The article by Dorothy Tombaugh preceding this one describes many clever and resourceful adaptations that can be made to assist visually handicapped students in chemistry laboratories. Her work shows what can be done if the teaching of visually handicapped students is viewed as a challenge and not as a burden. Tombaugh’s article also contains good general approaches to accommodating visually handicapped students in the laboratory, so we will not repeat them here. We agree strongly with her stress on allowing the visually handicapped student to attain the maximum possible independence, and with her warning against prejudice in favor of describing phenomena only in terms of visual observations.

In this article we will limit ourselves to aids that use modern electronics technology to enable visually handicapped students to make accurate laboratory measurements and to interact independently with computers and scientific instruments. Laboratory work is beneficial to visually handicapped students who are not science majors because it gives them an opportunity to make their own conclusions about Nature. For their purposes, the simplest apparatus will do. But for students who intend to pursue scientific or technical careers, access to instruments and computers is essential because their use is now so pervasive.

We will first describe some commercially available equipment and then will discuss some new aids being developed in our laboratory at East Carolina University.

Measuring Instruments
The article by Tombaugh mentions thermometers with voice output or audible null detection. Other measuring instruments suitable for use by the visually handicapped include a talking caliper sold by the American Foundation for the Blind AFB (1). A talking micrometer-depth gauge will also soon be available from AFB (2). Instruments for accurate measurement of length are seldom used in the chemistry laboratory, but we have included these devices to show that visually handicapped people are moving into occupations where accurate measurements are necessary.

Another important instrument is the multimeter. Previous versions for use by the blind were capable of about two-digit resolution (3). Now, however, a talking multimeter with a 3½-digit readout has been developed by Franklin Institute Research Laboratories and is available from AFB. Lazar Research Laboratories (4) makes a high impedance amplifier that enables any digital multimeter to function as a pH meter; this accessory could be used to convert the talking multimeter to a talking pH meter.

Unfortunately, there is no sensitive commercial laboratory balance that can be used by the blind. Triple-beam balances can be adapted fairly easily for use by the blind, as described by Tombaugh, but more sensitive top-loading balances cannot. A general purpose reading device called the Optacon, manufactured by Telesensory Systems (5), has been used to read video terminals and displays on counters, calculators, and multimeters (6). It could also be used to read the display of an electronic balance. (The Optacon senses characters or digits with a 6 × 24 array of phototransistors and presents the pattern in tactile form in a corresponding 6 × 24 array of vibrating points. The user guides the phototransistor camera with the right hand and feels the tactile display with the forefinger of the left hand. The user must be trained to attain skill in using the device.)

The Optacon can be fitted with different cameras. The self-illuminated camera intended for reading type could probably be used for reading top-loading balances with non-luminous digital readouts, if the readouts are accessible to the camera.

This pretty much exhausts the list of commercially available accurate measuring devices usable by the visually handicapped. The list is short, in part because so few visually handicapped people have pursued scientific and technical careers in the past, and in part because even some of the people who train and counsel the blind expect them to be satisfied with measuring devices that are an order of magnitude less accurate than those used by their sighted peers, because they are not expected to enter professions where measurement is important. We know of a geometry teacher at a school for the blind who requires no better than ±5° readings from a tactile protractor. She does not even teach her students to interpolate on a scale! Why? She says they do not need such skills (7). This kind of patronizing attitude is one of the worst impediments facing blind youngsters who have scientific talent. It is part of a larger pattern that was pervasive until recently and that cut across all handicaps. Neglect of the scientific education of handicapped children was regarded as permissible because they could never become scientists.

Computer Terminals
Computers are now indispensable tools for students in the natural sciences, and recent developments have given visually handicapped students access to them. Braille terminals have been available for several years. Triformation Systems Inc. (8) makes several models, ranging from a portable receive-only Brailor that embosses a 1-in. wide paper tape to a large send-receive model that prints 120 characters per second on standard Braille paper. Because of its speed, the fast version is suitable for medium-scale duplication of Braille text materials. Braille terminals are also made by Sagem in France (9).

Since only about 20% of the blind population read Braille, many blind students prefer to use devices with speech output. Talking computer terminals are now made by Maryland Computer Services, Inc. (10) and Automated Functions, Inc. (11). Triformation Systems also has one under development. Radio Shack sells a speech synthesizer for its popular TRS-80 personal computer and software for conversion of character strings to speech is available (12).

Talking terminals have the disadvantage of being unable to produce “hard copy,” but they are likely to be more reliable than Braille terminals because they contain fewer mechanical parts.

Current Developments at ECU
We first encountered the challenge of accommodating a blind student in a chemistry laboratory about three years ago. A blind student, Richard Hartness, had registered for our
The instrument has an output of on the front panel, enabling it to convert seven binary-coded decimal digits into speech. This makes peaks audible, and the timer function provides retention times. A second run can be made with the timer in the own converter to a computer. It can thus function as a talking age-to-frequency converter.

The talking instrument was intended to be useful in chemistry and physics laboratories and to some extent in biology laboratories. It is basically a 3½-digit multimeter with speech output but has additional features that might not have occurred to an electronics engineer. It can measure time, temperature, and pH. It has a low-level differential input so that it can be plugged directly into the recorder output of a chromatograph or into a bridge transducer. It has two voltage-to-frequency converters; one monitors the input level, and the other is a variable reference. The instrument can thus function as an audible peak and null detector and comparator. The counter can count an internal 100,000 Hz clock to function as an elapsed time indicator with a range from 0 to 999.99 s, or it can count external pulses, as from the titration apparatus to be described later. The counter can also be connected to the output of the voltage-to-frequency converter which monitors the input. In this mode it functions as a precision integrator.

The instrument has been used to perform pH titrations and gas chromatography. In gas chromatography, the audio output makes peaks audible, and the timer function provides retention times. A second run can be made with the timer in the integrator mode to obtain peak areas.

The talking instrument can be controlled externally by switch closures or by TTL logic levels. Its data bus is accessible on the back panel, enabling it to convert seven binary-coded decimal (BCD) digits into speech, or to output data from its own converter to a computer. It can thus function as a talking attachment or as a data acquisition system. We are now designing a simple interface that will enable the instrument to provide speech output for a Mettler PL200 electronic balance, which is readable to one milligram.

The speech module used in the talking instrument is available for $180 from Telesensory Systems; anyone skilled in the art can interface it to instruments with BCD output. We can provide interested people with detailed schematics of our circuits. Because of the availability of Franklin Institute’s talking multimeter, we do not recommend duplicating our instrument in toto.

As the design of the talking instrument took shape, it occurred to us that as powerful as the “dumb talking box” was, a “smart talking box” would be far more powerful. We envisioned a portable laboratory microcomputer with keyboard input, voice output (with unlimited vocabulary), and a variety of inputs and outputs that would allow it to be interfaced easily to almost any scientific instrument. We proposed such a system to the Bureau of Education for the Handicapped, and they are now funding its development. We call this system the Universal Laboratory Training and Research Aid (ULTRA), because it is indeed universal and can be used in any pursuit involving the use of scientific instruments. It is not limited to instructional laboratories but could follow a visually handicapped student through his or her training and into the workplace. It would be the ultimate personal computer, capable of functioning as a talking data acquisition and data analysis system, as a talking terminal, and as a stand-alone computer. The present version of the ULTRA system can be connected to a variety of sensors and instruments, such as pH electrodes, digital balances, visible spectrophotometers, IR spectrophotometers, titrators, gas chromatographs, or any other instrument that provides an analog signal for a chart recorder or a digital output. The system aids the student in collecting data and provides spoken output through a voice synthesizer. The student controls the data collection by typing commands on a keyboard; the computer responds with synthesized speech, or in some cases with an audio-frequency tone.

We are realizing the ULTRA with the Z-80 microprocessor. It is a two-processor system: one of the microprocessors runs the software used for performing chemical experiments, and the other generates synthetic speech. The system (shown in a block diagram in Figure 2) consists of the following basic modules:

1) A host Z-80 microcomputer with parallel and serial digital and analog input-output ports.
2) An interface module with circuits for conditioning signals from instruments or transducers.
3) A talking terminal to produce synthesized speech.

We are currently using a Zilog MCZ120 development system as the host computer; it also serves as our software development system. We are constructing a portable system which will function both as the host computer and the talking terminal in a laboratory setting.

The software for the talking terminal uses letter-to-sound rules developed at Bell Telephone Laboratories (14) and at the Naval Research Laboratory (15) to convert strings of characters into speech. These rules were implemented on the Intel 8080 microprocessor by Peter Maggs at the University of Illinois (16), using Votrax and Radio Shack voice synthesizers, and by Songco, et al. (17) at the Computer Research Division of the National Institutes of Health. We have adapted Maggs’ software for the ULTRA system. The talking terminal, shown in Figure 3, uses a keyboard for entry of data and commands and a Votrax speech synthesizer for spoken output.

Our goal in this project is to provide meaningful laboratory experiences for blind students. Much of the data collection in modern chemical laboratories is done with the aid of instruments which are either connected to a computer or which provide a visual display through a meter, chart recorder, video...
Figure 2. Block diagram of the ULTRA system.

Figure 3. Richard Hartness using the talking terminal. The satellite computer is housed in the case below the keyboard enclosure.

Figure 4. The interface box. Modular construction simplifies modification and repair.

Figure 5. A Bausch and Lomb Spectronic 20 showing simple tactile dial.

Figure 6. A Perkin-Elmer model 727B IR spectrophotometer interfaced to the ULTRA system.

We have tried to minimize the alterations that need to be made to instruments themselves. Electrical signals from the instruments are connected to an interface module, shown in Figure 4, for signal conditioning before they are sent to the computer. So far, all of the modifications of instruments we have made could be made easily by an electronics technician in a few minutes. The modifications of the Spectronic 20 in Figure 5 consists of a recorder output that intercepts the electrical signal to the meter, and a tactile dial for setting the wavelength. (More recent spectrophotometers have recorder outputs as standard equipment.) A pH electrode can be connected directly to a high impedance input on the interface module with no additional adaptation. We have made a minor modification to the Perkin-Elmer 727B IR spectrophotometer by attaching a microswitch to the chart bed so the computer can detect the start of a scan. This IR spectrophotometer is equipped with a recorder output that can be connected to the interface module. A set-up of the experiment is shown in Figure 6.

Titration experiments are carried out using the piston buret

screen, etc. The ULTRA system is designed to give blind students experience with the chemical instruments that are normally found in freshman and sophomore laboratory courses. It can provide them with a degree of independence that is not attainable with just the help of a sighted assistant. It is designed to give them "hands-on" experience in the laboratory so they can perform the experiments themselves instead of having an assistant do much of the work for them. The computer system encourages independence by not providing any spoken operating hints for an experiment unless the student requests them using a HELP command. Operating instructions for each experiment will of course be available in Braille and on audio cassettes. Messages from the computer are not verbose; the assumption is that the student has done his or her homework.
shown in Figure 7. A retroreflective sensor is attached to the piston buret so that graduation marks can be detected when the buret is turned to deliver the titrant. The computer counts the graduation marks that pass under the detector, and can compute the volume under commands from the student. The endpoint is detected by monitoring the voltage of a pH electrode immersed in the solution being titrated.

In the titration experiment a rapid change in the pitch of the tone reflects changes in the experimental parameter being monitored. In making pH measurements the pitch is proportional to the pH of the solution being measured. The student can detect the pH differences of different solutions by monitoring the tone and can hear the electrode drift. Of course, quantitative data may be obtained from the ULTRA system through the voice synthesizer. In the titration experiment a rapid change in pH causes a rapid change in the pitch; the titration program saves data that are collected in the experiment and allows the student to find the endpoint by rapidly scanning the audible titration curve (or its derivative).

In the IR experiment the voltage-controlled oscillator provides a tone proportional to the absorbance, and the student can monitor the spectrum as it is scanned by the spectrophotometer. The ULTRA system provides quantitative data after the spectrum has been scanned.

A tone is also provided with the programs that aid in the operation of a visible spectrophotometer such as the Spectronic 20; the pitch of the tone is used to aid the student in adjusting the spectrophotometer for the 0 and 100 percent transmittance settings.

An important feature of the ULTRA software is the calculator program (18). This program accepts calculator statements from the keyboard and provides spoken answers. The calculator program has all of the features of most scientific calculators used by chemistry students. Much of the data collection software is built around the calculator routines, enabling data collected during an experiment to be stored in the calculator’s storage area in the computer’s memory. The user has access to the data through the calculator program and may perform any required calculations on the data for use in writing laboratory reports. Uniformity in the commands from one experiment to another is achieved by using the same general purpose command-interpreting subroutine for all of the experiments as well as for the calculator.

Thus far we have written software to aid blind students in performing experiments that use the following instruments:

1) pH electrodes,
2) visible spectrophotometers such as the Spectronic 20,
3) IR spectrophotometers, and
4) a piston buret.

We are continuing to develop software for additional instruments. Arrangements for the commercial production of the ULTRA system will be made through the Bureau of Education for the Handicapped in the near future (1983–84). We expect the cost of the system to be less than $10,000.

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