Computers In Biological Education

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Wise use of Computers In Biological Education (CIBE, pronounced cyber, as in cybernetics) can enhance the educational value of our courses, and educational enhancement is a goal we all have as professional educators. My goals for this article are: to discuss CIBE, its actual and potential use, value, and problems; to provide insights from several points of view (including that of one professor in one course, integrated use of CIBE at the departmental level, and CIBE activity at the national level); and to convey some idea of the excitement of CIBE being shown by both teachers and students.

The following comments are based on a philosophy and overview toward the subject which has developed through my use of CIBE over the last 15 years, including: actual creation and use of computer modules in various biology courses; having offered a course for students at Notre Dame on CIBE (not on biological research); our experiences from offering an annual one-week, summer workshop at Notre Dame for biology teachers from other institutions; and my role as chairman of a university biology department in directing CIBE activities and the commitment of limited departmental resources.

It is impossible to cover CIBE adequately in one or even a series of articles because it is so multifaceted, every facet is quite complex, and the ideal CIBE system varies greatly with different courses and schools. All I can hope for is to provide a feeling for what using CIBE involves, so that teachers might be motivated to learn more about the topic.

This is an exciting time to be in education and one of the reasons is CIBE. Just as the Industrial Revolution has increased our physical capabilities, so too is the Computer Revolution increasing our mental abilities. As more schools acquire computers, the limits of their use will be only our creativity and the amount of effort that we are willing to expend. Like many readers, I am a biologist, not a computer professional. I received no training that is not also available to you.

History of Electronic Computing

Electronic computing began in the 1940s and has developed exponentially ever since. Rarely can a generation or two of people claim to have lived in a period that will so drastically alter the course of education and of the world. The history of electronic computing is one of superlatives, exponentials, and expletives! By this I mean that regardless of the characters chosen (e.g., number of computers in use, number of additions per second, cost per addition, ease of use, number and diversity of users), when they are plotted on a graph over time from 1940 to the present, the result is never a straight line but always a sharply ascending or descending curve. In addition, the latest value of the curve is always attaining a maximum or minimum beyond that previously known. The discipline of computing is obviously a dynamic, changing system. More and more of your and my biology students will be "computer-wise" due to previous training at school, home, or computing clubs.

History of Biological Computing

Until the 1970s, biocomputing lagged behind such other fields as business and economics, but such lags are decreasing constantly as computer prices decrease and experience among biologists increases. The uses of computers in life science research have been diverse. Interestingly, biologists working at the organismic level or below have used them primarily for automated data accumulation, as part of laboratory instruments, in molecular graphics, and in sophisticated image analysis. Above the organismic level, major uses have included information retrieval, multivariate analysis, and simulation of ecological and other systems.

Two dates are important for the *educational* use of computers in biology. By 1970, a substantial number of biology teachers were able to gain access to campus maxicomputers via remote terminals that were available even in their offices or laboratories. And, by 1980, "standalone" microcomputers became available to substantial numbers of life science teachers. CIBE is experiencing its exponential phase of growth on a national scale for two additional reasons as well. Until recently, few faculty were exposed to computers during their graduate school years. In addition, computers really required a lot of real time and knowledge to understand how they worked, and to keep abreast of new developments.

Components of a Computer System

A computer system consists of three parts. *Hardware* refers to the actual physical components of a computer. These include items such as various keyboards for input, the central processing unit, main memory, storage devices such as discs or cassettes, and video display screens and printers for output. The size of hardware varies greatly. In the first few decades of electronic computing, only maxicomputers were available. These are important even today for CIBE and usually can be found as the major component in a university computing center. Minicomputers became available in the late 1960s and, while still expensive (e.g., $10,000 to $20,000), they signaled the first possible availability of computers for use in biological research and teaching laboratories. Microcomputers are based on microprocessor technology (a "computer on a chip"), and have been widely available to biology teachers only in the last few years. Examples include models like the Apple, the TRS-80, and the Atari. Microcomputers cost from $200 to $2,000 or more, depending on whether a television is available for use as a video monitor and on the amount and type of storage and peripheral devices desired.

Software refers to the set of instructions that a person enters into the computer to indicate what operations are to be performed. A set of such instructions is called a program. Programs may be written by biologists themselves or they may be purchased from a large number of suppliers, which range from organizations devoted to using computers to enhance undergraduate and high school education (e.g., CONDUIT), to other biologists or students who have created one program and wish to share it for fun or profit. The major types of programming languages include machine language, assembler language, basic and compiler languages, interpretive languages, and authoring languages (a type of applications program). Today biology teachers wishing to create a program need use nothing more difficult to understand than the well-known BASIC language. Or, easier still, they may choose to use special authoring languages. Lubar (1981) reviews four such authoring languages available for the Apple II microcomputer. Radio Shack just announced an authoring language for its TRS-80 microcomputers. While the latter languages permit a teacher to create software in a way that is closest to normal prose, use of other languages permit more control over what can be done.

People are the third component of a computer system. Such people include idea-generators (like teachers, teaching assistants, and students), programmers, and users (our students).

Each of the above three components of a computer system are essential. Biology teachers planning to use a CIBE module must understand the three components to the degree required to assure their pedagogically meaningful integration into the course. Never think only in terms of using a particular kind of hardware in CIBE, e.g., an Apple or TRS-80. Rather, plan and think in terms of a total computer system, with the hardware being only one of the essential parts. This approach, coupled with significant amounts of classroom discussion about the computer exercise both before and after students actually use the computer, will help assure meaningful CIBE use.

What is a Computer?

Computers have been defined in many ways, some of them unprintable! Computers may be considered as information retrievers, data accumulators, etc. These concepts will be discussed in a subsequent section. But perhaps the best definition is that computers are an extension of the human mind. They not only are extensions of our minds as teachers, but also extensions of our students' minds. Whether you view computers as an extension or as a replacement of your mind is entirely your decision. But it may be the most important decision of your life!

Reasons to Consider CIBE

Computers can allow us to teach what we already teach, but better and more easily. For example, as more and more biology involves value-oriented education and decisionmaking, simulation by a computer can provide students with realistic, vicarious experiences of real bio-societal systems. Such simulations allow them to see the results of choosing different alternatives in such a system. Examples of such use include the simulation of world food production, or endangered species, or the effects of using different insect- or weed-control strategies.

Computers can increase students' interest in the subject matter. This arises partly because of their novelty and their ability to increase students' mental powers. Such positive properties allow computers to create enhanced learning contexts. In addition, by requiring each student to do something, to respond to questions or to make decisions for a simulation, CIBE also can permit, even demand, creativity.

Computers can decrease boring tasks associated with even simple exercises. For example, in ecology it is difficult to generate several large populations of plants that are randomly distributed in an abandoned agricultural field, and then several clumped populations. In addition, each has to be sampled repeatedly and statistics calculated to test whether organisms are randomly distributed or not. The computer quickly can perform all of these functions. It is much faster than using a mechanical process, such as sampling colored chips, each color representing a different species. The important point is that students have more time to think about what such results mean biologically.

Computers allow students to learn at their own pace, and according to their own diurnal rhythm. In other words, computers have longer office hours than teachers and teaching assistants and rarely get grumpy!

Computers permit a high level of individualized instruction. Paradoxically, the allegedly impersonal computer can provide a more personal education. While this may be material for a psychological thesis, an important corollary emerges: CIBE can provide a better education to more individuals in a heterogeneous group.

Finally, computers can help provide a more value-oriented education. One way is to allow students to evaluate alternative decisions concerning interdisciplinary systems of our society that have a biological component. Examples include the decision to spray pesticides to control Med flies or mosquitoes in a populated area, and choice of the "best" alternative concerning world food production. Students use a computer model of the societal system of interest. As they try alternatives (e.g., varying land yield per acre and pollution levels) they develop several valuable insights: the real world is finite in specific properties; no alternative is a panacea; each alternative is a compromise; and the probability of making the most humane decision is increased as more biological information and wisdom are available to the decisionmaker.

How Computers Can Be Used

Computers can be used for at least nine different tasks: information retrieval; data accumulation; data analysis; simulation and systems analysis; decisionmaking; experimental control; course review; computer-managed instruction; and word processing. The following paragraphs discuss each of these in turn.

Information retrieval is useful to teachers as well as students. The former can use information retrieval as they prepare for lectures or to provide students with background information. Students can use information retrieval to carry out term assignments. Information that can be retrieved is either about relevant literature or about raw data.

At one extreme, literature retrieval can use commercially available data bases, e.g., BIOSIS contains information from Biological Abstracts. Searches can be performed online by the biologist, or often through the information specialist located in the school's library. At the other extreme, some biologists have created computerized files of literature relevant to one or more courses. Sometimes the literature bank is initiated in connection with a course. For example, in a recent biogeography course, students had to provide on a weekly basis a punched deck of computer cards which contained information about two relevant references. Each was deepindexed with a set of descriptors. Every week the cards were added to the computer and the expanding literature bank was made available to students for online searching. Intermediate projects also exist. Crovello (1979) describes the Indiana Biological Survey Literature System. Basic and expanded information on each project or a published reference dealing with biotas and environments within Indiana is added annually to a computerized file. It is co-sponsored by the University of Notre Dame and the Indiana Academy of Science. Custom searches are available for a fee.

Information retrieval is not restricted to retrieval of literature references. More and more data of interest to bioeducators are being stored in the computer. For example, Professor R. A. Hellenthal at the University of Notre Dame has his Aquatic Biology students input data on the physical, chemical, and biological characteristics of surrounding lakes which students visit during their weekly laboratories. This information is the basis for subsequent analyses that are necessary for a term paper. An added attraction is that since this procedure has been followed for several years, students currently in the course not only have available to them information in an easily retrievable and analyzable form from the current year, but also from previous years.

Data originally produced for research purposes can be valuable in bioeducation. For example, results of a study of certain plant species in the Soviet Union (Crovello 1981) can be used to point out principles of plant geography. Perhaps the most promising source of raw data, especially for environmental biology, is that associated with the GEOECOLOGY project at Oak Ridge National Laboratory (Olson, Emerson, and Nungessner 1980). It makes available information on many environmental, biological, climatic, and societal characteristics. The important point is that it is easily retrievable (if one has the correct host computer), and it is extremely valuable when considering realistic simulations of biological systems in which a society component occurs. Finally, information retrieval can be used to make a teacher's life more efficient. For example, I have information on about 10,000 2 x 2 projector slides in a computer file. When I desire a list of all slides dealing with one particular topic in a course, or one geographic area, or one flowering plant family, I indicate those criteria and the computer prints out a list containing only those few relevant slides.

Computers are also useful in *data accumulation.* Ignoring manual accumulation, which involves observation of information and keystroking it into the computer, two other types exist: semi-automated data accumulation and fully automated data accumulation. The best example of semi-automated data accumulation involves a digitizer whose stylus or pointer is positioned by hand. For example, the stylus may be positioned at a point signifying one end of a leaf. By depressing a foot pedal, its X, Y grid coordinates are then automatically stored in the computer. The stylus is moved to the other end of the leaf, and its X,Y coordinates are input into the computer. Total leaf length can then be calculated simply by allowing the computer to solve the Pythagorean theorem.

In bioeducation, fully automated data accumulation is most frequent in animal behavior exercises. Various types of analog devices costing only a few cents can be attached to homemade activity cages. When the activity to be monitored begins, such devices are turned on or off by the animal's movements. This information is relayed directly to an analog to digital converter which converts the analog electric signal to one that the computer can understand. Such information can be recorded around the clock as frequently as the teacher desires, be it once per minute, per hour, etc. More importantly, information from scores of activity cages can be obtained simultaneously and without artifacts due to investigator error or due to an investigator intruding into the experimental system. Of course, the important point is not just that more valuable, complete information is obtained, but that automated data accumulation lets students devote more time to analysis of what the results mean.

Data analysis has two complementary modes, statistics and graphs, and both should be used. For example, data from the animal behavior study just described can first be plotted on a graph with the X axis representing time and the Y axis indicating level of activity. Different cages, some of which might contain different species or different sexes, can be plotted simultaneously on the same graph and given different symbols. Simultaneously, time series and other statistical analyses can be performed to test for patterns and correlations. In genetics experiments, computers permit frequency analyses to be performed which not only test simple genetic ratios but also the effect of artifacts like different laboratory sections, different media, etc. In an ecological laboratory, students need only enter original measurements from field studies of different forest sites to obtain information on such valuable ecological measures as importance value, basal areas, etc. Or the results of laboratory experiments studying the population dynamics of a species can be entered into the computer and analyzed quickly for such important traits as intrinsic rate of increase and net reproductive rate. Again the effects of artifacts can also be estimated and partitioned out of the final analysis.

Systems analysis and simulation of biological phenomena can be considered an extension of the scientific method when the biological system becomes too complex for normal analyses, or are just impossible to analyze via experiments. Examples include: the exploration of enzyme kinetics in a physiology course; the evaluation of the role of different ecological, political, sociological, and other effects on the status of an endangered species; and the effect of changing certain parameters such as land yield, total population, and amount of pollution on the amount of food per capita that can be produced over the next 100 years. Simulations need not be extravagant or complex to be of value in teaching a biological phenomenon which students have difficulty understanding. For example, students at first may not understand that it is not the absolute values of certain hormones that determine ovulation, but rather the ratio between two hormones that is important. This can be demonstrated quickly using a simulation program. Another result of using systems analysis is that the systems diagram itself can be of great value in helping students to understand the biological phenomenon more deeply.

Decisionmaking can be an important function in bioeducation. For example, in general biology, students are presented with a tree leaf. They are then asked to identify to which species the leaf belongs. Interacting with the computer, the proper identification can be made. A great advantage of the computer over a key presented in a text is that if the character in a couplet is unavailable, the computer will continue with other characters. In addition, printed copies of the key and accompanying text materials do not have to be provided each student. It is simply stored in the computer. Another example of computerized decisionmaking used in General

Biology at Notre Dame involves the program Logodx. Designed for physicians, it includes information on 86 symptoms of 336 human diseases. Students are given a set of symptoms from a hypothetical patient, and asked to determine which disease the patient might have.

A completely different type of decisionmaking usually is coupled with systems analyses and concerns resource management. For example, the endangered species simulation developed at Notre Dame allows users to input a certain amount of resource units. Questions asked in class discussions before and after students actually run the program include: how does one decide how much of limited resources should be used to save a particular species; and what is the best resource allocation strategy in terms of effectiveness and/or of ethics. Similar questions can be asked when students use the world agricultural model. In particular, it is best to try to maximize food per capita over the next 50 years, or to choose a solution that produces less food but also reduces population oscillations due to its being more removed from the maximum limit of environmental production?

Computers can also be used to *control experiments.* They can control the temperature, humidity, and light cycles of a growth chamber, but more importantly they can be seen as tireless, round-the-clock investigators if necessary. An example from animal behavior involves the insertion of electrodes into a bee which has been made stationary in an experimental apparatus. The electrodes are attached to the computer and the environment of the bee is changed. Two kinds of information can emerge. First, information on the characteristics of the bee is stored for later analysis. More impressively, depending on what the bee does, the computer can be programmed to change environmental conditions. So if the bee's heart rate increases, then perhaps the program may reduce ambient temperature. Or if the bee begins to move its wings as if to fly, then the air movement in the experimental chamber can be increased to give it the sensation of flying.

Computerized *course review* can involve several of the above uses, for example, simulation and information retrieval. But it may also involve drill and practice of various sorts. The most common is the presentation of a multiple choice question with five possible answers. The student chooses an answer, and then the computer indicates whether the choice is right or wrong. If wrong, it gives an explanation why it is wrong. If right, it provides some additional information about the phenomenon. At Notre Dame we created BIOQUEST, a set of 334 such multiple choice questions, answers, and replies. It is divided into eight areas: biochemistry; genetics; developmental biology; physiology or anatomy; physiology or behavior; evolution; taxonomy; and ecology. Users can choose answers, proceed to the next question, or proceed to any specific question. Currently BIOQUEST is available for the IBM 370, TRS-80, and the Apple II. For the latter, all of the questions, answers, and replies fit on two floppy disks which can be used one at a time.

Depending on the sophistication of the computer program being used, complicated branch patterning from question to question may be possible. Thus, two students beginning the same review might start with the same questions. But after perhaps ten questions, if their pattern of incorrect answers is different, the eleventh question may be different for each student.

Computer-managed instruction uses computers for course management and includes tasks such as student recordkeeping, testing, test scoring, and the creation of customized remedial assignments. In sophisticated computer-managed instruction program packages (for example, the TIPS system), a large bank of multiple choice test questions is maintained and each is characterized as to what part of the course it relates, its level of difficulty according to Bloom's taxonomy, etc. Students may take tests for different parts of the course and then are given customized assignments to help them improve their knowledge of that part of the course. They also may be given a message by the computer to see their teacher. Just as important, the teacher regularly receives detailed reports. They summarize the performance of individual students as well as the performance of the entire class on each test, including an indication of which questions might be more difficult than others, which might be redundant, etc. A working use of the TIPS computer-managed instruction program in biology was described at the 1981 NABT convention by Professor R. Garcia of Clemson University.

A less sophisticated approach to multiple choice test creation (not its actual administration) would be to maintain a large set of potential questions on a floppy disk of a microcomputer. Only the teacher would have access to it and he then could efficiently revise certain questions and then print a selected subset to be used for an upcoming examination. Many hardcopy printing terminals accept ditto or mimeograph masters, so no need would exist for laborious retyping *and* proofreading! The set of 334 multiple choice questions in BIOQUEST described above could form the beginning of such a test question inventory.

Word processing describes everything that a department secretary might do plus additional analysis of alphabetic information. For example, production of a student's term paper or a teacher's problem set or syllabus is simplified since the user need only type in the first draft and then only retype any mistakes. The computer rearranges and spaces so that the final copy looks like a professionally typed document. In addition, many word processing programs can create a table of contents, an index, etc. The major use of word processers in CIBE is to save both teacher and student time so that they can explore other areas of biology.

Types of Biology People Needed for CIBE

A successful CIBE module requires normal biology teachers who for good reasons have not involved themselves directly with CIBE programming. Their role is to provide ideas for quality use of CIBE and to support reasonable requests for personnel and equipment. Biocomputing teachers are those who do what other teachers do but also might write their own programs or oversee others who do. They might interface with the school's computer center or math department as well as with other biology professors. They might also offer courses in biocomputing. Finally, they oversee the best and proper use of departmental computer equipment and help plan for future growth of CIBE.

Students are the major users of CIBE modules. But, just as importantly, they should be contributors. They should not be seen just as receivers of education, but should also contribute ideas, programs, and writeups. In fact, they often learn at least as much when they contribute as when they are just users.

Evaluation of CIBE Modules

Evaluation of a CIBE module is difficult from the start because it involves evaluation of educational effectiveness. The problem is that education is similar to concepts like growth. Not just one, but many individual characteristics describe growth (e.g., total body weight, types of tissue, development of certain organs). Similarly, evaluation of a CIBE module could involve evaluation of any or all of the following characters: monetary costs; costs in professor's time; cost in available students' time; enhancement of learning levels which in turn can be measured as amount of information retained in one day, versus one week, versus one year; the amount of wisdom and insight developed; the amount of analytical, problem-solving, and experimental ability developed; and the amount of creativity allowed or demanded. Or the evaluator may choose to measure the change of students' attitudes toward a subject, such as increased excitement to learn more about it. The number of rigorous statistical analyses to test the hypothesis of no difference between conventional and a CIBE approach is small. The few available published studies deal only with a few of the many criteria that can be evaluated. Perhaps the best set of evaluation criteria is the set of answers to our earlier questions of why computers should be used in bioeducation (e.g., they allow us to do what is now difficult or impossible to do). If the teacher and students feel that one or more of these goals is achieved, then the CIBE module might be retained in the course. Crovello (1982a) discusses evaluation of CIBE modules, including hardware, software, and people.

Problems and Disadvantages of CIBE

CIBE could turn students off if its use is not well planned and well integrated into a major laboratory or lecture sequence. Most meaningful CIBE modules will not be successful without adequate explanation and discussion before and after students use the computer. For computer systems that involve a large host computer with many other simultaneous users, poor response time could also be detrimental to the success of a CIBE module. That is, if the time between which a student enters information or a command into the computer and the computer response exceeds 5 or 10 seconds, it probably does more harm than good to use the computer. CIBE could hinder growth of certain analytical skills such as the ability to manually calculate the square root of a number. But it is not clear that all such possible skills need be remembered. And more importantly, CIBE could foster new analytical skills of greater value. CIBE could use up limited financial resources of a biology department. That is why I recommend *wise* use of CIBE.

A much greater problem is that many high schools and colleges have no adequate reward system for the teacher who devotes significant time and effort to create a successful CIBE module. The quality of education is increased, but it is difficult for administrators, the majority of whom still have no direct CIBE experience, to appreciate the value or the effort involved in the creation and implementation of a successful CIBE module.

Planning for CIBE at the Departmental Level

Planning for effective use of CIBE at the departmental level is a challenge, because most facets of the computer system (hardware, software, people) are changing. For example, microcomputers and home computing are becoming more sophisticated and less expensive every year. In addition, every year more students and faculty will have "grown up" with computers. I suggest the following general guidelines. A teacher should not plan completely alone. Do not duplicate in the department what the campus or school computer facility might offer, be it hardware, software, or people. This may be especially true if using a campus facility is cheaper and requires no room commitments in your department. Chairpersons should make assistance available to faculty who request it. Do integrate computer resources wherever possible within the department. This may involve resources earmarked only for teaching as well as those for teaching and research. It is economic, efficient, and intellectually enhancing to share computer resources. The worse situation in terms of both economy and psychology can occur when several independent computer systems are allowed to develop within a department. Not only will rivalry develop for limited funds, but less cooperation among teachers will develop since each has to become proficient on the computer each is using.

How to Get Started in CIBE

If only one type of computer is available (e.g., a microcomputer in the biology or mathematics department), then that type of machine is the one that will be used. On the other hand, if a choice is available, the extreme choices are to begin with a small microcomputer or with a large, campus maxicomputer. Your decision depends on many factors, including the time and other resources you have available to develop CIBE and the specific requirements for your purposes. If at all possible, join a group or at least involve another colleague or students in your learning experience. Following good pedagogy, we learn faster in small groups than by ourselves. Visit the campus computer center or the microcomputers in use in other departments. Learn from a colleague who is already involved in CIBE.

Educators should understand how a computer works, but they need not become adroit programmers. Many biology teachers have made excellent use of CIBE programs created by others. This is nothing to be ashamed of. It simply depends on one's interest and what programs are currently available. Many of the programs used as examples throughout this article were created at Notre Dame, run on TRS-80, Apple, or IBM computers, are available for purchase, and are summarized in Crovello and Hellenthal (1981a,b). Excellent CIBE programs are described in the CONDUIT catalog (CONDUIT, The University of Iowa, P.O. Box 388, Iowa City, IA 52244). The number of large and small companies offering programs is growing rapidly. To help bioeducators learn what is available, at Notre Dame we have begun a computer-based CIBE Register, The International Register of Computer Programs and Data Bases for Bioeducation. I invite readers' help in at least the following ways: submit program or data base descriptions (write for copies of our standard form); suggest additional characteristics which should describe each entry in the Directory; and indicate what specific biology topics need program or data base development most.

No book exists on all aspects of CIBE, although one is in preparation (Crovello 1982b). Valuable texts covering parts of CIBE include those of Randall (1980) and Spain (1981). Crovello (1980) reviewed previous work in a state-of-the-art report on CIBE. Peters and Johnson (1978) produced a valuable guide for creators of educational software. It also can be used as a guide for educators who wish to evaluate others' CIBE programs. Additional general references include Bork (1981) and Taylor (1980). Biology educators should read journals such as *Byte* and *Creative Computing* regularly. Finally, you may wish to attend one of the annual National Education Computing Conferences (for more information contact its Steering Committee Chairman, Dr. Gerald L. Engel, Department of Computing Science, Christopher Newport College, Newport News, VA 23606).

Current Decisions and Dilemmas in CIBE

The computer industry and all components of the multidimensional CIBE system are undergoing great changes. Just as the progress of science involves extended periods of steady, slow growth interrupted by periods of great activity (Kuhn 1970), so too does CIBE. CIBE no longer is a question of the haves versus the have-nots, but rather the want-tos versus the don't-want-tos. The biggest dilemma facing a biology teacher or department today is whether to carry out CIBE on a large central site computer (a maxicomputer), to purchase a series of standalone microcomputers, or to use both. The situation, and perhaps a solution, is somewhat similar to the allocation of microscopes among and within departments and courses versus the requirement that some be dedicated to a single course. Problems such as the risk of transport of a microscope versus their expense must be considered.

Space does not allow me to describe a detailed decision tree here, but obvious parameters that must be considered in making a sound decision include the total cost of the different computer systems. Cost estimates must involve software, including its time-consuming documentation so that if something goes wrong a knowledgeable person can try to fix it. Also left out of many cost analyses are maintenance costs. These involve maintenance costs of both hardware and software. Frequently in a schoolwide computer system, individual departments are not required to maintain equipment. The number of *available* terminals is important. It means nothing to say that a campus computer system can support 100 terminals if when they are most needed (usually in the afternoons), it is almost impossible to obtain an unused one. The closeness of a computer terminal or microcomputer to the classroom is important. Twenty years ago no one thought anything of having to walk completely across campus to the computer center to deposit their set of program and data cards, to walk back across campus, and then to repeat the process to pick up the output the next day or even two days later. Now, many teachers and students believe it is not worth the effort to go any farther than their office or laboratory to use the computer. Rightly or not, if this is the psychological mindset of people that might be involved in potential CIBE uses, it has to be considered. Additional psychological factors affect biology teachers and are important. For example, in general, they might favor microcomputers partly because the teacher has full control over it. He or she has absolute priority for access to the computer 24 hours per day. Teachers also prefer this because as they learn to use the computer by themselves, they can make mistakes in programming and no one else will know about it. A final consideration if a microcomputer configuration is chosen is to be sure that it in fact can perform the desired simulations, etc. Microcomputers are quite powerful, but they are still limited in many ways.

CIBE at the National Level

To determine the extent and nature of computing in bioeducation, CONDUIT conducted a survey in 1976 of 3,500 life science departments. A similar survey was conducted in 1979 (Crovello 1980). In the latter, of the 3,297 life science departments receiving questionnaires, 684 (20%) of department-level questionnaires were returned, while 618 (18%) course questionnaires were returned. They described 894 separate courses, which was three times the number described in 1976. Reasons cited by department heads for lack of computer use included: lack of training (31%); lack of equipment (17%); lack of time (15%); lack of funds (14%); and lack of interest (14%). A total of 63% of department heads believe that CIBE use would increase in the next two years while 36% felt it would remain unchanged. From the responses of 608 biology professors who reported on the use of computers in 894 life science courses, 73% felt there would be an increase in computer usage in biology education while 25% felt it would be unchanged. Major reasons professors gave for increased usage in the field include: better hardware; better software; and growth in the field. Major problems in using computers in bioeducation cited by the professors include: lack of time (21%); lack of software (14%); lack of equipment (13%); and absence of academic reward (10%). Interestingly, the areas of biology using computers in teach ing the most include: ecology (18%); general biology (10%); cell biology and physiology (10%); applied biology (9%); and genetics (6%). Major computing uses include: data analysis; problem solving; simulation; and drill and practice. CIBE use is occurring at all levels of undergraduate and graduate education, and courses of all size enrollments use them. Most student usage is via interactive terminals, but batch processing is still commonly used (at least in 1979).

Conclusions

Computers are into bioeducation in all areas. The only limit to their valuable use in bioeducation is our imagination, our will to work, and determination of how to best use them in our local situation. Computers are exciting biological tools because they permit previously impossible analyses; free us and students from drudgery; and they excite students, partly due to providing increased mental ability and partly due to allowing increased creativity. Computers are decreasing in cost, increasing in abilities, becoming more accessible physically, and becoming easier to use, both by bioeducators and their students. Students ought to be involved in all phases and not just as users of the educational system. For each biology department and each individual course, some nonzero combination and level of computer usage exists that can optimize educational quality. Computers cannot replace good teachers, but they can enhance their effectiveness. Computers are the only type of teaching or learning aid besides the professor that require students to be active participants. I suggest that we are ethically bound as professional educators to investigate seriously any available tool that might possibly increase educational quality. Furthermore, CIBE can be fun, both for students and faculty! Finally, computers, by doing tasks that therefore are not uniquely human, can make us more human! That is, they can provide more time for us to think and to help us and our students grow as human beings.

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