, but can be used to supply excitation voltage to a bridge-type transducer, as can the 12-V source. The 6.9-V supply in the Workbench board is described as regulated, to give an especially steady excitation. But the manuals for both systems warn that the power sources available on the connection panel might not supply a full eight transducers at once—perhaps only two or three. (With the 12-V supply from the Workbench board, transducers might be connected both in series and in parallel, to a fairly large total, depending on their resistances and voltage requirements.) Thus for multiple transducers, it may be necessary to use an external battery or power supply anyway; so the differences between connection panels are not critical.

In contrast to these two systems, MacLab has no internal board for the computer; the hardware is external, with connections by way of the serial port. (This means that data may be acquired using a MacPlus; a MacSE or Mac II is not required, but the hardware is much more expensive.) The external hardware includes a power supply for transducers and circuitry for balancing, zeroing, and calibrating them, preamplifiers for magnifying weak signals, and a stimulator. The frequency response on one channel is 40 kHz, sufficient for nerve impulses. There are no provisions for digital input or output for use in controlling instruments, although the stimulator output can be used for some kinds of control. The model I have seen provides only four channels of analog input, one channel of analog output, and no digital input or output (compared with 8, 2, and 8, respectively, for the other two systems.) A newly available version offers eight channels of analog input, but still no digital capability.

Software. Both Labview and Workbench can be described as programming languages that use Macintosh icons instead of written commands. The programmer selects icons from a menu and arranges and connects them by “wires” into a flowchart. The software instantly creates a program that carries out the operations indicated. The flowchart remains as an easily readable documentation of how the program works. National Instruments uses the term “virtual instrument” for these programs and for their visual representation as flowcharts. LabVIEW is an acronym for Laboratory Virtual Instrument Engineering Workbench. For some particular instruments, National Instruments offers prewritten virtual instruments in which the appearance of the computer screen closely mimicks the front panel of the instrument being controlled and monitored. In this discussion, I will occasionally use the term “virtual instrument” for flowchart programs of either system.

For building a virtual instrument, there are icons representing particular analog input channels (for receiving electrical signals that may vary in any pattern), analog output channels (for emitting electrical signals in some pattern), and digital input and output channels (for signals that are either on or off). Each of these external icons represents one of the sets of screw-terminals on the external panel. There are also internal icons for generating values or pulses, turning parts of the program on or off, and performing a great variety of mathematical and logical operations on signals coming to them. Finally, there are icons for logging data onto disk and for displaying it in meters and charts.
Once the programmer has in mind which icons to connect in what order, this is easily accomplished with either Labview or Workbench, using the mouse. A particular setup might take 15 min to construct with Labview as opposed to only 5 min with Workbench, because in Labview the mouse must be changed into particular “tools”, and because “wires” must be removed from them before icons can be shifted. But the result is a somewhat more readable flowchart. Similar tradeoffs without great advantage to either system can be noted with regard to many other small differences in the styles of the flowcharts of Labview and Workbench.

The really critical difference between Labview and Workbench is in the number of different icons. Workbench has only 11 (although some of them represent a great variety of functions that can be chosen), whereas Labview offers many more, maybe hundreds, often with multiple options. A large fraction of the Labview icons perform functions that can be duplicated by combining two or more Workbench icons; another large fraction perform functions and manipulations of data that cannot be so duplicated with Workbench.

Its many functions make Labview not only a data-acquisition system but a powerful data-processing program as well. It can perform not only algebraic manipulations but sophisticated statistical analysis and several kinds of Fourier analysis, among others. It appears that most often these analyses would be performed on already-collected data, but some might be important on-line for changing, automatically, some aspect of the whole setup.

Workbench, in comparison, has limited data-processing capabilities. Many algebraic functions of two streams of data may be calculated and then logged, displayed, or used to control something, but statistical and other analyses are hardly represented. Thus any detailed analysis of data acquired from Workbench requires logging the data and entering them into a spreadsheet, statistical, or graphics program.

Any analysis of recorded data that is done by a data-acquisition program can be done equally well by one of these other programs, so the critical importance of capabilities for data analysis concerns what can be done on-line. The first important reason for a data-acquisition program to include some processing abilities (as both Labview and Workbench do) is to give immediate display of the derived output of some instrument, for immediate use. The second reason, potentially much more important, to use the results of calculations to turn on logging or fast recording, to prompt the sending of a digital control pulse, or to control the response to an incoming signal impulse. Labview offers a greater variety of calculations that can be used for such purposes.

The problem with having multiple icons for programming and multiple choices for calculations, as Labview does, is that there is so much to learn before a virtual instrument can be constructed. Although the manual describes each icon, it is difficult to know which description to look up, and in what sequence the descriptions must be studied to be intelligible. Furthermore, the manual is uneven in its treatment. It gives a good description of how to manipulate and “wire” icons on the screen and how to use simple calculation icons to achieve a result. However, it gives very little guidance in the use of the more advanced features, i.e., multiple icons for controlling analog input and output, and “structures” for defining the sequence or duration of particular operations. Consequently, it is just not practical to use the manual to teach oneself to use Labview to construct a variety of virtual instruments. In sharp contrast, one can easily learn to build virtual instruments with Workbench, using just the manual.

Feasibility: hands-on experience. These opinions are based on and illustrated by my hands-on experience during the summer of 1989. Workbench manual in hand, I created, in a few hours, a virtual instrument that displayed my ECG very well, and I added a feature that kept the mean voltage at zero. In a few days, I modified and augmented this into a virtual instrument that supplied excitation to a force transducer and displayed its output, that corrected the output to zero when no load was applied, and that calibrated the virtual instrument to give a display in grams. At first, I had to type in values (generated by the instrument) for zeroing and calibrating, but in another day’s work I modified the virtual instrument, so that when I pressed a button (with the mouse) when there was no load, the instrument zeroed itself; with a 2-g standard added, I pressed another button, and the instrument calibrated itself. I am now confident that I can learn to perform a greater variety of such control and data manipulations and can show my colleagues and students, in minutes or hours, how to begin to do this for themselves.

My experience with Labview was different. The National Instruments representative had used Labview to create for me a couple of virtual instruments for displaying ECG (it took him a number of minutes). Using the manual, I worked for several weeks to modify and augment one of these to display calibrated data from a force transducer. For 2 wk I was as frustrated as I have ever been; then I began to understand how to do such simple things and construct a quite satisfactory virtual instrument that I could zero and calibrate by typing values from a display into an icon. I spent a week or two trying to duplicate my Workbench provision for automatic zeroing and calibrating, but I was not successful. (I think I was pretty close when I decided to quit!) I would guess that if I spent 2 or 3 mo doing nothing but read the manual and tinker with Labview, I could learn to use it quite effectively (and so could some other biologist). But it would not be an efficient thing to do (and might not yield a sane biologist!)

National Instruments offers 3-day training courses in Labview for about $500 per person; in retrospect, it would have been wise for me to include a Labview training course in my evaluation project. It is my judgement that a department should plan to use Labview only if it can provide such training for everyone who is expected to create new virtual instruments. I suspect that even with the training it would require quite a bit of practice to become and remain proficient in Labview. Given the slim budget of our department and the only tentative interest on the part of some members who might profit from a data-acquisition system, I was not able to recommend
that we choose a system that requires so much training for its users.

How much did our department lose by not choosing Labview, the more powerful system? I cannot give a clear answer to that question. For data that have previously been gathered, Labview has many provisions not provided by Workbench for processing, comparing, and displaying them. However, the most important of these processing capabilities are otherwise available. Faculty and students at Drake University have Microsoft EXCEL available to them; this or another spreadsheet program can perform most of the manipulation, statistical analysis, and graphing in which we might be interested. Also, quite a number of the functions of which Labview is capable, fast Fourier analysis is an example, are more commonly used by physiologists and engineers than by physiologists and biologists.

The third system, MacLab is, again, quite different. There is no programming (iconic or otherwise) to perform special tasks, although there is a great deal of choice about such things as amplification, calibration, sampling rate, and display. MacLab can perform several analyses of data, different but somewhat comparable to the capabilities of Workbench, but not approaching the variety of Labview. MacLab has several built-in functions difficult or perhaps impossible to duplicate with Labview or Workbench—that a physiologist might find very attractive. Most notably, one can review a complicated curve on the screen, use the mouse to select a portion of it, display that portion in greater detail, and store just that portion in spreadsheet form. Also, if one points with the mouse to a particular point on a curve on the screen, the program will display the numerical value (to several decimal places) of the coordinates at that point, and if desired, the slope. Other provisions similarly mimic and facilitate the kinds of examination commonly made of data gathered with physiological recorders and oscilloscopes. Data is logged to disk for further analysis on a spreadsheet just as with the other two systems. If one wishes only to duplicate (at a saving) the actions of physiological recorders and simple oscilloscopes, to add a few new analyses, and to record data for computer processing, MacLab is the easy way to do it. Its manuals are detailed and well written, specifically for physiologists and their projects. But one must then settle for the (very nice) options that MacLab offers, and for only a very limited ability to control instruments. (World Precision Instruments now offers a software program, WaveEdit, that costs $400 and is said to work on any data in spreadsheet form and that includes many of MacLab’s abilities to display data in graphic form for closer examination, selection, and storage. This capability may prove useful whatever system is used to acquire the data.)

Speed. All three systems can record data for a limited period in a “fast mode”, with sampling frequency limited only by the hardware: 40 kHz for Labview and MacLab, 10 kHz for Workbench. I presume they all function as advertised. (I have used this capability of Workbench, quite successfully, to record, calculate, and eventually display the “loop” of electrical axis of the heart.)

During normal (as opposed to fast) operation, however, the three systems differ significantly in “cycle time” and, hence, in how faithfully any rapid changes of a signal are displayed or recorded. The cycle time is a function of how fast the software performs various calculations and adjustments. The effect of cycle time can be illustrated by my experience with displaying the ECG. A virtual instrument made with Workbench displayed an acceptable ECG on a continuous basis. Similarly, one of the standard options of MacLab did this at least as well.

By contrast, the similar Labview virtual instrument displayed ongoing ECG very imperfectly and inaccurately, not much more than an occasional blip on the line. This was not due to any deficiencies in the virtual instrument made for me by the National Instruments representative; rather, it was because Labview is very slow and cannot handle such rapidly changing signals. To understand this difference in effective speed, I compared cycle time (time between successive sampling of data) for my Workbench and Labview virtual instruments that zeroed and calibrated the output from a force transducer. The rival setups were nearly identical in number of icons and equally straightforward. However, the cycle time of the Workbench instrument was only 35 ms, whereas that of the Labview instrument was 1.1 s, nearly 30 times as long. It was only by accident that a sampling rate in this range would detect any indication of an ECG pattern! (This shows why, for rapidly changing data, the analytical and processing power of Labview cannot be used on line and must be applied only to data already recorded. This applies to complicated Workbench manipulations as well.)

Inventing new capabilities. The Workbench literature includes fairly detailed instructions to programmers who wish to create new functions to use; such functions become new options within the calculation icon. But programming such new functions requires skill with a programming language. Thus the level of difficulty of using Workbench increases abruptly from “iconic programming” to “new functions.”

Although MacLab does not have a provision for simple iconic programming, the company offers (at a cost of $595) a programming system using Pascal for creating new applications.

This is where Labview is clearly superior to the other two systems. All the new functions one might need are already available, symbolized by icons. Although it is more difficult to learn and to use for simple applications, Labview would seem to be no more difficult for complicated applications than for simple ones.

Like everything else in the computer world, data-acquisition systems are changing rapidly. All three companies considered here have recent or expected innovations in both hardware and software. National Instruments’ newest catalog offers new, less expensive boards for classroom use. Strawberry Tree says a board with higher frequency response is imminent. World Precision Instruments now offers eight channels, and, eventually, digital control.

It would be comparatively simple for both National Instruments and Strawberry Tree to make their systems far more attractive to physiologists and biologists than they are now. They could create half a dozen virtual
instruments to gather the kinds of data most commonly of interest to physiologists and biologists, supply these virtual instruments on a disk, and accompany them with detailed instructions for their use. The virtual instruments would not need to be much more sophisticated than those I made last summer. Given such aids, new users could begin to use LabVIEW or Analog Connection Workbench immediately. Some users would never need to create new virtual instruments for themselves; these would fill all their needs. Those who wanted innovations could easily copy and then modify these standard virtual instruments or follow their patterns in creating new ones.

**Costs.** Any of these systems could replace, at considerably lower cost, most or all of the functions of standard physiological recorders and simple oscilloscopes, while adding the capability of reading data directly into computers for further detailed analysis. Comparative cost among the three systems depends not only on the list prices, but also on particular components chosen and any educational discounts that may be available.

The list prices (in US dollars) for the configurations compared in this article are as follows, based on the most recent price lists I was given.

**National Instruments:**
- Board 1,195
- Connector 150
- Labview 1,995
- Total 3,340

**Strawberry Tree Computers:**
- Board 1,190
- Connector 179
- Workbench 995
- Total 2,364

(The cost of a spreadsheet program for analyzing the data must be added to this.)

**World Precision Instruments:**
- MacLab 2,925
- MacBridge 975
- Total 3,900

(As with Workbench, detailed data analysis requires additional software.)

The most expensive component of any of these systems is the computer itself, preferably with a hard disk, if any amount of data is to be collected. That is where WPIs MacLab has the advantage, since it can be used with any Macintosh. The particular boards for Labview and Workbench whose properties have been compared here are for a (relatively expensive) Mac II. For multiple use in a student laboratory, it would be preferable to be able to use the same iconic programming capabilities in a (less expensive) MacSE (the smallest Macintosh that will accept an internal board.) Both companies make boards for the SE that might be suitable for student use, but with limitations.

National Instruments offers the Lab-SE board for only $595. It has the same numbers of analog input, analog output, and digital input-output (I/O) lines as the board for the MacII, and an even faster sampling rate of analog input, i.e., 125 kHz. But the analog input channels are single-ended instead of differential. It is my understanding that it is either difficult or impossible to use single-ended channels for signals from bridge-type transducers, a major part of physiological instrumentation. So their suitability is doubtful. (A representative of National Instruments informs me that it would be possible to construct a virtual instrument that converted the 8 single-ended channels into 4 differential ones. If that virtual instrument is supplied, the Lab-SE board would be much more suitable for use in physiology laboratories.)

Strawberry Tree Computers offers the ACSE-12-8 (for the SE) for only $695. Its analog input channels and digital I/O channels are like those of the board for the Mac II. But the SE board does not support any analog output channels, a moderately serious deficiency. The use of analog output to supply excitation current for bridge transducers can easily be replaced by connecting these to the several fixed-voltage supplies present on the connecting panel. Uses of analog output for providing stimulating impulses at programmed times can probably be replaced by using an external power supply (such as a stimulator) and regulating it by way of the digital output. I suspect that these substitutions would prove practical in student laboratories, so that this board would be useful.

**COMPARATIVE SUMMARY**

All three systems were judged suitable for use in student laboratories; they will gather the kinds of data we are likely to want for the kinds of experiments routinely done. Each system, however, has limitations. The MacLab system cannot be used for digital control of instruments, which may be important for some teaching purposes. The suitability of Workbench for recording nerve impulses depends on a new board with higher frequency response. The Labview system does not work well for displaying a fast signal on-line. But it is the only one of the three capable, by itself, of doing nearly all the kinds of data manipulation and analysis which might be of interest; the other systems must be supplemented with other analytical software such as a spreadsheet.

The versatility of both Labview and Workbench was judged quite sufficient for all our anticipated needs (although that of Labview is quite a bit greater). The versatility of MacLab is much less than that of the other two; this difference was decisive in eliminating it from consideration for our immediate purposes of investigating all possible applications.

The feasibility (ease of use) also differed decisively. MacLab is much superior in this regard, whereas Workbench requires more effort than MacLab but is still quite acceptable. By contrast, it would be feasible to use the Labview system only if all those people putting it into operation took a training course in its use. On this basis, Labview was eliminated from consideration for our department at the present time.

**USING COMPUTERS IN TEACHING LABORATORIES**

It has now become truly feasible for physiologists and other biologists—with no special training in either electronics or computer programming—to use computers in teaching laboratories for acquiring as well as manipulating data. The three systems reviewed here can, to differ-
ent degrees, make such use feasible. Just what applications of this technology are practical, and how much these applications can improve the educational process, are matters still to be determined. Our department will be considering these questions intently in the near future and probably for a long time to come. Other departments will need to make the same judgements. The following possible uses are among those that need to be evaluated.

**Recording data for later analysis.** Data recorded directly into a computer are stored in a form directly accessible to spreadsheet and statistical programs, eliminating the necessity of keying in the data. For isolated values, this is of limited value, except that the values are presented in numerical form and need not be estimated from a tracing. The real utility comes if there is interest in a continuous stream of data or a whole sequence of sampling points or if the computer can be used to pick out the points of interest from such a stream or series. Some laboratory exercises may be devised or improved by taking advantage of these capabilities. All three systems reviewed here record data quite satisfactorily, but only Labview provides, of itself, a wide choice of further analyses.

**Constructing physiological simulations.** Any physiological process or control system that might be simulated with an electromechanical model can be even more easily simulated with a virtual instrument constructed using Workbench or Labview. Kiel and Shepherd (6), using Labview, have published a simulation of several cardiovascular functions. Constructing such simulations is much easier using icon-based programming than with conventional programming languages. The available options for display will probably not allow the simulations to appear either realistic or esthetic, but the available labeling capabilities can allow them to be quite informative. With Workbench (but not with Labview) it would be suitable to assign the construction of simple simulations as student exercises.

**Enhancing and replacing instruments.** Any device that emits an electrical signal in proportion to some quantity of biological interest can be connected to the computer with one of these systems reviewed here and be zeroed and calibrated. The data can be sampled and recorded continuously or at chosen intervals or circumstances, all with minimal difficulty and at no expense after the initial investment. This means that it may be cost effective to replace physiological recorders (and some associated equipment such as preamplifiers and stimulators) with computer systems. Beyond this, it is possible to take antiquated but still functional measuring instruments already available in a teaching laboratory and, by connecting them to a computer system, turn them into modern “smart” instruments capable of various calculations and enhancements. The Labview and Workbench systems lend themselves well to this kind of use. With Workbench, it would even be possible to have students plan and program the enhancements to be made with certain instruments; this would be a way of assuring that the students understand what their instruments are doing. In contrast, MacLab can receive, amplify, and record the output from instruments, but the connection cannot be as thoroughly customized as with the other two systems.

**Automating laboratory manipulations and data gathering.** Many experiments that might be of interest in a teaching laboratory require several hours of elapsed time, during which conditions are manipulated and data is gathered. Such an experiment cannot be fitted into a 2- or 3-h laboratory session, and there are often many practical difficulties to having even a few of the students work during the extended period necessary. Such computer systems as those described here may make such extended experiments more feasible. Many experimental manipulations (turning lights on or off, adding some ingredient to a solution, even adjusting the tension of a connection) can be performed by electronically controlled switches, pumps, or motors. With computer systems (Labview and Workbench) that can send and receive digital signals, it seems as though it would be relatively easy to prepare a program that would control such manipulations and record the ensuing data (which could be scrutinized during the following session of the laboratory.)

There are, however, several immediately obvious problems to such an ambitious scheme. How to make connections of digital control-signal devices to the computer is not intuitively obvious, and the manuals of both Labview and Workbench lack a complete discussion. Even more importantly, the various peripheral devices needed for such automation come with many different specifications, and the physiologist/biologist is unlikely to be confident of which ones are most suitable. Because the costs of such devices range from fairly expensive to very expensive, it is not cost effective to model which are suitable by buying many kinds and trying them all. It will require efforts by many people to determine whether such automated arrangements are suitable for student laboratories and to instruct biologists in setting them up.

I look forward to reading, in future issues of Advances in Physiology Education, many descriptions of the successful use of computers in teaching laboratories.

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**REFERENCES**