THE USE OF MICROCOMPUTERS TO ENHANCE THE TEACHING OF PHYSICS IN THE SECONDARY SCHOOL

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ABSTRACT

For several years microcomputers have been used to extend the study of physics at the secondary level at Selwyn House School. The many systems and methods that were used by students of varied backgrounds in both physics and computer science, are described and evaluated. Observations of the computer's effect on the students' learning and the new role of the teacher are made. Further applications of and enhancements to the microcomputer systems are suggested.

Depuis plusieurs années les micro-ordinateurs sont utilisés afin d'enseigner la physique au niveau secondaire à l'école Selwyn House. Les étudiants, de formation variée tant en physique qu'en informatique, se sont servi de plusieurs méthodes et de nombreux systèmes; ceux-ci sont décrits et évalués. Des remarques sont faites à propos de l'influence qu'a l'ordinateur sur l'apprentissage des étudiants et au sujet du nouveau rôle qu'il confère au professeur. De nouvelles utilisations ainsi qu'améliorations aux systèmes de micro-ordinateurs sont suggérées.

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TABLE OF CONTENTS

INTRODUCTION. 7

HISTORICAL NOTE .8

Description of school and students

Description of science background

Computers at Selwyn House

Observation and challenge

Computer background of the students

THE BASIC APPROACH. 13

The style

One tool in the arsenal

Philosophy of informality

A successful equation

Suggestions as to the role of the educator

Summary

POSSIBILITIES 22

What computers are and why they are used

Simulation/games

Data-gathering devices

Word processing and utilities

C.A.I.,C.B.I. and C.A.L.

Class management

IMPLEMENTATION. .27

Leading questions

Usual homework

Report styles

Laboratory approaches

Alternative laboratory approaches

Outside the classroom

Classroom activities

Work with outside institutions

Spinoffs

Summary

OBSERVATIONS. 60

Students

Approach to problem solving

Impact in the students' milieu

Impact on the teacher

Communication skills

In Conclusion

BIBLIOGRAPHY. 76

APPENDIX I GOOD PHYSICS IN GAMES AND SIMULATIONS. 81

APPENDIX II KINEMATICS PACKAGE 87

APPENDIX III THE TIMER. 96

APPENDIX IV DRAGON PATROL. 101

APPENDIX V ELAS 104

APPENDIX VI ELECTRONICS BIBLIOGRAPHY 109

APPENDIX VII SELECTED PROGRAM LISTINGS. 110

INTRODUCTION

Good teachers are always on the lookout for innovative techniques that may improve their style. In the past, many advances in technology have offered devices which teachers were not slow in bringing to the classroom. Many of them, such as film, slides and video tape recorders, allowed information to be stored and disseminated in an appealing way.

Ease of filing and flexibility in data display have made the computer an important business machine. Many teachers are coming to realize that this medium also allows students to involve themselves with information processes in new ways.

The purpose of this paper is to present the ways in which my students and I have been using microcomputers in learning physics, and to share observations about our methods.

It should be understood that the descriptions of applications that follow are meant to serve only as examples of when and how to involve the microcomputer. They represent a personal approach that has evolved in my particular situation.

I believe that the applications presented illustrate that there are advantages to using the microcomputer in the teaching of physics.

HISTORICAL NOTE

Selwyn House School has just celebrated its seventy-fifth anniversary this past year, 1983-84. It is a private boys' school, a member of the Quebec Association of Independent Schools, and is situated in Westmount, close to urban Montreal.

Description of school & students

Four hundred students in grades one to eleven study as many as ten academic subjects each year. Class size rarely exceeds twenty boys. Athletics is compulsory, and team sports and extracurricular activities ensure that every boy has some interest to pursue. Academic competition is fierce and every course demands much of the boys' time and effort.

A great deal is asked of the teaching staff as well, most of whom take on extra duties, such as teaching classes for a colleague who is away, coaching sports or leading club activities, all as a matter of course.

Description of science background

The secondary school (grades seven to eleven) course of study in science begins with a program based on ecology. In grade eight the boys are introduced to chemistry and physics. By the end of that year, they are expected to handle the rudiments of experimental measurement, control of variables, experimental design and graphical analysis of data.

The physics program, with which I am primarily involved, begins in grade nine. At this point, general science is still compulsory. The boys are given a broad conceptual introduction to energy, power, machines, buoyancy, heat, electricity and magnetism, astronomy and kinematics, as time permits.

Informal pencil-and-paper Piagetian testing was done at the beginning of grade nine (Lawson & Wollman 1978; see also Lawson 1978, Renner and Paske 1977). From these rough data, it was found that a high percentage (about 55%) of the population were formal or transitional thinkers; the remainder (about 45%) were working at the concrete stage. These results were supported later by informal teacher assessment.

In grade ten, the Physical Sciences Study Curriculum (P.S.S.C.) physics course is an elective which more than ninety percent of the students take to keep their science options alive for study at a College d'Enseignement Generale et Professionelle (C.E.G.E.P.). The second part of the P.S.S.C. course is offered in grade eleven to about half the students. The rest may opt for the regular stream 512 course.

Students graduate from high school at an average age of sixteen. All of our students continue their education after leaving Selwyn House School. A few enter straight into universities in the United States or provinces outside of Quebec but most choose to continue their studies in Quebec.

Computers at Selwyn House

In 1975, Selwyn House was renting facilities and computer time from Dartmouth College, in New Hampshire. Organized primarily as an extension of a mathematics club, its use was limited to a few students. Programming was done with paper tape which made error correction time-consuming and, therefore, costly. When it was clear that the terminal was not worth the expense, it was disconnected later that year.

In 1977, the school purchased a Southwest Technical Products 6809 based microcomputer with one smart terminal, two disk drives and a printer. Editing programs was no longer a tedious task with this machine's powerful screen editors. No extra costs were incurred even when it was used often. There was one major inconvenience. This very powerful device was hidden away in a corridor in the back of the library, for want of space.

Even so, the student response was immediate and overwhelming. Groups of two, three or four students would constantly hover about the computer, acquiring information by watching their peers. I was staggered by how quickly they learned. Despite equipment constraints and a frustrating timetable and work load, these boys learned faster than they could have otherwise been taught. When one boy figured out a new command or technique, in a very short time it was common knowledge. When someone had difficulty, there was always someone willing to share expertise.

In the ensuing years, Selwyn House has installed fourteen Apple II+ microcomputers in a special room in the now redesigned and air-conditioned library. Formal courses in computer science have been organised. Happily, the students are still working with computers outside of class time, at school and at home, and are still learning faster than they can be taught by other methods.

Observation and challenge

I experienced first hand the explosive exponential nature of the learning curve while acting as computer-room monitor in those early days. I was convinced that it was not the machines themselves that were the cause of dramatic rates of learning, but the student's perception of knowledge to be discovered, the challenging immediacy of being in the presence of things not yet understood. Certainly, the drive to control was a strong motivator. Getting an expensive piece of machinery to respond and obey is great fun.

With or without the computer, I wanted similarly self-motivated learners in my physics classes.

Computer background of the students

The students at Selwyn House today enjoy the opportunity to play with and learn about computer science, starting in the elementary school. Most of the the boys entering physics class bring with them at least some knowledge of the machines. Many are accomplished amateur programmers. The results of a recent survey (Sept.1983) show that forty six percent of the students in my classes have access to microcomputers outside of the school. Seventy seven percent of all the students indicated sufficient knowledge to use the devices should they be made available. More important is the fact that eighty four percent expressed the desire to involve themselves in physics projects which included microcomputers, if this could be arranged.

At school today, time and equipment are still not readily available to many students of physics who wish to pursue explorations with computers at Selwyn House, but the desire to do so is there. The desire expressed certainly represents the existence of a wealth of potential teaching opportunities. The question is how to actualize some of these.

THE BASIC APPROACH

Before describing the ways in which the microcomputer has been used at Selwyn House School to enhance the teaching of physics, it must be understood that they are adjuncts to my basic approach and not a central theme.

The style

The formation of students' ideas and perceptions is critical. Situations which illustrate a concept are often presented without technical vocabulary (as suggested by Griffiths 1975) or rigorous mathematical analysis. Concepts are not always explained when first introduced. If "mistakes" are observed in students' paradigms, the errors are not immediately crushed as a matter of course. Students are counselled that errors, even basic conceptual errors, are not "bad" but are a normal part of the formative process.

Whether or not they accept a model from a teacher or a textbook, they are expected to assume responsibility for its development and application. If the idea is not a "good" one, they can be made to encounter its shortcomings in the laboratory. For example, in a simple circuit experiment, if it is expected that adding resistors to a circuit will always decrease current, then adding a few resistors in parallel and measuring the new current may cause a conflict with this model.

Such experimental "error" can be instructive. Students are told that much "good" physics can happen when things go wrong. They are encouraged to equilibrate, that is to reconcile apparent conceptual conflicts (Piaget 1972; also Inhelder and Piaget 1964: 292). No matter what the books say or what the student expects to see, in an experimental situation what occurs is always correct. Reality is the right answer. For the student this can mean redesigning an experiment or modifying an inadequate paradigm.

Each student must make sense of his conceptual models any way that he can. It is important, then, to make many ways available to him.

One tool in the arsenal

The physics teacher has a wide variety of approaches available. What is essential, however, is not the number of strategies used but a selection of appropriate ones used effectively. The computer has proven itself effective in certain instances, but it is not always the best method. In some cases, it is not appropriate. (Further development of strategies not dependent upon microcomputers is supported by Bork 1979; Want 1980, and others)

I advocate the use of "string and sticky tape" experiments. Using familiar or homemade things allows students to identify with the physics more readily. On the other hand, I am not opposed to using more expensive devices. I use lasers, but only when a slide projector beam or ordinary light bulb will not do. I use few films, as I prefer the immediacy of demonstrations and lab exercises. Given this commitment to keeping things straightforward, where do computers fit in? Are they not technologically-intensive machines that are incomprehensible to children?

If the usual equipment does not get an idea across, then something else must be found. Students at Selwyn House have used tape recorders and oscilloscopes to measure the speed of metro trains using Doppler shifts, phototransistors across the "=" button of a calculator to count vibrations of a pendulum, and video cameras to measure the acceleration of gravity. A computer is no more "hi tech" than any of these; in fact, it is less so than a video camera. In the effort to deal with physical reality, the computer is one tool among many.

A computer is no more of a black box than the calculator and it can be made as "transparent" as the video camera; that is to say, the user is not aware of the complexities involved; he sees only the desired effect. Tinker (1981) suggests that children readily acquire an intuitive feel for the computer and that their explorations with it tend to "demystify the tool".

The computer and all of these other devices produce an effect in the class that is greater than the sum of their parts. They raise as many questions as they answer. They become part of the students' experience in the study of physics. Although all of these devices can be considered part of enrichment activities (except, perhaps, the oscilloscope in some courses) all of them can and do stimulate interest, not only by what they do but also by their operating principles.

If encounters with a computer may be part of a student's experience in physics class, what sort will these be?

To alleviate apprehension and dispel misgivings, the students are told what the role of computers will not be. Because facility with a computer should not, in my opinion, be a prerequisite for a high school physics course, I tell them that microcomputers will not be mandatory in any way at any time!

No programming skills are required. No previous experience is necessary. No part of the curriculum will be missed if a student decides not to use a computer. No laboratory experience will be incomplete without one.

It is very important that the student realize that the computer is not meant to replace a "real" experience (Smith, Spencer and Jones 1981:140). The computer will not be used just because a real demonstration demands more time and effort.

If difficulties arise in concept formation or experimentation that cannot be handled in any other way, then perhaps a computer can be used to advantage. Once it has been selected as a possible candidate to solve a problem, a few of its attributes must be considered.

Microcomputers were designed as single user devices. Only two or three students can successfully crowd around one. If one is to be used in a classroom setting, this must be considered.

Computers are fast. This is sometimes a drawback when it is made to communicate with humans who are slow.

Computers are expensive. Thus, availability remains a concern.

Computers take a lot of talking to before they will do what is required. Sometimes it takes more time than the task is worth. An important skill to develop is gauging accurately the man-hours of work required for a project's completion, before taking it on.

All of the above constraints on equipment and time will help explain the following observations and conclusions.

Philosophy of informality

For a number of years now, the computer has been used by our students in self-paced, often extracurricular, learning. The work took place usually outside class time and was organized by an individual, or a small group on an ad hoc basis. Rarely was a tangible reward in the form of marks offered or expected.

The computer was used to study physics even in the beginning, in the days when there was only one machine. An informal catch-as-catch-can philosophy evolved of necessity. Few would be involved at any one time. It was fun to do; it was intellectually stimulating, and it worked well. Groups would form and dissolve quickly. When some of the equipment constraints were relaxed through boys obtaining their own computers, the informal network expanded. Computers never became an integral part of the course work, tutorial exercises or laboratory management (unlike Milsop 1981 or Hickey 1982). The relaxed research-like atmosphere was invigorating (like Rafert and Nicklin 1982: 110). Less structured encounters were more enjoyable and in the long run more efficient than any classroom exercises.

The benefits of the computer excursions outweighed the price of development time and hardware costs.

It is my belief that a casual, episodic, individual approach is best, for two main reasons. First, a lockstep program cannot give information fast enough to an interested student. Secondly, if a student is not interested in using computers to learn physics, I cannot justify bothering him with this medium until he is ready to appreciate that it can be useful to him.

A successful equation

Experience has shown me that when a student finds an appropriate tool to study an area of particular interest, then intense learning happens spontaneously on many levels. In these situations, the teacher's role is less that of a teacher and more of a resource person.

Of course, areas of interest will differ for each student at a given time. The teacher must appreciate that each child's pace will be different. Each may have a unique level of awareness in physics, coupled with varying degrees of facility with the computer. Further, the abilities and desires of the student will modify his perception of the appropriate tool for the job. (Bork 1979)

All of this argues again for individualized treatment. As well, it warns against foisting hardware on a student who is not ready, and at the same time encourages the teacher to have it waiting for the moment when he will be ready. More than that, students should be made aware that this alternative is available to them so that it can be considered as an option, a part of his decision matrix.

Suggestions as to the role of the educator

The role of the educator is manifold. It is of prime importance to set up, manoeuver and present opportunities for the student to pursue areas of interest in physics. Examples of how this may be done are found in the section on implementation (pages 27-59).

A teacher should encourage students and evaluate their various projects. Both can be done simply by letting the child know that his progress is being watched with interest. As marks are not usually offered, I am interpreting the word "evaluate" here to mean the critical reinforcement of the child's perception of his project's worth. By allowing these to be extemporaneous projects, marking is not necessary. If the student values the teacher's judgment, he will ask for it.

The teacher as resource person must decide when and if it is appropriate to share his experience, books and papers, and to what extent. A resource person is not an answer man. Some thought should be given to the student's particular situation before a ready solution, or even direction, is offered.

The educator does not have to have solutions at his fingertips. Students can learn by example if they observe the research skills or investigative techniques of their teachers. They may realize that their own contributions are significant if they can help the teacher find a solution. A shared interest can supply a necessary spark where material resources fail.

The educator can play a valuable role in guiding students, on an individual basis, in their choices of appropriate approaches.

Some students may be intrigued by the microcomputer because it is trendy. I feel it is not proper to lure them into a study of physics with the promise of this or similar expensive toys. If the study of physics is the goal, then the teacher should keep in mind the limitations of the computer and see if another device or technique would be more effective.

Once the decision to use the microcomputer has been made, the educator's job is not yet done. How will it be used? Will he use simulations or will it be an ancillary analytic tool? Will the student build his own software or is there a program package ready made that he can use or modify?

The student may appreciate a frank discussion of the relevance of his work to the course material. If it is extracurricular or off the topic entirely, he should be made aware of this.

Finally, guidance is necessary when deciding the cost of the project. Are there better ways to spend the time and effort?

Summary

In or out of class, the microcomputer can be used as a tool of investigation. The number of students using it at any one time will fluctuate as their needs change, but one way or another many will become involved. Beyond what was done by all students during classroom exercises or demonstrations, on the order of sixty percent of the students of grades ten and eleven used the computer to pursue independently their studies of physics. This figure does not include those who were indirectly involved with the authoring of software or as users of software built by friends. For those students who use it, the microcomputer is a small but active part of their experience in physics.

POSSIBILITIES

What are computers and why they are used?

Computers are already an intimate part of high school life. Many facets of everyday life incorporate computers in one way or another. The ubiquity of the technology is well known. It is here to stay because it is so useful. What follows is an overview of broad categories of uses for which physics teachers have found microcomputers eminently suited.

Simulation/games

A simulation imitates the function of some aspects of a system. It can be used to investigate the system in an indirect way. Just how indirect often depends upon the complexity or size of the system, or on the efforts of the programmer. Simulations allow the high school student access to systems that are unavailable without a microcomputer.

A dual-trace, triggered, storage oscilloscope is too expensive for many schools to buy, but the screen traces are readily simulated. Students can gain experience using microcomputer function generators, nuclear rate counters or Fourier synthesizers for one package price.

Simulations can be used where the actual experiment is too dangerous to perform. In the relatively safe environment of the microcomputer, the student may paddle boats close to the edge of a waterfall and even over it, or plot high energy gamma ray scatter patterns. Very fine flight simulators are now available for the microcomputer that provide a wealth of experience which can be transferred to the physics class.

The physicist programmer can do things that are impossible in the laboratory. Friction can be removed with the touch of a button. Planets can be set in motion. New force laws can be postulated and tested.

Physical processes that happen too quickly or too slowly may be simulated and studied.

Simulations can provide numerical answers where analytical solutions are either too difficult or impossible. (For examples and further discussion, see Riggi 1980; Wild 1979; and Krane 1981) They allow active participation where direct naked-eye evidence is unavailable (Sauer 1980).

These simulations can be highly motivating for the student as he controls what he studies. These programs can be rich in aural and visual information, and quite captivating.

Data-gathering devices

More than just a voltmeter or timer, a microcomputer can be made to gather and display different kinds of information, even from the same sensors. Very much depends upon the extent of student participation and the way in which the processed data is displayed. Interpretation of tables and graphs generated as the student modifies the system under study allows him to begin to derive relationships between variables. Programmed control of these variables guides the student to a progressive understanding of the physical concepts involved (Fernandez et al. 1980).

These devices are also useful for demonstrations, as they allow a large number of episodes in a short time, and are flexible enough to handle investigative questions as they occur. They are, in general, satisfyingly accurate.

Useful and stimulating, the measuring capabilities of a small computer not only save money (small systems are available for less than the cost of an oscilloscope) but also provide a reliable system that is patient as well as fast. The microcomputer can be a millisecond timer or it can take sky brightness readings every hour for days (Curd and Geilker 1982).

These machines are being used to teach techniques of data analysis (Fernandez et al. 1980), to make useful calculations and to produce displays: eg."fast data transformers" (Tinker 1981).

Word-processing and utilities

Many students have libraries of utility programs which include tools that can be used to help them produce reports or analyse data. These include word-processors, data spread sheets and graphics tools that can produce graphs, charts and diagrams.

C.A.I.,C.B.I. and C.A.L.

Computer-assisted instruction (C.A.I.) or computer-based instruction (C.B.I.) or computer-assisted learning (C.A.L.) are terms that many authors use interchangeably. Under these terms, I lump instruction units replete with leading questions and branching answers; Bork's Socratic dialogs, homework problem generation (e.g. Schaefer and Marschall 1980) and tutorial drill and practice sessions. These approaches permit immediate feedback or evaluation, and often remedial instruction as well, if desired. Some systems produce individualized assignments that often allow the motivation of being self-scored. Some instructors have students run trial prelab data analyses using data generated by their microcomputer.

I have not taken the time to produce or to use many of these packages. I feel they are one step too removed from the physics of the world and are concerned more with the world of physics on paper. For the time and money involved with these applications, I prefer print.

Class management

The computer is very good at filing test scores, calculating averages and banking questions. It can generate tests for the purposes of instruction, practice or remediation (Wood 1981) , and it can run correlations. General office uses such as data base management, spread sheets and word-processing are also available to the teacher.

IMPLEMENTATION

The following are actual case implementations of the microcomputer in various ways to enhance the learning of physics in my high school over the last five years, 1979 to 1984. These are mainly associated with the P.S.S.C. students of grades ten and eleven, where class time is at a premium. Some applications in grades eight and nine are also included. It is not practical to present a discussion of all approaches attempted so a classification of program styles will be presented with examples.

Leading questions

It is a simple matter to include in a lecture a question of interest that can be pursued using a microcomputer. During an introductory discussion in grade 9 on significant figures, I posed an innocent looking question: What is the decimal equivalent of 1/97 ?

The next day we compared answers and discovered that not every calculator gave exactly the same answer. Some enterprising youngsters had taken the division to forty or fifty decimals by hand without finding the repeating pattern that their mathematics teachers taught them to look for. Again, no two boys had the same digits exactly, owing to errors in calculation. They were further upset when I told them that I did not have a calculator any better than theirs and could not supply them with the "right" answer.

This simple excursion, designed to highlight the distinction between digits and what a number means, made a few points; who cares about the fifty fifth decimal anyway, the teacher is not going to supply all the answers in this course, how do I find out for certain what the fifty fifth decimal really is ? Some hinted, quite properly, that if it is not significant maybe it is not worth the time. A couple of students decided to write a computer program that would divide two integers and find the quotient's repeating unit.

Weeks later, one of these boys walked into class with a computer page filled with the required digits. The boys who had calculated by hand pulled out their old answers and checked them against the sheet. They shared in the realization that there existed another tool for finding solutions that can be applied with success. A word of caution : not one of the boys who worked the answer out by hand questioned the validity of the computer answer. Where a difference in digits occurred, they assumed that the program had produced a correct answer. The dangers of this presumption should be discussed with them.

Open problems need not be solved by computer, but if all else fails it is nice to know that it exists as an alternative. At the beginning of grade 10, students do not know trigonometry. During a class on velocity vectors, I described a man in a rowboat who could row at 3.0m/s in a current being swept toward a waterfall at 5.0m/s. Which direction of rowing would maximize the rower's chances of survival ?

This problem does not force the use of microcomputers. Many tried scale drawings to get a solution. Some tried to learn enough trigonometry to solve it. A few wrote a program that found the rower's position after one second at any angle, and then programmed it to try every degree, then every tenth of a degree, and so on. These fellows did not win by getting the most decimal places, but they were close.

What is so special about this technique? It is simple enough that it is easily understood by the students who develop it, but it is powerful enough to handle extremely complex problems. The next day, someone suggested that the original version of the waterfall problem was not realistic. As the boat got very close to the waterfall, the current should have increased. That made sense but also made the problem much more difficult to solve. Most of the students left the question there. Only the fellows with the computer program had any idea how to proceed further.

Usual homework

The homework problems in the P.S.S.C. textbook are difficult enough to prompt some students to consider unorthodox methods of solution. The bus and pedestrian problem in Chapter nine (Milsop 1981), the elliptical orbit problems in Chapter thirteen, the space-walk problem in Chapter fourteen - any number of these are difficult to solve analytically. All of them can be approximated, simulated or graphed with a computer. This does not always give an answer, but it may lead to one. It may give a student an extra little insight into what is happening or what the problem is really about.

The linear algebra homework from Chapter ten of the P.S.S.C. text usually produces a spate of two and three dimensional vector arithmetic packages, replete with coloured arrow illustrations of addition, subtraction or multiplication of vectors.

Report styles

More teachers and students are using word processors to handle daily jobs. Homework can be submitted and corrected with relative ease using this very powerful tool. I make it known that I will accept homework prepared this way, either printed or on computer diskette. Some who are motivated to try do enjoy it. (See also Bork 1979:17)

The same holds for laboratory reports. A student's programs that can tabulate and calculate and transfer numbers to plotter functions can be used to good advantage.

Homework and laboratory reports are done on the computer, and not just because it produces clean copy. The tabulated numbers do line up nicely and the report is easy to edit, but the real advantage is the ability to manipulate data and graphs. This allows the student to consider many "what if..."

type questions and to test ideas or techniques that would otherwise be daunting. In the grade ten course, students try their hand at fitting simple functions to experimental data. Here, the ability to produce graphs quickly and easily is an obvious asset. This allows the student to use trial and error to fit curves to his data. More interesting is the ability to transform the data to produce log/log plots. This allows the student to sidestep trial-and-error methods and investigate power-curve fitting.

Laboratory approach

Laboratory exercises are often organized in my courses to allow students creative freedom. A typical example from kinematics may be to find the velocity and acceleration of some object. The procedure, in fact the type of motion, is unspecified. This kind of open experiment allows the students to consider and evaluate different approaches. One of the options now available may be to use the microcomputer in some way.

From the literature, it appears that a lot of work is being done with computers in the laboratory (e.g. Quist 1982) Many people use computers as an integral part of the course, requiring of all an intimate knowledge of the machine, whereas in my course the use of a computer is not a requirement. However it is allowed where appropriate (see page 14).

Alternate laboratory approaches

One of the first laboratory experiments in grade ten asks the students to find a way of expressing as an algebraic equation the apparent relationship between measured light intensity and distance from a constant light source. Although light intensity is not handled in the P.S.S.C. manual, the required techniques of data analysis are discussed. Photocells, phototransistors, photoresistors, even Joly photometers, were made available, as were candles, flashlight bulbs and meters. One student who had shown interest the previous year was encouraged before the day of the experiment to modify his game paddle hardware so that photoresistors could be attached in series. He wrote a program to gather data from the sensor and to plot a graph of reading versus distance. He naturally thought that this was light intensity versus distance.

Why was the computer an appropriate tool for this student if I believe that it should be used only if no better device can be used? Everyone else was using a photocell connected to a galvanometer. This arrangement does not directly plot a graph, but more light caused the needle to go up, and with less light the needle dropped. One can get the feel of the phenomenon easily enough with this device. Other students noticed that angling the solar cell plate affected the readings and led to further investigations. Some also measured the effects of reflectors behind the source, and others of filters in front. The system was accurate, effective, obviously motivating, and had the advantage of giving simple, direct readings. For those who chose to experiment with the solar cell, that was where it ended.

Hofstadter in "Godel, Escher, Bach: an Eternal Golden Braid" (1980) suggests that, being a high level beast, man tends to intellectualize on high levels of abstraction and worries about the lower levels only when things go wrong. The meter attached to the photocell can be thought of as a light intensity meter because the numbers the needle pointed to are roughly proportional to light intensities falling on the detector, within a certain range of values. Inserting a computer between the sensor and the number display led to the choice of a photoresistor instead of a photocell and this caused a problem on one of Hofstadter's "lower levels". A photoresistor was chosen as the detector, because the computer's analog to digital converter can be thought of as internally assigning a number roughly proportional to the resistance of a sensor attached to a special input port built onto the machine. This detector's resistance does vary in response to light intensity, but in a very non-linear way. Consequently, the computer sensed data and plotted graphs which did not look right. This student had looked in the textbook and had expected to see an inverse square curve, and was frustrated to find that his graphs were not the right shape, but that his friends' graphs definitely were.

This was where the computer proved its worth. It was only after four or five trials under varying conditions produced similarly-shaped curves that the student was ready to accept that the shape was correct, in that it was consistent, repeatable and precise. Thus, the first reason for using the computer was that it produced graphs quickly.

The second reason was conceptual. Inserting another "black box" facilitated the distinction between the concept of light intensity and the number used to measure it. The number was no longer identified as light intensity, but as the system's response to light intensity. The higher level problem of defining a light intensity unit and subsequently mapping it to system response is a little different from calibration. Once the mapping is described, it can be incorporated into the graphing program so that the system response will be linear with light intensity. This is an example of a way of making a non-linear transducer part of a linear detector system. The reverse is also possible if, for instance, you wish to plot logarithmic scales.

In grade ten kinematics, students are asked to measure the acceleration of an object of their choice. Objects are dropped with ticker tape attached, and cars are rolled down inclined planes as teams time the motion with stop watches. One pair programmed a computer to show a picture of a rocket accelerating across the screen. The computer recorded where it had drawn the pictures at each instant so it could be programmed to calculate the acceleration in screen units per unit of time squared, which the students converted to metric after they had measured the distance and time scales.

This method certainly produced the most uniform acceleration of the class. It sidestepped many measurement difficulties which, I hasten to add, had been confronted by these students in previous excursions and would be again later. The technique was deemed appropriate for a physics experiment because of the open nature of the problem and because I felt that the discussions which ensued outweighed the lack of more complicated measurement activity.

The computer did give the feeling that the rocket accelerated, and quantified that feeling. In that respect, the exercise was successful, but I was not willing to accept the students' laboratory reports unless they could pinpoint what it was that had accelerated physically. In doing so, the students were forced to articulate the limitations of their model - a worthy problem. One of the boys made a strong argument that his program was not a simulation at all but was really generating motion.

In another alternative laboratory situation, the grade eleven P.S.S.C. students were asked to store an amount of energy somehow and convert it to kinetic energy, and estimate the efficiency of the process. One group wanted to release an iron ball close to a powerful magnet and measure the kinetic energy just before impact. They could not think of a non-intrusive way to do this with acceptable accuracy. I offered them the use of a prototype timing system using a microcomputer, which they adapted to their needs.

A light beam is shone across the path of a moving object and is detected by a phototransistor, which is mapped to a memory address in the computer through the built-in port. When the object moves into the beam, the phototransistor shuts off and the memory switches from a zero to a one, indicating that something is blocking the beam. Three independent phototransistors enable changes in velocity and acceleration to be measured.

A program timed changes in the phototransistor states, and displayed on the screen the configuration of the detectors and the time elapsed since the last change. The accuracy of the timer is +/-0.03ms. The spatial resolution of the phototransistor is under 1 mm. For a more complete description of this timing system, see Appendix III.

The velocity just before impact with the magnet was estimated and kinetic energy was found. One member of the team calibrated a spring scale and plotted a force-distance graph as the ball approached the magnet. He was surprised to find that the shape of the curve was an inverse cube. The area under a portion of this graph represented an approximation of the change in the potential energy stored. As it turned out, the efficiency was so high that they could show that the ball had not rolled much as it moved toward the magnet.

In a similar case, a class of regular stream (Physics 512) grade eleven students was given a problem in experimental design. They were to measure the acceleration of gravity using a method different from the one they had used in grade ten.

One pair of students used this same computer timing device. Others in their class used ticker tape timers, stop watches, pendulums, tape recorders and other devices, and produced reasonable results with little difficulty. The pair of students using the microcomputer had a great deal of trouble, and the data they gathered was too unreliable to be used. The results were useless but the exercise was not. One member of the pair was a computer enthusiast who was keen to use electronic toys in the laboratory. He thought it would be easy. His partner feared computers and did not know how to use one. He thought it would be impossible. In the end, both did more physics than computer science and both spent much longer on the project than the other groups did. They later reported that they had both found it a worthwhile and enjoyable experiment, partly because their work after school started drawing crowds of passers-by from the hallway to see their design, offer suggestions and share some of the excitement.

The microcomputer has been present in our laboratory as an option for experiments requiring fast data processing, simulation and data gathering. In what follows, the use of the computer outside of the laboratory is described as both an extension of existing investigation beyond the usual limits, and an augmentation of the kinds of systems that can be investigated.

The P.S.S.C. manual describes the vector analysis of the forces on a ball in flight. This represents the first half of an exercise for our grade eleven students. The second part requires a synthesis of the trajectory of a given object. The student can choose to describe the motion of a football kicked through the air, with or without wind, the interaction of a rocket with a planet, an alpha particle with a gold nucleus, or some similar system. Many realize that the repetitive nature of the calculations is well suited to the arithmetic power of the computer.

The best programmers produced software that did the whole job with varying friction forces and gravities. The trajectory was plotted point by point on the screen and dumped to a printer to be handed in. More significant to me were the less experienced students who coded some portion of the problem and plotted the results by hand. These boys enjoyed the newfound realization that they could use the computer to help reduce the amount of drudgery they had to do. The students who did not use the computer still appreciated that even more complicated trajectories could be predicted using similar techniques.

The same sort of extension arose from a grade ten experiment on interference patterns from two wave sources. Some students tried to set up three or four sources in the same ripple tank to see the pattern. One fellow decided it would be interesting to write a program to draw concentric circles to describe any configuration of sources. A few of his friends also decided to write variations of this program, allowing different wavelengths or phase shifts. One boy plotted only those points where the circles intersected. This produced some very interesting results. (The power of this technique is illustrated nicely by Stein and Dishman 1982.)

Many systems which are impossible to study in the normal laboratory environment can be successfully modelled by computers, and experiments may be run on these simulations.

A delightful program written by a tenth grade student for an Atari microcomputer shows a box full of little bouncing dots representing molecules of an ideal gas. A graph of pressure versus time is plotted, and every time a little dot hits a wall the pressure jumps up a bit. The number of particles in the box and the temperature can be varied. The beauty of this model is the visual feedback of what happens when the parameters are varied. This is especially useful where direct naked eye evidence is unavailable. (A similar program for the PET computer is described by Zimmermann 1979.)

Some students wondered what was so special about Brownian motion as opposed to any other type of random motion. They programmed simulations of particles which moved in other types of random patterns and compared them with Brownian motion. The importance of mean free-path and velocity distribution became clear as the students programmed different fluctuations in the motions of the particles. (For a more involved simulation of Brownian motion see Mishima et al. 1980.)

Many students' hypotheses were independently tested or studied with computers. One grade nine student built a model of an orbiting satellite and brought it to me because it did not look quite right to him. A glance at his program showed that the physics of the model was correct but for one detail. He knew nothing of vectors at this time and the equation he made up to separate the force into components was not correct. I told him so and he went off. I do not know how he came across the correct functions but the next time I saw his program it was working properly. In fact, it was better in some repects than a program I had made to do the same orbital simulations, and I told him so and asked if I could use his program for a demonstration for grade eleven. I think we were both impressed.

From testing alternatives to inverse square laws, to modelling planetesimals, to bouncing balls in varying gravities, it is apparent that students enjoy mirroring the world on the computer screen. And in order to do so, they are prepared to learn the physics, iteration techniques, Monte Carlo simulations, successive approximation, and difference methods required. They are not just getting good at what they are doing, they are learning how to go about getting good at doing things. They are developing faculties for internalizing and articulating models.

Of the many other examples of testing theories on file, this last one illustrates a feature common to most microcomputers, but one not described in any manual I could find. It was introduced to me by a student in grade eleven who had been intrigued by a question which came up in both his physics and his calculus classes: how many times does a ping pong ball bounce if it bounces a fixed percentage of its height each time? It was an interesting theoretical problem, but one which he had already come to grips with. He had even simulated a ball bouncing with a computer program to solve a problem similar to that described by Milsop (1981) and knew that the number of bounces was mathematically infinite. What he really wanted to know was how does this model compare to a real ball's motion?

To find out, he tried dropping one on a hard surface but found it impossible to count the bounces because they happened too quickly. Instead, he got his computer to listen to the bounces and count them.

It happened that his computer loaded programs by listening to a tape recorder play coded sounds. He pressed "play" and "record" while monitoring the cassette input memory address and found that it reacted to any sound in the room. He wrote a counting program and began experimenting. The sensitivity was surprisingly good. It could hear the ball strike a table many meters away. The first test saw the computer count a single bounce as many events. It became apparent to the boy that the computer reacted to the movement of the microphone diaphragm and not the bounce per se. He programmed a software filter to distiguish single bounces (individual bursts of high frequency).

Using his sound-counting system he was able to count an amazingly high number of bounces in each trial (over one hundred in some cases) and determine the time duration between each as well. Smith, Spencer and Jones describe a similar experiment (1980) with comparable precision, but conclude that their procedure is too complicated to be used in an introductory college laboratory. This ability to detect sound led him to develop other programs, such as speech encoding systems and schemes that sped up speech playback without increasing pitch. This independent, self-motivated experimentation quickly led to high level physics concepts and resolved them in a way that proved satisfying and fruitful.

Outside of the classroom

Some students who are not led by occurences in the classroom, or motivated by laboratory exercises to further study, have still expressed a desire to involve themselves in some physics project using the computer. Suggestions related to material under study or concerned with upcoming topics were often helpful in giving direction to these creative energies. Such students may rely on those with greater experience to choose topics of intrinsic value. Interest is lent to projects because others consider them worthwhile.

Some were interested in producing programs that other students would use. One year (1979) a grade ten fellow wrote a "black box" game similar to one described in Byte magazine (1984). It was used as part of an exercise in inductive reasoning in an eighth grade science class. The program would simulate particles shot through a black box. The students would control the directions of the shots, and by observing the deflections of the paths, try to induce the shape of the object hidden inside.

The following year, when this same student learned that particle deflection was an important technique in probing subatomic structure, he was motivated to produce a program which simulated Rutherford scattering from heavy nuclei. The program controlled the aiming error, the particle charge and its energy. Those who used it quickly realized the effect of each of these factors on the scattering angle and distance of closest approach.

Projects, like the scattering ones described, need never be considered complete. Another student may run across such a project and develop it further. A black box game led to a Rutherford scattering game. This, in its turn, could lead another student to test scattering from other force fields, or multiple scattering from clouds of particles, or comparison studies with Klein-Nishina scattering of gamma rays. The scope of what can be considered expands as they play.

Children are fascinated by computer games. In an effort to tap this source of playful interest, I have produced three games designed to reward the physics student.

The first attempt was a modification of the classic "Star Trek" game. To make the game more appealing, attention was given to action on the screen. To make it less atavistic, the goal was shifted from the slaughter of sapient lifeforms, to locating and defending a particular star system. The pedagogical goal was the formation of energy conservation tactics.

Energy was available from certain star bases and other less obvious sources. This energy was used in life support systems, shields, engines, lasers, and scanners, the usual space paraphernalia. Constant attention was given to the procurement, conversion and conservation of energy, the only meaningful commodity in the game.

The second program was an adaptation of the old checkers board game of wolf and goats. In this version the computer controlled the movements of a beast on an eight by eight grid. The player communicated moves to four field agents, and attempted to manoeuver them into positions which block the beast, and eventually herd it back to the top of the grid. All pieces moved as in checkers. The beast could move backwards but the agents of the user could not. In the simplest version, if all the best moves were made, the beast could always be driven off. In the more advanced game there is a large and a small beast. I do not know whether the best moves could force a win in all cases.

The player called a particular agent by his designated number, and specified the move using grid coordinates. The agent would then describe a problem, perhaps concerning the terrain or the whereabouts of the beast. The solution would involve some physical principle. If the player failed to answer correctly, the agent would not make the move. The player could call upon another agent until a move was made.

Informal observations of students showed that the artificial intelligence of the program facilitated an anthropomorphic response to the beast. They would wonder out loud where "he" would decide to move next. They were upset when a physics question caused them to lose a move. They did not like the questions, but they played. Even though they recognized that the physics aspect was an artificial, and sometimes unpleasant, appendage to the game, they still played to try to outfox the beast. (A variation of an adventure series type game modified to teach physics is described by Hickey 1982).

The third game was an attempt to familiarize the student with the various graphs of motion encountered in kinematics. In this game, the player attempted to dock a rocket craft with a moving space station. The screen gave him a small visual display of the action, and graphical representations of their motions. Graphs of position, velocity and acceleration versus time of the rocket and the station were plotted simultaneously. In advanced versions the station remained invisible until docking was completed. This forced the student to rely more heavily on his interpretation of the graphical description of what was happening.

A demonstration mode was available to illustrate the relationships between motion in the visual display and the graphs that were plotted. Stop action, slow motion, and a strobe feature enhanced the clarity of presentation. Constant acceleration, simple harmonic motion and other simple motions could be programmed and demonstrated. Graphs could be cross referenced and checked for consistency and accuracy.

At first, many students found these graphs a mysterious way of describing motion, but after a while most were able to use them easily. The immediacy of the game situation developed graph interpretation skills quickly.

Many of the games on the market today are a rich source of physics material. There are motion games of all sorts, adventure puzzles and mapping games, projectile motion games, and games based on force field interactions. Many are good for the physics student. Some have errors in physical principle. These should be rooted out and discussed if the students are playing them.

The most impressive games to me are the ones that the students make themselves. Programming airplanes moving in three dimensions, radar simulations or mortar duels, require a great deal of acumen. The students who build them are practising physics, as well as computer science, especially when it comes to evaluating whether the programs are working properly or not.

As mentioned previously the microcomputer is well suited to tutorial and remediation applications. Students can work at question banks or tutorial programs in their leisure time, independently of the teacher. But on a higher level, the computer allows independent study of systems in ways not possible before. "Elas" is an example of this kind of study.

"Elas" is the name of a program developed by a grade ten student. The program simulates wave motion on an elastic cord. Each particle of the cord interacts with its neighbors with a force proportional to the distance between them. One end of the cord is controlled by the user so that arbitrary wave shapes can be injected.

This simple program was modified to illustrate all manner of wave phenomena, at speeds slow enough to be studied and understood. Simulations were made of reflections at fixed and free ends, of reflection and transmission at interfaces of different media, of longitudinal and transverse waves, and much more. It was like having a programmable slow motion camera. In my opinion this type of independent study was particularly valuable to the student and to those friends and classmates who became involved, and I encouraged it.

There are other ways that independent study can be organized with a computer. Commercial modules can be run. Numerous articles in computer magazines describe simulations of various kinds. The adoption of these are second best as a candidate for the student's perception of a needed study tool. His own design and implementation of a program is preferred. When he sees simulated motion unfold on the computer screen, there is an intimate understanding of how it occurs if he ordered the processes which produced it.

How closely the effects mirror the real world is a consideration often overlooked in ready-made packages. If the student makes the program, this comparison may be the only way he can tell if he is on the right track with his simulation. Reality takes the place of the answer in the back of the book.

Classroom activities

Microcomputers can serve a useful purpose in the classroom environment. I have found them to be effective in a supplementary role, to help promote single, well defined physical concepts or processes. It is appropriate as another view of material already presented. If it is done well, the point will be communicated quickly. Thus, short activity sessions are better than long ones, and do not allow students to become bored.

Three types of classroom implementation have been tested. Examples of each follow.

One of the most difficult parts of a kinematics course is the interpretation and sketching of graphs of motion. After gathering various data sets in the laboratory and plotting a few of their own graphs, I used the kinematics space game demonstration, described above on page 45, to give an overview of the material.

To help the students get as much as they can from brief encounters like this one, sheets showing sketches of the most important graphs handed out beforehand, save the bother of trying to copy from the screen into their notebooks. I did not do this all the time, and noticed the difference. Doing so also insures that they have something concrete to carry away with them, to remind them of what they saw. They were also given free access to the program for study.

I found that some people do not relate well to outer space themes, so for some demonstrations, the same program was used, but a small car was shown on the visual. The control paddle was wired to a little plastic car that rolled up and down a backdrop of a small town. It is surprising the effect familiar objects have when trying to relate to graphical abstractions.

It is very important that the student take something concrete home from a demonstration. In the modern physics section of the grade eleven course, while the lecture and problem session during class went on, the microcomputer printed out density plots which represented solutions to the Schrodinger equation. At the end of the period each student walked out with one of these plots and though the shapes were similar, each was unique - a nice illustration of the predictability of random events. This could not have been done with a photocopier.

For special sessions the entire computer room at Selwyn House can be booked so that a class can work two or three to a terminal. This setup allows each group the freedom to accomplish directed activities in their own way, and move quickly with their own approach to the topic under consideration.

At the end of grade ten, those students going on to the advanced physics stream in grade eleven were given one or two extra classes which introduce orbital mechanics. Over the summer they were to complete the study and a series of textbook and observation problems. To foster an appreciation of just how special and peculiar the almost perfectly circular orbits of the planets are, the last class ended with a trip to the computer room.

Each group was given a program which closely simulated the orbital path of a body when the user specified an initial starting point and velocity. Their task was to set up initial conditions which would produce motion as close to circular as that of most of the planets, an eccentricity of less than 0.1 was acceptable. They found that it was surprisingly difficult to do.

This loose class structure demanded individual, intellectual responsibility. When they had finished, some groups or members of a group left. Some continued to try different radii and velocities in an effort to determine an algebraic relationship. Some noticed that orbits tended to precess, probably due to discretization errors, and attempted to determine what controlled the rate of precession. Some left the computers and began discussing what processes could possibly have caused all of the planets to move this way. All but a few had finished with the machines after thirty minutes.

The microcomputer is not usually well suited to use in an activity which involves the participation of an entire class, but I did find that the following were successful.

At the beginning of the kinematics section in grade ten the students use stopwatches to measure the average velocity of tennis balls and other objects. To then introduce the idea of instantaneous velocity and acceleration, I wanted accurate measurements of velocities at various times during a run. Photogate timers were used to sample times over relatively small distance intervals in the first two or three meters of a short foot race.

The program used was an adaptation of the millisecond timer introduced above (on page 36, see Appendix III for details and other suggested applications of this program). The computer would display the elapsed time between breaking the light beam of one gate and breaking the beam of the next. With the distance measured between the gates, the students were able to calculate not only their average velocity for the entire race, but also their velocities at times during the race.

The entire class of twenty was timed in one forty minute period so that results could be calculated and compared before they left. The efficiency and accuracy of the timing system was one reason for using it. Of greater interest was what happened after the official trials were over. Students took over the device and began, on their own, to do all kinds of tests. They ran with and without shoes. They timed karate chops. They compared the speed of a meter stick in full swing to the whip-like motion of a section of hose borrowed from the faucets.

Again I wish to say that it is this kind of self-directed play which is excellent for the proper development of an understanding of physical concepts. Opportunities to allow and encourage it should be sought.

Another reason for this particular excursion was to show the students that this device was a resource available to them should they wish to pursue it. Further, I had hoped for suggestions from them that would make the system more useful. Not only did some volunteer to improve the software, but word somehow got to grade nine students who then built their own detector and timing systems at home.

Work with outside institutions

This work refers to projects of a scientific nature, undertaken by a few students, for companies or institutions outside of Selwyn House School. There are many computer programs that are simple in concept, but require more time, effort or expertise than the institution is willing to supply. Some of our students have, from time to time, volunteered their effort and expertise to these jobs.

In one case, a series of problems was given to us by the Pulp and Paper Institute of Canada, Paprican. These involved the simulation of the outputs of a Kraft process, a three dimensional graph routine to display results and a sophisticated curve fitting routine. Upon completion of the main program, the student in charge was invited to go to the plant to install the program and demonstrate its operation. He was shown around the research facilities, and saw firsthand where his contribution fit into the grander scheme of things. The experience brought the boy into contact with scientific work that mattered in a real way. He was working with people on the cutting edge of knowledge in that field, and he was helping them do things that they would not otherwise get done.

The responsibility of getting the job done by the deadline was his. The motivation was not marks in a teacher's book, but the appreciation that his reputation was at stake.

Exposure to research gives students a picture of science as a vital force in the world beyond the confines of the school walls. This is a valuable perspective.

Even my own studies at McGill Universtiy were able to motivate students. When I learned about Euler angle rotations and told the students about them, a few proceeded to write programs that did the matrix transformations. Several students volunteered to translate programs that I made for cell membrane physics simulations in Basic, into Fortran to run on McGill's machines.

Such projects are not difficult to find. An advertisement in an issue of Scientific American led a few students to the travelling salesman's problem. That is the one that requires finding a closed loop connecting scattered cities so that they are visited once and only once, in such a way as to minimize some quantity associated to each path such as cost or distance. The advertisement made it clear that Bell Canada was one of many companies that could save money if solutions to this problem could be generated (see also Wheeler 1983, and Armour and Wheeler 1983). Three students brainstormed the problem and suggested algorithms that were developed and tested over the next two years. Research with McGill's mathematics department revealed that their technique was a fast, new hybrid just being discussed in the literature.

Spinoffs

After working for a number of months using the computer to help with some small problems in physics, the students began to gather together programs which helped them. Text editors, graphing packages and the like became part of the students' repertoire. To these the students would add such specialized physics software as they may have developed for themselves. To organize, evaluate and disseminate useful programs, a library of sorts came into being. A student who wished to try a software package brought a blank computer disk and copied it to take home or to use in the school's computer room. When he finished with the program, he kept it or erased it as he wished. Any improvements or additions he may have wished to make were gratefully accepted, screened and made available to others.

In addition to motivating study and work in physics, this simple vehicle encouraged work in computer science and mathematics as well. Many of the programs received solved quadratic equations, calculated slopes, fit curves to data and the like. Programs that do vector algebra were popular for a while. Wheel re-inventors, who wished to practice computer science more than physics, submitted two and three dimensional plotters with linear or logrithmic scales.

Not all projects submitted to the library were large and complicated. Some students, in working through a problem or laboratory report, saved time by making a short program that calculated kinetic energy or angle of refraction. These boys were encouraged to share this work. They had not realized that such things would be of interest to anyone else, but those are just the kinds of programs I would expect to see on a physics library disc.

Some programs were designed by students to demonstrate certain aspects of physics theory. One amusing program attempted to illustrate how momentum is conserved in closed systems by showing a series of cartoon-like simulations. This short program epitomizes one aspect of the microcomputer's role, that is, the single concept vignette.

In addition to encouraging much useful, well directed effort, the library makes available practical software and games to the school's physics community. Not just the secondary school physicists became involvled. Some of the programs were taken by fourth graders.

One of the side effects of bringing microcomputers into the classroom was an interest in the technology. Extracurricular activity now includes a great deal more work in electronics than in the past, which I think is a direct result of this interest.

Electronics is a regular part of the P.S.S.C. physics course in grade eleven. Hooking things to the computer ports provided many opportunities to discuss and illustrate principles. Just getting the output ports to control light emitting diodes (LED's) required the calculation of the value of a current limiting resistor. This brought up questions concerning the non-linear voltage/current response of the LED's and a discussion of their physical properties. Should the resistor be placed in series or parallel or does it matter? What effect will the power drain have on the port? How can the computer be used to control 60watt light bulbs?

The capacitor was a mystery to many, even though the characteristics of it were well understood. They could appreciate that some electrical engineer designing a radio would have to be able to build filters but it was not part of their immediate experience. Then it became fashionable to speed up the repeat key function of their microcomputer. This feature is maddeningly slow on the Apple. Adding a capacitor the right way made the keyboard function respond quicker.

One pair of grade eleven students studied transistor switches in the physics laboratory so that they could hook up their computer to a radio controlled car. After describing the layout of the room, they wanted the computer to guide the car safely around it. Not satisfied with this, they began looking for ways to get the computer-car to map a room by itself.

Contrary to most laboratory manuals I've seen, the Wheatstone bridge is not often used to measure unknown resistances. It is, however, very good at taking the small resistance changes of a transducer and giving voltage changes large enough for an Apple computer to read as a number with its game paddle port. This technique can be used to measure a wide variety of physical characteristics. If the set up is not sensitive enough, then students can be introduced to operational amplifiers.

In grade nine, simple circuit theory was studied. Practice included applications which were of use to the student. The Apple computer comes with an onboard speaker that has no off switch. The addition of a single pole, single throw switch was something many could not do. A few were motivated by the desire to modify their machine and succeeded. A variable resistor thrown in for volume control of this speaker made an excellent project.

Some projects saved the students money. A few built their own joystick. More motivated grade nine students have attached phototransistors across push button inputs to produce light pens. There are many simple modifications that a student can do to enhance the capabilities of his computer.

As new skills are acquired, some people enjoy the challenge of competition. In the past, many students have proposed informal contests. During the section in grade eleven where statistical mechanics was introduced, an example having to do with randomizing distributions somehow led to a contest to see who could get a computer to thoroughly shuffle a deck of cards the fastest. After deciding what shuffling meant, the contest began. I held the record for about three weeks until one boy cut my time by about thirty percent.

There were other contests over the years: who could get the most decimals, or the most accurate motion simulator, or the fastest graph module. I noticed that many times situations that began with a boy saying "I bet I can ... ", often led to "I bet we can ...". This in turn often led to it getting done.

There are more formal contests such as science fairs and the like. These are designed so that facility with powerful computing machines is not a great advantage. Still, more and more computer related projects are being entered.

Formal contests on a smaller scale have a place in my physics classes. The example of the best direction for the oarsman to escape the waterfall shows the open ended type of problem that I consider appropriate. The computer here is just one approach where many are possible.

One very fruitful way to see computers used to learn physics is to walk into the computer room when it is open to the students during free time. I have, on numerous occasions, found physics being done there without my knowledge. Often the children involved did not know that I would be interested in something they considered the playing out of an idle curiosity.

If I did not see any physics happening, I would sit down at a terminal and start my own. The ones who had their own personal projects got the idea that I was interested and showed me some of their work. We shared programs and ideas and learned from each other.

Children learn extremely well by example.

Summary

The microcomputer has extended the study of physics beyond the intellectual confines of the classroom or laboratory. It has motivated children to investigate beyond the curriculum.

In formal settings, the computer effectively illuminated short, single concept presentations. Time, the disc and a computer were made available outside of class for further study.

In less formal situations, the microcomputer was used where appropriate, at the right time and with the student who was ready.

The teacher today must remain alert to new opportunities. The technology is out there; and children are using microcomputers to learn and apply physics.

OBSERVATIONS

Students

When given lots of freedom, many students responded with initiative that took them beyond the curriculum. Challenges to apply computers to physics offered, to those who were contemplating pursuing the sciences, engineering or computer science, an opportunity to learn and apply skills that would be valuable later on in their careers (sentiments shared by others, notably D.L.Want 1980). It was not always the brightest scientifically nor the most mathematically inclined who became involved. The less gifted sometimes found that a few simple programs would ease the burden of calculation and save them some time. This is very important to the child who may believe that his low standing in mathematics means that he is poor at doing all types of mathematics.

The student who investigated physics with the computer could find himself outside the scope of the text and beyond the knowledge of the teacher . This realization on the part of the student usually caused an interesting shift in perspective. A topic under study became, in a way, his own. The methods and applications were part of his self expression. It could make him unique. Applications were attempted not because they were "practical", but because he wanted to see them happen. It was exciting.

Part of the motivation was undoubtedly the exercise of control, control over expensive and mysterious technology (Perry interviews Papert 1984; and Zamora 1984:43), or control of the programming. Even if someone else's software was used, there was the undersanding that it could have been modified. More important for me was the creative control the student had over how he might attempt to assimilate or express new concepts in the study of physics. A world of new techniques and possibilities was available to him. The fact of the computer's presence encouraged the student to exercise control over what he chose to study.

The feedback that students who use computers get, did not come just from the machines. Much has been written about the effectiveness of quick machine response. In my estimation the more important feedback came to the boy from his community. If his mother was impressed with his programming of such a complex device or if his friends found his new simulation intriguing, these were powerful influences and shapers of the self image.

There are many ways that success can build confidence in a physics class. The computer timer, described previously on page 36 and in Appendix III, was being used to measure the speeds of runners over short distances. The fellow who was found to be the fastest was a shy boy whose low marks on tests reinforced his desire for anonymity. Now he had a reputation in the physics class as a winner, he was a respected member of the class. Such opportunities for simple successes should not be overlooked.

One last, interesting observation related to feedback from the community, I feel was indirectly the result of offering few if any marks as encouragement for extracurricular work with computers. Students would freely share their research with their fellows, instead of keeping it confidential to insure the highest marks in the class. Students became colleagues rather than competitors, and I suggest that in sharing their efforts they gained recognition from their peers.

Approach to physics and problem solving

Those who choose to do physics with the aid of a computer, learn skills in some different ways than those who do not. Certainly they learn how to use a computer and its programming language. In "Mind Storms", Papert suggests that this, in itself, is a great step for the child (1980:27) . In practising flow charting for the computer, he practises "linearizing complexes" and identifying subgoals. Writing subroutines requires the ability to generalize processes required to perform these subgoals. Logical "if...then" statements, the concept of an array of values, multiple processes such as looping and functions as subprograms, are all part and parcel of learning to handle the computer.

Another important concept that the student-programmer may develop, is the sense that an answer to a question in physics can be an equation rather than just a number. Most questions found in a textbook require a single number, but many questions in physics require the description of a process. Many students of algebra are confused as to what an equation represents. It may be a bunch of symbols that can produce a number answer. It may represent a curve on a graph. Students who are familiar with computer techniques may recognize that an equation can be regarded as a performance. The computer can take the equation that represents, say, the position of a ball falling, and perform it on the screen. The directions for the performance of a process is a rich metaphor for an equation.

In addition to the technical skills required to run the machines, many students are motivated to study computational skills. Trigonometry allows graphics to be placed on the screen properly. Differential geometry is a much more natural way to describe the motion of objects through space (Papert 1980:27). Many simulation techniques, from the numerical solution of differential equations (for a good discussion see Stanley 1983) to Monte Carlo simulations, are practised from grades nine to eleven.

These powerful computational approaches allow higher level problems to be considered. I walked into class one day with a half meter length of chain, laid it on the front desk with five or six links hanging over the edge and let it go. It clattered to the floor. I tried a few times and found that ten percent of the chain's length hanging over the edge was not enough to cause motion but one more link would send it accelerating to the floor. The students were asked to describe the position-time relationship for the chain. In previous years I could never have hoped for more than a qualitative description. In two days a grade ten student submitted a list predicting the time at which each link would go over the edge of the table. I had not produced an answer of my own prior to posing the question. It was a tough problem and I admit that I had difficulty checking the accuracy of his solutions.

In addition to becoming involved with more advanced areas of application, students also encountered higher level difficulties. Some learned the importance of the Nyquist frequency, when their sound recording program was tricked by aliasing (high frequencies appear low). Roundoff errors and discretization errors caused simulated waves to disperse and orbits of planets to appear to precess. The usefulness of an exact algebraic or differential analytical solution became apparent when computer simulation run times were estimated to require years to reach an approximate solution. These sorts of problems are not often recognized by students. Often an experienced teacher can help to identify an intractable difficulty. In a few cases he cannot.

The freedom that the student has to approach physics in these ways carries with it a tacit responsibility. The models he constructs and the processes he evolves are his own. The onus of insuring that they are apt models rests with the student. Care should be taken to make him aware of this.

Impact in the students' milieu

A few would begin to use the computer on some project, and friends would offer, or were enlisted, to help. Those playing with other things wandered over to see what was being done. Soon a sizable portion of the class and others in the computer room knew that physics was being done and how it was being accomplished.

Other grade levels became involved. I can still see the bemused look on the face of an advanced grade eleven physics student when a fourth grader came up to him and asked for help with the equations necessary to resolve the coordinates of the cannonball he was trying to lob into a castle. The young student had looked up the equations of motion; he just wanted help with the vector algebra. It impressed the grade eleven student even more when the child understood his answer.

The tidy boundaries delimiting subject areas began to blur. The inquiring minds unleashed were ubiquitous. Any mathematical concept was fair game, and was often dragged into the physics class for exhibition. Thermal dynamics, electrostatics and quantum mechanics would steal into chemistry class. Imagine explaining Van Der Waal's forces with an electrostatics simulation.

Our geography department was forever describing projectiles going off course because of a little understood force attributed to Mr. Coriolis. According to their story, this was the same fellow who explained why toilets drain with a clockwise swirl in Australia. It is difficult to illustrate other perspectives and the effects of adopting a spinning planet as reference frame, but one grade ten boy attempted the task.

One lovely example of the impact of computers in the physics class spilling over into other areas of the students' experience comes to me from the English department. I overheard some boys in grade eleven discussing an idea that their English master had mentioned. It seemed to have been his opinion that if enough monkeys were given typewriters, they should eventually produce all of Shakespeare's works by banging away at random. Knowing that they were familiar with probability calculations, I asked them to predict how long we might expect to wait for this event. After calculating a number that was larger than any they had ever come across, I suggested that they lower their sights a bit. Would it be reasonable to assume that one monkey could produce just one fragment of a Shakespearian line in his lifetime. The quotation chosen seemed simple enough: "to be or not to be". The calculation was done and the estimated improbability of the event was frankly not believed. In the true spirit of scientific philosophy they made a computer into a random monkey machine. The idea caught on and for days many computers spewed out nothing in the least like English. Once again Shakespeare's reputation is secure thanks to a three line program and a handful of grade eleven epistemologists who now have an inkling of just what it means to meet a number larger than any they had ever seen before.

Some students have come to realize that they have useful skills to offer the world in that they have played a useful, albeit modest, role in research programs such as the one described with the Pulp and Paper Institute.

Perhaps computers are not for everyone, but those who did use them found that their effects propagate like ripples in a pond throughout their academic lives and their community.

Impact on the teacher

The incorporation of computer technology into my teaching repertoire has taken a great deal of time and effort, requiring new skills and new approaches, but the rewards were great. If nothing else, the excitement of new topics of study in education and physics that it has presented, have kept me vital and well motivated. It has forced me to author software in many computer languages and to learn to construct hardware devices. More than this, it has brought about important evolutions in two areas: methodology and communication skills.

Work with microcomputers has been gradually integrated into the fabric of the course. As D.L.Want (1980) suggests, this material was in addition to what the students would have done, it was not a replacement for any resources already at their disposal. Organizational skills were necessary to coordinate the work of student authors of computer software with class work as the need arose. More important was the need to bear in mind the total course picture (Bork 1979:12

suggests this evolution).

Perhaps in part because some of the work attempted was outside the teacher's expertise as mentioned previously, there was a change in some teacher/student relationships. These interactions shifted from the teacher at the front of the room, to teacher as role model, resource person, even co-worker. The atmosphere was much like that between a professor and a graduate student (sentiment echoed in Papert 1980:115).

Related to this change in relationship is a change in perspective. The teacher is no longer the answer man. In fact he is no longer the center of activity. The student is doing physics. That is the pedagogical goal, the doing of it. The teacher is not just there to correct the answers produced. It is a matter beyond finding the "right" formula. The student must understand and recognize what can be abstracted from a real system, what is essential and what can safely be left out (discussions on the role of the physicist, R.Boire 1983). It can happen that neither student nor teacher has a clear idea of what is going on or what is involved. Both must learn to cope with this.

As I watched students working with computers and physics I was aware that I was learning about learning. Almost everyone enjoyed being taught at Piaget's concrete level, at least at first(Champagne et al. 1980; Renner and Paske 1977). Later the students were drawn toward the formal level. I was most impressed with the way simulations helped to effect this transition.

Bork calls simulations "controllable worlds". Papert calls them "microworlds". (The two are not strictly the same thing. Papert deals more with the style of the programming. The concepts are close if you consider programming activity.) Both see in simulations the ability to concretize procedures (Bork 1984; and Papert 1980:156). Both Berger (1984) and Papert sell the computer as a transitional tool. The computer screen enables one to visualize processes and possibilities. It makes it easy to practise "what if..." questions on procedures as well as parameters.

"Controllable worlds" allow the teacher to provide his class with a common base of experience that can be discussed. For example, not all students have run races that are timed. Most are not able to easily connect the concept of velocity with that of time (Kolodiy 1977). The computer may help by moving things about the screen at different velocities and displaying only time data so that such connections can be made. Better, it may time actual races.

The focus of experiences can be modified if necessary. If the students are trying to get a feel for kinetic energy, races can be run and instead of times, instantaneous kinetic energies can be recorded on the screen. It will be possible for some slow people in the class to win these races if the idea is to produce the highest kinetic energy during the run.

Champagne suggests that computer simulations help students reconceptualize mechanics paradigms.

> "The preliminary results indicate that carrying out simulated experiments in fictitious worlds in which the laws of physics can be modified does indeed, in combination with real-world experiments, encourage students to articulate more clearly the Aristotelian and Newtonian formulations. In addition, after the simulation, students show some indication of differentiating more clearly between the actual physical behaviors of Aristotelian and Newtonian physics." (Champagne et al. 1980.)

The building and molding of computer simulations, then, can supply a Piagetian-like learning environment. Papert assumes "that people learn best if you put them into a situation where they have to work with the domain of knowledge itself...they have to learn about processes and work with them in a very personal and involved way" (Perry interviews Papert 1984). Because of the control aspect he suggests that the student's body image, even kinesthetic sense, can become involved (Luehrmann and Dwyer 1984 also suggest that just using prepared software is not enough). The student engages in compensatory activity, coming to grips with his perception of what should happen and what is actually happening. He is constantly comparing his paradigm of the physics with his paradigm of reality. This spontaneous activity, according to Piaget, is the process by which causal explanations of physical phenomena are developed; "the only means ... at our disposal is a continuous attribution to mental structures, analogs we believe we see again in the real world." (Piaget 1972.)

Another way in which "computer worlds" have modified my methodology is by adding a new type of laboratory experiment.

I am not referring here to the use of the microcomputer as data gatherer or analyser. Nor am I thinking of its use as a prelab experience in the style of Wilson (1979) to familiarize the student with the design, procedure and typical data. Nor is it using the computer, as Chonacky (1981) suggests, as a supplement to stimulate critical thinking and prepare the way for hypothetical and deductive reasoning. This type is more fundamental than that.

When a simulation is used there is a certain loss of scale. Size and time can be distorted and compressed. Students may see numbers without quite knowing what order of magnitude to expect. The example of the chain falling off the side of the desk is a good one here. Should it have taken half a second or two seconds? When a computer gives a student an answer, even if the student knows exactly where his solutions came from and how they were produced, he may not know if the procedures he used were appropriate. How can the student know that the computer screen is right?

This leads quite naturally to the notion of the laboratory as a yardstick on reality. Experimentation becomes the test of the computer model (Patterson 1980). The ultimate authority is not the answer in the back of the book or the computer program, but what can be measured from the real world. The best test of the falling chain simulation is to carefully drop a chain.

It sounds simple, but most students will not try it if left to themselves. The computer answer has the feel of rightness and surety. Reality is messy. How can any measurement technique compare to the precision of the computer? The new "microworld" methods require no more experimental testing than any other approach, but the teacher must be sure to demand no less.

Communication skills

Papert makes a great deal of the new language computerese gives to English (Papert 1980:22-27,155). I have noticed two ways that computer literacy has helped children do physics.

First, there are new words that describe processes. Most students are now familiar with a simple looping procedure whereby a section of programming is repeated a specified number of times. This concept of looping arises often in physics, especially sections dealing with net force or total momentum and energy, integration and the like. I have found that those students who recognize the idea of looping, can more readily interpret the mathematical symbols that code these operations, as processes and not modifiers.

Papert highlights the distinction between propositional knowledge, "knowing that", and procedural knowledge, "knowing how" (Papert 1980:22-23). Physicists, being more concerned with the latter type, benefit when the language is enriched with words that not only deal with procedure descriptions but also include words that (he claims for the first time) describe the processing procedures. Such things as "nesting loops" or "recursive calls" are powerful concepts that would be very difficult to describe to someone who was not familiar with the concepts through their familiarity with the computer. Notice the shift in perspective illustrated in the program, "Elas", if one thinks of a wave as a loop on the activity of one particle, embedded in a loop that spans the medium.

The active term, "debug", describes a process that is often necessary in computer programming. It occurs after the computer lets one know that a mistake has been made. It is an interactive, Piagetian, compensatory activity almost synonymous with programming. The analogous process described by the term "scientific method" is striking.

In addition to learning new information processing capabilities the student, in learning different programming languages; Basic, Pascal and others, learns different processing styles. The difference in style is similar to the way Papert (1980:135) describes science as being less like learning about things, and more like getting to know people . The nature, the depth of what is experienced, is rich enough to be described this way. It is like the difference between learning classical mechanics, statistical mechanics and quantum mechanics, or perhaps the difference between learning thermal dynamics in physics and learning it in chemistry. The student becomes aware that he is not just learning new material but new information processing styles.

Secondly, once the concepts and the language are assimilated by more than one person, communication is enhanced. Papert claims that work with the computer brings to the teacher and the student an increased awareness of their own intellectual processes, i.e. programs, because of the constant need to modify them on the computer (Papert 1980:22,115,137). These new processing skills, he suggests, require new communications skills to discuss them. The student must communicate needs and question the structure of the models he is building. The teacher must be able to understand and respond effectively at the same high level of awareness.

This reminds me of the work of Vigotsky, Bruner and Luria (Stones 1966) where they suggest that, when language is involved, there is a change in the nature of the learning process. I cannot help wondering whether the children who have the background and the vocabulary of computer science internalise the processes of the world in new ways when they learn physics.

Bork (1979:7) believes that educators have only just begun to learn how to use the computer effectively. There is speculation that new expectations may lead to new curricula, and that the new technology affords us a fresh look at the purpose of these curricula (Montreal Gazette 1983).

In conclusion

The use of the microcomputer is not so much to put students in touch with physics, but to help young physicists in some small way, to grasp reality more firmly. Where it has been used, in my experience, it has been a powerful and compelling addition. Those students who participated expressed enthusiasm and enjoyment.

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APPENDIX I

GOOD PHYSICS IN GAMES AND SIMULATIONS

What follows is a concise list of items that will aid the teacher in evaluating computer programs for use in a physics course. These items are most applicable to software of the game or simulation type.

A program should have a specific purpose in the course. The teacher should know not only the content of the course material exercised by the program but also the part it plays in the larger scheme. Will it be used instead of, or in addition to, other material? Does the teacher want it experienced by the entire class, or is it for independent study?

More important perhaps is to decide whether the program is simulating a physical phenomenon or a mathematical model. If its primary purpose is to present a model already removed from the physical reality it is meant to represent, then its value is dubious. Examples of the simulation of a mathematical model are the ray tracing programs which illustrate Newtonian optics and programs which generate electrostatic field diagrams. I see no advantage to these as they are just doing what the student should be practising for himself. In some cases the teacher must decide if it might not be proper to dispense with the computer.

Programs should be imaginative, but the physical realism should still be good enough to provide a substantial metaphor. By all means, test other force laws or pretend the speed of light in a vacuum is 3m/s, but be very sure that the student is aware of the differences between what he sees on the screen and what he would see in the laboratory.

It is sometimes difficult for someone who is familiar with a program to appreciate the degree of complexity it presents to the neophyte. If a program is too confusing it weakens the connection between the presentation and reality. It is better to allow degrees of difficulty chosen by the user, or have levels programmed in some sequence. Very often, when presented with a choice of difficulty, students will immediately opt for the most difficult, become frustrated and walk away. The best way to gauge the difficulty of a program is to try it out on a few of the students it was meant for. Field testing and revision is an important part of the process of software development.

Instructions should be clear and concise. If they are presented by the program, as opposed to a user's guide, bear in mind that the student will only assimilate one sentence per screen. The computer is a speed machine, and the student will most often prefer to miss the information in favor of getting right into the action.

Interactive programs are always better than simulations that the student just sets up and leaves. The student should feel that he is in control or that he is an important part of a process. A program that allows this will not only be more successful but it will be used more often. Personal involvement makes almost any game or simulation more meaningful. Even an inane video game can become a part of a student's concept of self worth if he can compare his score with his friends' scores.

Presentation should take into account that man is more at ease with analog data displays. The programmer's attention to audio and visual displays can enhance the effectiveness a great deal. A dial indicator and a sound of increasing frequency is more effective in showing acceleration than numbers flashing at the bottom of the screen. If numbers are used, try to present them as integers of no more than two or three digits. Long strings of decimals, even if correct, serve only to distract and confuse. Diagrams should be as lifelike as possible. At times the machine will not allow decent graphics. A sine wave of low amplitude will look like a square wave if the screen resolution is not fine enough.

Check the accuracy of the program so that the results are reliable and accurate. Sometimes the model that the program is based upon is only reasonable over a small range of values. It may not correctly handle objects that are required to move at some large fraction of the speed of light, or it may allow accelerations that would break normal materials or crush people. Both the teacher and the student should know how the program reacts to all "what if " activities. The limits of the machine and the model must be known in order to avoid errors, or to appreciate them.

Models should be rich enough to allow other questions to arise beyond those under direct study. It is easy to simulate the motion of a pendulum bob by solving equations that describe a simple harmonic oscillator. Will it properly describe the period of a pendulum at different amplitudes? If the purpose is to illustrate that these are independent then it will certainly work. If the purpose is to investigate the relationship between period and amplitude then it will certainly fail since no pendulum, indeed no real oscillator, will behave so that the two are independent. Should complicated elliptical integrals be used to simulate the motion? Again, only if the point is to show that these complicated things can approximate this motion. Much better would be to set up some simple force law, perhaps allowing for just the tension in the string of the pendulum and gravity, and allow the program to simulate the motion of a particle in accordance with this law. Later the user may wish to add friction of some sort, or perhaps take into account the stretching of the string. This technique is not very difficult and it allows the excitement of seeing the expected results and at the same time, presenting a few surprises.

Remember the example of the program that shows the formation of the image of an object through a lens? Would the program show a halo of color around the image the way any cheap lens would? Always keep in mind that a simulation, no matter how wonderful, is never as rich as reality. Think carefully about allowing a child to pursue questions with a computer. Encourage supplementary or alternative laboratory research where possible. The computer will always give the student an answer. How will he know if it is the right one?

The following appendices contain examples of software packages that have evolved with use in the classroom and with student independent research activities. Only the bare bones of the software are presented in the attendant listings as the students continually and spontaneously modify or suggest modifications, every time they are shown. This is always encouraged as it helps all of the students to appreciate that programs are not locked and untouchable, but are malleable tools, that can be adapted to a student's personal requirements. This causes the student to identify the computer as not just a tool, but his tool, under his control. The computer is now no longer a player of programs, the way a video machine plays tapes. But rather, the computer can be viewed in its rightful function, as the environment in which the student can develop the process that is the solution.

APPENDIX II

KINEMATICS PACKAGE

This package consists of two parts: classroom demonstrations for illustration and practice; and a game which gives students a reason to practise. The demonstrations were written for use on an apple II+ with 48k and paddles. The game does not require paddles.

I used these programs only after the students had measured motions in the laboratory; plotting position, velocity and acceleration versus time graphs. The programs served to give each member of the class the experience of making an "object" on the screen move and simultaneously see the graphs that are used to describe that motion. The programs are meant for each student to use on his own, but I have found that a class demonstration provides useful instruction and piques curiosity.

I began by controlling the object's motion myself with the paddle controllers, making sure to point out what the object on the screen was. The first year I did this, one student had not realized that the little thing running around the top of the screen was in any way related to the graphs below. I explained that the paddle controls the motion of the little thing and the graphs are only a record of how it moved.

There are walls at each side of the screen that limit the distance the object can travel. It was great fun to run the object into them and watch the result on the graph. The discussion that ensued usually highlighted the fact that not many of the students had fully appreciated that, although the motion of the object was side to side on the screen, the graph response was up and down. If the object was held stationary by a wall, the lengthening of the graph line did not indicate motion to the right, but time marching on.

I then ran the object from one wall to the other and asked them to watch where the object was when the graph crossed the zero position axis. A paper arrow was then placed at some arbitrary point on the screen above the pathway of the object. Students were asked to draw in their notes the shape of the position graph as I sent the object again at a uniform velocity across the screen, and indicate on their drawing where it would pass the arrow. This drawing I considered very important as the activity produced a record of what was shown and caused some students to internalize what was being done for them. Leaving the object against a wall, I walked about the class until I was satisfied that all had attempted the graph. I then ran the object across the screen and as it passed the arrow, and stuck a second arrow onto the screen at the point on the graph where the object passed the arrow. From this they corrected their notes if necessary.

A volunteer was then asked to pilot the object so that it stayed underneath the arrow. Without the aid of velocity data, it was suprisingly difficult to get the object to stop. After a few frustrating trials it was time to introduce the second graph.

All of the above, including introduction, discussions and volunteer trials, takes three or four minutes.

Next, the same program (see Listing 1), modified to display the position and the velocity versus time graphs, was shown. Simple changes were made to control which graphs were displayed. Changing line 85 to GOTO 122 would cause no velocity graph to be displayed. Changing line 122 to GOTO 125 would cause the acceleration graph to be skipped. The graphs of forward and backward motions were observed. The slope of the position graph was related to the velocity graph. The slope of the velocity graph was discussed. It was now a relatively simple matter to stop the object and look at the velocity graph. I ran the object from one wall to the other at a constant velocity, and back again at a very irregular velocity and allow the visual comparison of the two areas under the graph.

Showing all of these relationships took, typically, seven or eight minutes.

The same sort of thing was done with the addition of the acceleration versus time graph. Of particular interest was the action of the acceleration graph when the object hit the wall.

No higher time derivatives of position were shown as the acceleration graph is just far enough removed from changes in position to confuse many students. One way to short cut this confusion reaction is to allow them to use the paddle controller themselves to get the feel of it. The way the control is set up, the paddle determines the force on the object, so the acceleration graph is a picture of the force on the object. This seemed to be much more intuitively satisfying to the student.

Showing the acceleration graph relations with slopes and areas took under five minutes.

Now the space game was demonstrated and the graphs and controls were described. The game is based on the demonstration modules. It is used to give the student the feel of frictionless rocket control, and to experience information being transmitted through the motion graphs in an immediate way. It is, in many ways, just another hand-eye coordination video game. The twist is that the link between the hand and the eye includes the graphs. More advanced versions of the game also require the development of strategies to complete time limited tasks.

The basic scenario involves a space shuttle matching the position and velocity of a runaway communications satellite, linking with it, then guiding it into a new, prescribed orbit. This basic game can be made more useful by incorporating any of the enhancements described in the next section. One popular feature was the use of a double call 35095 after line 5200 (Listing 2). This causes the satellite, when normally visible in the viewscreen to become invisible. It blinks on and off the screen, remaining invisible for longer periods as it gets closer to the shuttle. The students called this effect the cloaking device. It forces the students to rely even more heavily on the graphs for information during docking.

These four programs can easily be shown in one class period with time left over for homework assignments. This is not to say that all of them should be used at once. Some twenty percent of the individuals in my classes were quite overwhelmed by the amount of material, and took days to catch up. I found this tolerable only because to another twenty percent of them, it was interesting, exciting or so easy that it was boring. The rest were somewhere in between. These were the ones who could get the most out of independent study, spending time with the program assignments or other assignments with little supervision required.

The assignments can be organized in many ways. The student can be given a set of graphs and asked to describe the motion that they record. A description of a motion can be given and the student would be required to sketch the shapes of the graphs. Perhaps one or two graphs could be shown and the students asked to sketch in the ones that are missing. The students may be encouraged to duplicate the motions described in the assignments on the computer screen to check their answers.

Alternative demonstrations are available. The program can be given a predetermined force law that will govern the motion of the object. This can be done at line 40 in the program listing. The teacher can now demonstrate accelerated motion with or without fricton, simple harmonic motion, accelerated motion with air resistance showing the idea of terminal velocity graphically. The brighter students may find it challenging to program such things for themselves. If the teacher has not the time or the inclination, these students may find it exciting to be given the responsibility of producing these demonstrations for the whole class to see.

The following is a list of suggested enhancements of the core program described in Listing 1:

One idea would be to modify what the paddle controls. Instead of directly programming the paddle to determine the object's acceleration, let it determine the velocity. This lends a whole new feel to the controls. Let it directly control position, as it does in most video games, and watch the unreal accelerations that are produced. It feels very different when the paddle is related to kinetic energy. Any quantity can be represented so that the students can get an intuitive feel for it by watching its graph plotted along with any of the others.

This "getting the feel" of a simulation is especially useful when trying to convey the difference between the so-called Aristotelian and Newtonian systems. Allow games to be played with friction, then play the same game without friction. The experience of being able to turn off friction is very helpful when learning the concepts of net force and free body diagrams.

One simple enhancement that has nothing to do with programming is to draw a dial scale on the paddle. This would help the student control the object's motion until he is more familiar with the interpretation of the graphical information.

A zoom feature would allow closer analyses of selected portions of the graphs with greater accuracy. Adding numbered scales would allow calculations and accuracy checks to be performed. Stop action and slow motion buttons might be a help during demonstrations. A strobe option would leave the track of the object at regular time intervals determined by the user. A vertical cursor could visually align features on one graph with those occurring simultaneously on another. Integrators and differentiators could display numerical relations between the graphs painlessly.

A graphics dump allows the user to stop the action and have a copy of the screen printed on paper for closer inspection. Many printer interface cards support this feature and require one or two buttons to be pressed. This may be a way to produce homework questions, or a way for the student to generate his answer on the screen and hand it in later. If the student encounters something interesting or confusing during his play, he can stop the action, print it out and bring it to class for discussion.

Sound can be used effectively in a number of ways depending on the way the simulation is set up. Pitch can be related to velocity or some motor sound. The sound might also be used to indicate that rockets are firing.

Multiple objects can be moved and tracked with color coordinated graphs. The objects that are moved can be selected by the user, the shapes could have something to do with the type of friction encountered. Spaceships could be used for a frictionless system, while cars and boats and glider planes could be used for systems with friction.

Various vector quantities could be illustrated by drawing arrows off to one side. Velocity or force or both simultaneously could be shown as they occur to show this other method of representation.

Remember that it is the nature of computer games to become boring when they are mastered. By allowing the students to make some of these improvements, they will probably spend far more time practising and critically analysing while debugging their modifications than they would have with any ready-made software.

APPENDIX III

THE TIMER

In its present configuration the counter/timer consists of three phototransistors connected to the paddle input port with the three required 2 000ohm pull up resistors. Amplification and threshold detection are unnecessary with the new TIL81 phototransistors. Light is made to shine on the detectors. When the object of interest passes by, interrupting the beam, the detector signal change is recognized by the computer. Flashlights or ordinary lightbulbs may be used indoors with no concern for background radiation, such as overhead lighting, since the detector is directionally sensitive. In bright sunshine scattered light is a problem. Placing the detectors inside cardboard tubes allows the system to reliably detect changes even when the light sources are placed 8,0m away from the detectors. This is about the width of a running track or a narrow road. Thus the system is capable of timing trucks, bicycles, and people, as well as the usual laboratory paraphernalia.

Detector spacial resolution is of the order of 1mm. With special slits, this resolution can be improved to 0,3mm. The distance from one photogate to the next has been as small as 3,0cm and as large as

75m.

The software support described in Listing 4 begins timing immediately. When the machine language program, Listing 5, detects a change in any of the detectors, it saves the time since the last change and the current on-off configuration of all the detectors, then begins timing again. It can do this for 128 changes. Each such event may have a duration from 0,06ms to three hours. This represents a sampling frequency range up to 16kHz. The accuracy of the timer is only as accurate as the internal clock of the microcomputer. Check the hardware reference manual of the machine in use and be wary of computers that take time out to refresh their dynamic memory.

As the edge of a very slow moving object, less than 0,05m/s, passes a detector, its shadow may cause the system to bounce. This means that the detector will change its signal many times, flipping from on to off and back very rapidly, even though the shadow is passing slowly. This problem can be reduced in a number of ways. Schmidt triggers or various filters could precondition the signal. I preferred to keep the hardware simple and handle the flipflopping data with a software filter. It simply ignores changes that flip back to the previous configuration.

The system has been used in the laboratory to measure students' running speeds. This is a high participation activity which motivates and involves a large number of students. It gives them a feel for the S.I. metric unit. A fast speed is 7m/s for a human. Depending on how many detectors are used it can also get across the idea of approximating instantaneous velocities. On first exposure it is a good idea to space the photogates at equal distances so that the times will immediately show which intervals were faster.

Many motions can be tested with the same setup. Karate chops and tennis swings, pendulum bobs and fan blades have all been measured. Even wave motion in the wave tanks can be timed. The geometry of the detector setup really gives a concrete experience of the difference between propagation velocity, measured with the photogates placed horizontally, and the medium's velocity, measured with the photogates placed vertically just above the surface.

The system gives excellent results measuring the acceleration of falling objects. We dropped five objects three times each, in fifteen minutes. The detectors can be set up many different ways, depending on the strategy the students wish to use. The objects can be dropped from rest or thrown. Timing can be made to start at the moment of release or after the object has fallen an unknown distance. The effects of air resistance are easily apparent and always surprise the students.

We used a similar system to measure the acceleration due to gravity using a pendulum about 6m long, suspended from the ceiling of our gymnasium. It swung with an amplitude of about 10cm for almost one hour. The value found was 9.798m/s/s.

Many other sensors besides photodetectors can be used with this system with no software modification. Magnetic proximity switches or mercury switches can be used. Almost any number of switches or photodetectors can be connected in series. An electret or a carbon microphone can be connected to measure the period of sound vibration. The cheap carbon microphone I used required no amplification. Simple debounced contact switches can be used to measure human reaction times.

The display of the data on the screen is currently in desperate need of modification. The user should be able to select from a number of display modes. Large, easily visible letters and digits should be used when the entire class must see the data. Graph plots of position or velocity versus time would be useful. The ability to produce a printed copy of the data is a must. Students should program this right away.

This is a fun device, do not keep it locked up in the physics laboratory. Offer it, along with a dedicated support team, to your physical education department for running tests on their athletes or for the school's track and field day. Measure motor speeds, or camera shutter speeds. It can even be used to check the pitch of the school's orchestra.

APPENDIX IV

DRAGON PATROL

This game is well described in the text (page 43) and in the instructions found in Listing 6. It was created as an interactive questionnaire, an alternative to the drill and practice programs. It should be made clear that the purpose was to make a game that rewards the good physicist, otherwise the point of some of the questions will be lost. This program will only have appeal to those individuals who find the strategy part of the game interesting and challenging. If a remedial practise or homework package is required, this may not be it. The program was written for an Apple II+ with 48k without an eighty column card. A calculator is handy while playing the game.

The instructions may not make it clear that full S.I. metric format is required for a student's answer to be correct. This means that the units must be proper and the decimal is a comma. Failure to comply will result in game penalties.

The various levels of difficulty affect the number of beasts attacking, and how often they get to move. It also controls how often the more difficult questions are asked (this is set at line 550 in Listing 6). It also determines the duration of some types of penalties. An example of this is found on line 5060 in the listing.

Pressing the control "D" button causes the screen to be printed on the printer to copy sample questions for practice or discussion.

Sample questions from vector kinematics, polar coordinates and wave mechanics are included in the program Listing. These may be modified, deleted, or added to. At the beginning of each new chapter in the textbook, a new version of this game could be circulated so that students could see what is coming up, or practise for tests.

Questions are added as subroutines at lines 1000, 2000, 3000, etc. The samples in Listing 6 illustrate the various programming options available.

Question one requires no response from the player. After a delay, set in line 1020, it returns to the main program automatically. Subroutine 994 is the time delay routine. Q tells the main program that the question was answered correctly.

Question two shows how to ask a question that just requires a key word as an answer. If it is chosen, Q is set to 1. If the wrong word is chosen, Q is set to 0.

Question three shows the use of two important subroutines. Subroutine 964 is used to take in the student's answer. Subroutine 946 separates the student's answer into a numerical part, called NM, and the units, called UN$. In line 3050 the accuracy of the numerical part of the answer is checked. In line 3060 the units are checked.

Question five is interesting in that the penalty sets the value of a parameter called F. The value of F determines the number of turns that the beast will be invisible to the player. This leads to some interesting situations when, later on, a vector question requires the position of the beast. The ES seen in this and other questions represents the level of difficulty of the game. The programmer may wish to take this into account when asking a question or deciding upon a penalty.

Any number of questions may be stored, limited only by the memory capacity of the computer, or its virtual disc memory. Once the question subroutines are in place the main body of the program must be told where to find them. This is done from line 510 to 520 in the example listing. The questions are chosen at random by line 500. If more than seven questions are being used, be sure to change the range of line 500 so that it can choose higher numbers.

APPENDIX V

ELAS

This program is one of a number of simulations produced by students just for fun. The idea of presenting this one here is to show an example of the power of a very simple simulation technique. The author, Tom Ford, uses point to point modelling to simulate the tensions in an elastic cord so that a disturbance of some sort will propagate, allowing the wave motions to be studied. A large number of simplifications were made. Even so, the wide application of the program to a great many wave phenomena and the fact that, crude as it was, the program did produce measurements that were accurate enough to hint at proper mathematical relationships, made this simulation an invaluable learning tool for Tom and many of his friends.

Some of the phenomena that were considered are mentioned briefly in the text (pg. 45). The Listing 7 shows the basic program configured to model a uniform elastic cord which has its right hand end fixed. Of course it is not really uniform, it is a series of discrete points connected one to another by a force law. Forces caused by tensions in the cord produce an acceleration of some particles of the medium which in turn cause the velocity to change. The new velocity of each particle is calculated according to the sum of the forces acting upon it in lines 240 and 260 of the listing. Note that in this instance the force is directly proportional to the distance between particles. This means that there is tension in the cord at the outset.

A disturbance can be introduced at the left hand side of the cord by moving the left hand end of the cord with a joystick controller. Transverse, longitudinal, or any strange wave form can be described at this end. The disturbance will propagate down the length of the cord with a speed that depends mainly on the tension in the cord, which is controlled by the choice of a variable, K. When a pulse encounters the fixed end, reflection occurs. The action of this reflection occurs slowly enough for detailed study.

To modify the program to model free end reflection, allow the calculation of the new velocity and position of the right hand end point. Changing line 280 to read FOR I = 1 TO N, and inserting a line 275 YY(N) = YY(N) + K * (Y(N-1) - Y(N)), will do the job.

Transmission and reflection from one medium to another is accomplished by changing the constant, K, half way down the cord. Inserting a line 234 IF I = 1 THEN K = K1, and a line 235 IF I = INT(N/2) THEN K =

K2, will change the spring constant from K1 to K2 at the half way point. It is not the most elegant, nor is it the most efficient way to program it, but it is simple, and it works.

Interference of waves can be simulated by programming pulses at each end of the cord simultaneously.

Nonlinear force laws can be simulated by changing lines 240 and 250 appropriately. Water waves can be investigated in this way, but it is difficult to choose the proper force relationships.

One good suggestion, made by one of Tom's friends, was to highlight one or two particles of the medium so that its individual motion might be tracked more easily. This illustrated very well some basic distinctions between the motion of the medium and the motion of the disturbance through the medium. Stop action, slow motion and strobe tracking capabilities associated with the highlighted particles would be useful classroom demonstration tools. The ability to print selected frames on a printer would allow a student to build an action sequence similar to that produced using high speed strobe photography.

Relationships between propagation velocity and various things like tension, amplitude, shape or medium velocity can easily be studied with reasonable accuracy. Remember that certain concessions were made against accuracy for the sake of simplicity. Even so, it was clear that propagation velocity was not simply proportional to the tension in the spring. The data can suggest whether it is proportional to the tension squared, or the square root of the tension.

Note that the choice of K, a constant related to the tension in the cord, implicitly affects the accuracy of the simulation by changing the size of a particle's displacement in each time interval. In this simple model, no provision for increasing the time resolution of the simulation had been included. A "K" value greater than 1 produces instabilities in disturbances that increase in amplitude.

There is also a blinking, ripple effect that is an artifact caused by the way the program updates positions on the screen. It can be eliminated entirely by drawing the new positions on a second, internal screen display memory area and switching between the two displays.

An experienced programmer is not the same as an experienced physicist. Roundoff error and errors caused by the discretization of the medium will accumulate as the simulation progresses. The programmer can also choose to approximate the new position of a particle by adding the new velocity times one time interval to the old position. This crude approximation has only speed of calculation in its favor. The students certainly saw that something was wrong because of the way "wavey junk" accumulated behind the original pulse. They attributed this junk to dispersion, a new idea to them, and one about which little is written at the high school level. So they spent a lot of time studying soliton propagation and trying to find a software filter to eliminate the dispersion as it occurs. I did not feel that it was my place to curtail this activity because I found it instructive for them, and because of the impact it would have in the field of communications theory should they succeed.

If the program is found to run too slowly, it may be compiled or rewritten in machine language. Such a machine language program was written by Christopher Pratley, a student in the same graduating class as Tom. The increase in speed was spectacular, but the accumulation of junk increased as well. These kinds of tradeoffs in time, accuracy and ease of modelling are always made in any attempt to produce a new model in physics. At the high school level, they are encountered most keenly when building computer simulations.

APPENDIX VI

ELECTRONICS BIBLIOGRAPHY

The following were used in the design of various prototype timing systems, one of which is described in Appendix III.

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APPENDIX VII
SELECTED PROGRAM LISTINGS

Listing 1

```
11  REM
12  REM    KINEMATICS
13  REM
14  HOME
15 P2 = XX * PCOEFF + 20:V2 = (A1 + A2) * .2 + V1: IF  ABS
(V2) > 2.01 THEN V2 = 2. *  SGN (V2)
16 PCOEFF = 48 / 255
17  HGR
18 T1 = 0
19  HCOLOR= 1
20  HPLOT 0,7 TO 279,7
21  HPLOT 0,4 TO 279,4
22  HPLOT 0,45 TO 279,45
23  HPLOT 0,115 TO 279,115
24 P1 = 45:X0 = 130:A1 =  PDL (0) / 63.75 - 2:V1 = 0
25 V0 = 115:A0 = 170
26  HPLOT 0,170 TO 279,170
27  HCOLOR= 3
28  REM
29  REM       MAIN
30  REM
39  FOR I = 0 TO 558
40 A2 =  PDL (0) / 500 - 0.25
44  IF XX = 278.4 AND A2 > 0 THEN A2 = 0
46  IF XX = 1 AND A2 < 0 THEN A2 = 0
50 V2 = (A1 + A2) * .2 + V1: IF  ABS (V2) > 2.01 THEN V2 = 2.
*  SGN (V2)
61 XX =  INT (V1 + V2 + .5) * 0.75 + X0
63  IF XX > 278.5 THEN XX = 278.4:V2 = 0:P2 = 16: GOTO 66
64  IF XX < 0.9 THEN XX = 1:V2 = 0:P2 = 71: GOTO 66
65 P2 = 70 - XX * PCOEFF
66  HPLOT XX,1 TO XX,3
68  IF  INT (XX) =  INT (X0) THEN  GOTO 79
69  HCOLOR= 3
70  HCOLOR= 0
72  HPLOT X0,1 TO X0,3
74  HCOLOR= 3
79 T2 = T1 + .5
80  HPLOT T1,P1 TO T2,P2
85  REM   VELOCITY PLOT
90 VP = 115 - V2 * 7.4
100  HPLOT T1,V0 TO T2,VP
115  IF V2 - V1 > .28 THEN A2 = .3
120  IF V2 - V1 <  - .28 THEN A2 =  - .3
122  REM  ACCELERATION PLOT
123 AP = 170 - A2 * 50
124  HPLOT T1,A0 TO T2,AP
```

```
125 X0 = XX:T1 = T2:V0 = VP:A1 = A2
130 P1 = P2:V1 = V2:A0 = AP: NEXT I
135  PRINT  CHR$ (7)
136  VTAB 22: HTAB 5: PRINT "AGAIN ? ";
140  GET A$: IF A$ = "N" THEN  TEXT : HOME : END
145  HOME
150  GOTO 17
```

Listing 2

```
100  REM
110  REM
120  REM         SPACE DOCK
130  REM
140  REM   CREATED BY BRAD MOFFAT
150  REM         JULY , 1981
160  REM       MONTREAL, QUEBEC
170  REM
180  REM
1000  PRINT  CHR$ (4);"BLOAD STARMY"
1010  HIMEM: 36000
1020  POKE 232,113: POKE 233,137: REM  SHAPE TABLE ($8971) IN
$E8,$E9
1030 VD% = 0:LE% = 5000:CE% = 5000
1040  SCALE= 1
1050  REM    DEFINE VARIABLES
1060 PO = 2000:V = 0
1070 ZP = 156:PF = 43:SP = 109
1080 TO = 3:PP = 500:SE = 63:FOUR = 4:LO% = 0
1090 HS% = 127:EV% = 12:ZV = 85:VF = 45 / 66
1100 TZ = 150:TF = 132 / 156:VT = 152
1110 VO = ZV:V2 = ZV - 12 * VF
1120 BV = TZ + 6
2000  REM   TURN ON GRAPHICS
2010  HOME : VTAB 22
2020  HGR
2030  HCOLOR= 3
2040  REM
2050  REM   DRAW FIELD
2060  REM
2070  REM
2080  REM   THE SCREEN
2090  HPLOT 8,0 TO 271,0 TO 271,53 TO 8,53 TO 8,0
2100  REM   ITS BORDER
2110  HPLOT 11,3 TO 268,3 TO 268,50 TO 11,50 TO 11,3
2120  REM   PLOT FIELD
2130  REM  POSITION FIELD
2140  HPLOT 2,62 TO 149,62 TO 149,157 TO 2,157 TO 2,62
2150  REM   VEL FIELDS
2160  HPLOT 151,62 TO 277,62 TO 277,109 TO 151,109 TO 151,62
2170  HPLOT 151,111 TO 277,111 TO 277,157 TO 151,157 TO
151,111
2180  REM   THE SHIP
2190  HPLOT 144,29 TO 142,26 TO 139,26 TO 136,29
2200  REM  BOTTOM OF SHIP
2210  HPLOT 144,27 TO 142,30 TO 139,30 TO 136,27
3000  REM
3010  REM
3020  REM   CHECK STROBE
3030  REM
```

```
3040 X =  PEEK ( - 16384)
3050  POKE  - 16368,0
3060  IF X = 174 THEN  GOTO 3120
3070  IF X = 172 THEN  GOTO 3160
3080  REM  "L"  LOCK ATTEMPT
3090  IF X = 76 THEN  GOTO 3180
3100  IF (X =  ASC ("K") OR X =  ASC ("U")) AND LK% = 1 THEN
LK% = 0: PRINT  CHR$ (7)
3110  GOTO 4050
3120  REM
3130  REM  ">"
3140 V = V + 1: IF V > 32 THEN V = 32: GOTO 4050
3150  GOTO 4050
3160  REM  "<"
3170 V = V - 1: IF V <  - 32 THEN V =  - 32
3175  GOTO 4050
3180  IF LK% = 0 AND CE% = HS% + 1 AND EV% = V THEN LK% = 1:
PRINT  CHR$ (7): GOTO 4050
4000  REM
4010  REM
4020  REM                              SHIP
4030  REM
4040  REM
4050 X = 0: REM  REQUIRE NEW REQUEST
4060  REM   UPDATE         P
4070 P = P0 + V: IF P > 4000 THEN  GOTO 10000
4080  IF P < 0 THEN  GOTO 10000
4090  REM
4100  REM   UPDATE          PS
4110 PS = ZP - P / PF
4120  REM   UPDATE          STAR DIFF
4130 VD% = PP - P / FOUR:PP = PP - VD%
4140  REM   UPDATE VELOCITY
4150  REM
4160 V1 = ZV - V * VF
4170  REM   UPDATE TIME AND
4180  REM    PLOT P,V FOR      SHIP
4190 T = T0 + 1: IF T > 148 THEN  GOTO 9000
4200 TV = T * TF + TZ
4210  HPLOT VT,V0 TO TV,V1
4220  HPLOT T0,SP TO T,PS
5000  REM
5010  REM
5020  REM                               ENEMY
5030  REM
5040  REM
5050  IF LK% = 1 THEN EP% = P:EV% = V:ES = PS:CE% = 1 + HS%:
GOTO 5130
5060 EP% = EP% + EV%: IF EP% < L0% THEN  GOTO 10000
5070  IF EP% > 4000 THEN  GOTO 10000
5080 ES = ZP - EP% / PF
5090 CE% = EP% / FOUR - PP + HS%
5100  REM
```

```
5110  REM    UPDATE VEL.'S
5120  REM
5130 V3 = ZV - EV% * VF
5140  REM
5150  REM    UPDATE  GRAPHICS
5160  REM
5170  REM   STARS
5180  CALL 34992
5190  REM   ENEMY
5200  CALL 35095
5210  REM    ENEMY'S
5220  REM     UPDATE GRAPHICS
5230  REM    CHECK END OF FIELD
5240  HCOLOR= 2
5250  HPLOT TO,SE TO T,ES
5260  HPLOT VT,V2 TO TV,V3
5270  HCOLOR= 0
5280 BT = T + 4: IF BT > 148 THEN BT = BT - 145
5290  HPLOT BT,63 TO BT,156
5300 BV = BV + 1: IF BV > 276 THEN BV = TZ + 2
5310  HPLOT BV,63 TO BV,108
5320  HCOLOR= 3
6000  REM   UPDATE ALL VARIABLES FOR
6010  REM   NEXT MAIN LOOP
6020  REM
6030 TO = T: REM     EVERY 2ND ??
6040 VT = TV:V0 = V1:V2 = V3
6050 SP = PS:PO = P
6060 SE = ES:LE% = CE%
6070  GOTO 3020: REM  MAIN LOOP !
9000  REM     T SCROLL
9010 TV = 152
9020 T = 3
9030  HCOLOR= 0
9040  HPLOT TV,63 TO TV,108
9050  HPLOT T,63 TO T,156
9060  HCOLOR= 2
9070  HPLOT 152,V3
9080  HCOLOR= 3
9090  HPLOT T,PS
9100  HPLOT 152,V1
9110  GOTO 6000
10000  REM
10010  REM    BOOM !
10020  REM
10030  END
```

Listing 3

```
*******************
*                 *
*  STAR SHIFTER   *
*
*******************
*
           ORG $88B0
*
*
VD         EQU $FB
VERT       EQU $FA
VPOINT     EQU $69
HCOLOR     EQU $F6F0
HPLOT      EQU $F457
EHX        EQU $FC
HPOSN      EQU $F411
XDRAW      EQU $F65D
*
*
           LDY £$03         FIND VD
           LDA (VPOINT),Y
           STA VD
*
           LDX £$00
           JSR HCOLOR
*
           JSR STARS
*
           LDX £$03
           JSR HCOLOR
*
           JSR UPDATE
           JSR STARS
           RTS
*
STARS      LDY £$00
           CLC              FOR ADDING (CPY DOES REST)
NEXT       INY
           LDA STAR,Y
           STA VERT
           DEY
           LDA STAR,Y
           ADC £$0C
           TAX
           INY
           TYA
           PHA
           LDA £$00
           ADC £$00
           TAY
```

```
          LDA VERT
          JSR HPLOT
          PLA
          TAY
          INY
          CPY £$16
          BNE NEXT
          RTS
*
UPDATE    LDY £$00
          CLC               FOR ADD (CPY DOES REST
PLUS      LDA STAR,Y
          ADC VD
          STA STAR,Y
          INY
          INY
          CPY £$16
          BNE PLUS
          RTS
*
*  STAR DATA TABLES FOLLOW   *
*
STAR      DFB 12,35,37,20,67
          DFB 45,97,11,106,37
          DFB 122,17,162,8,177
          DFB 35,207,23,242,41,251,19
*
*   ENEMY UPDATE
*
          LDY £$9
          LDA (VPOINT),Y
          BNE NOXPLOT
          INY
          LDA (VPOINT),Y
          STA EHX
          CMP £$00
          BEQ NOXPLOT
          CMP £$01
          BEQ NOXPLOT
          CMP £$FF
          BEQ NOXPLOT
          LDX £$0
          JSR HCOLOR
          JSR ENEMY
          LDX £$3
          JSR HCOLOR
NOXPLOT   LDY £$10
          LDA (VPOINT),Y
          BNE NOPLOT
          INY
          LDA (VPOINT),Y
          STA EHX
          CMP £$00
```

```
         BEQ NOPLOT
         CMP £$01
         BEQ NOPLOT
         CMP £$FF
         BEQ NOPLOT
         JSR ENEMY
NOPLOT   RTS
*
 ENEMY   LDA EHX
         LDY £$00
         CLC
         ADC £$0C
         TAX
         BCC YO
         LDY £$01
YO       LDA £$21
         JSR HPOSN
         LDY £$89
         LDX £$75
         LDA £$0
         JSR XDRAW
         RTS
*
*   SHAPE TABLE
*
         DFB 01,00,04,00
         DFB $27,$0D,$36,$1F,$04,00
*
```

Listing 4

```
12  REM
14  REM     TIMER  BASIC PROGRAM
16  REM
18  HOME
20 D$ =  CHR$ (4)
30  PRINT D$;"BLOAD HL£3"
40  DIM H%(128),L%(128),C$(128),T(128)
45  DIM T1(128),C1$(128)
46 X$ = "XXX"
47  GOTO 2000
50  PRINT : PRINT : PRINT : PRINT "READY ";: GET Z$: PRINT Z$
60  CALL 768
62  FOR I = 0 TO 128: GOSUB 1000: IF I < 3 THEN 64
63  IF T1(I) = 1 AND T1(I - 1) = 1 AND T1(I - 2) = 1 THEN 65
64  NEXT I
65 C = 2:C$(0) = "XXX":C$(1) = "XXX":X$ = "XXX"
66 N1 = 0:N2 = I - 1: GOTO 75
67  PRINT : PRINT : PRINT
70  INPUT "DISPLAY N1 TO N2 ";N1,N2
72  HOME
75  FOR I = N1 TO N2
90 TI = T1(I) * .06079 - .030395: IF TI < 0 THEN TI = 0
91  PRINT I; SPC( 3 + (I < 100) + (I < 10));C1$(I): PRINT
SPC( 11);" TIME = ";TI;"MS"
95  IF  PEEK (49152) > 127 THEN  POKE (49168),0: GOTO 123
96  POKE 49168,0
100  NEXT I
123  PRINT : PRINT "LIST, CNTRL LIST, FILTER, RUN, STOP ?";:
GET Z$: PRINT Z$
124  IF Z$ = "R" THEN 2000
130  IF Z$ = "S" THEN  TEXT : STOP
135  IF Z$ = "F" THEN  GOSUB 1079
142  IF Z$ = "L" THEN N1 = 0:N2 = 128: PRINT : GOTO 75
145  IF Z$ = "C" THEN  GOTO 67
150  PRINT  CHR$ (7): PRINT : GOTO 123
1000 T1 = L%(I) - 256 *  INT (L%(I) / 256)
1010 TM = H%(I) * 256 + T1 + 1
1020 BB =  INT (L%(I) / 256)
1030 BB$ =  STR$ ( INT (BB / 4)) + " "
1035  IF  INT (BB / 4) = 1 THEN ZB$ = "£ "
1036  IF  INT (BB / 4) = 0 THEN ZB$ = "- "
1040 BB = BB - 4 *  VAL (BB$)
1050 BB$ = BB$ +  STR$ ( INT (BB / 2)) + " "
1055  IF  INT (BB / 2) = 1 THEN ZB$ = ZB$ + "£ "
1056  IF  INT (BB / 2) = 0 THEN ZB$ = ZB$ + "- "
1060 BB = BB - 2 *  INT (BB / 2)
1069  IF BB = 1 THEN ZB$ = ZB$ + "£"
1070 BB$ = BB$ +  STR$ (BB)
1071  IF BB = 0 THEN ZB$ = ZB$ + "-"
1072 T1(I) = TM:C1$(I) = ZB$
```

```
1074  RETURN
1079 C = 2: FOR I = 2 TO 128
1080  IF C1$(I - 2) = C1$(I) THEN TT = TT + T1(I): GOTO 1210
1090 T(C) = TT + T1(I):TT = 0
1200 C$(C) = C1$(I):C = C + 1
1210  NEXT I
1215 C$(1) = C1$(1):T(1) = T1(1)
1220  FOR I = 1 TO C - 2: PRINT I; SPC( 3 + (I < 100) + (I <
10));C$(I): PRINT  SPC( 11);" T= ";T(I) * 6.079E - 2;"MS":
NEXT I
1230  RETURN
2000  FOR I = 0 TO 128:L%(I) = 0:H%(I) = 0:C$(I) = X$:T(I) =
0: NEXT I
2004  FOR I = 0 TO 128:T1(I) = 0:C1$(I) = X$: NEXT I
2005 TT = 0:C = 2
2010  GOTO 50
```

Listing 5

```
*
*   ASM AS PBTMLP FOR USE IN BEAM TIMER
*
*   BRADLEY J. MOFFAT
*   MONTREAL, QUEBEC
*   AUG. 1982
*
        ORG $300
*
LST     EQU $0450       DUMMY SPACE FOR
PNT     EQU $0452       FLYING POINTERS
*
KEYDATA EQU $C000
KEYCLR  EQU $C010
B1      EQU $C061
B2      EQU $C062
B3      EQU $C063
OLD     EQU $FD
OLD2    EQU $FE
TM3     EQU $FC
*
BELL    EQU $FF3A
CLK     EQU $C03A
*
        CLC
        LDA $6B         START OF ARRAY
        ADC £7
        STA TIME+1
        STA MORE+2
        LDA $6B+1
        ADC £0
        STA TIME+2
        STA MORE+3
*
        CLC
        LDY £2
        LDA ($6B),Y     SECOND ARRAY
        ADC TIME+1
        STA ST3+1
        INY
        LDA ($6B),Y
        ADC TIME+2
        STA ST3+2
*
*
        LDX £1
        LDY £0
        STY TM3         INIT TM3
        LDA £$E0
        STA OLD         INIT OLD
```

```
          STA OLD2
*
LOOP      ROL B2         FORM CONFIGURATION
          LDA B3         0=ON
          ROR A          1= BLOCKED
          ROL B1         PB1PB2PB3
          ROR A          LAST 5 BITS
          AND £$E0       CLEARED FOR
          CMP OLD        TM3 BITS
          BNE CHNG
          NOP            WAIT FOR
          NOP            SECOND CMP
          NOP            AT CHNG
*
TIME      INC LST,X      COUNT ANOTHER TIME UNIT
          BEQ MORE
          LDA KEYDATA    CHECK FOR
          STY KEYCLR     END REQUEST
          BMI OUT
          BMI OUT        WAIT FOR
          NOP            MORE AND MOST
          BPL TW
MORE      DEX
          INC LST,X
          BEQ MOST
          INX
          NOP            WAIT 5 CYCLES
          BNE TW
MOST      INX
          INC            TM3 INC TM3
TW        NOP            WAIT
          BNE LOOP       GO AGAIN
*
CHNG      CMP OLD2
          BEQ TIME
          PHA            UPDATE OLD
          LDA OLD        AND
          STA OLD2       OLD2
          PLA
          STA OLD
          EOR TM3        SAVE TM3 WITH CNFG.
ST3       STA PNT,X
          INX
          BEQ OUT
          INX
          STY TM3        WIPE TM3 AND WAIT
          BNE LOOP
*
OUT       STX KEYCLR     END GRACEFULLY
          JSR BELL
          RTS
```

Listing 6

```
11  REM
12  REM
13  REM     DRAGON PATROL
14  REM
15  REM
100  DIM S(4),W(4),C(8)
102  DEF  FN X(B) =  INT (( INT (B) - 1) * 3 + 15)
104  DEF  FN Y(B) =  INT (17 - ((B -  INT (B)) * 10 - 1) * 2 -
.00005)
106  POKE 34,0: POKE 33,40
108  HOME
110  GOSUB 308
112  POKE 34,16: HOME : INPUT " LEVEL OF DIFFICULTY (1 TO 10)
= ";ES$
114 ES =  VAL (ES$): IF ES < 1 OR ES > 10 THEN 112
116  IF ES < 6 THEN ES$ = "E"
118  GOSUB 120: GOTO 132
120  POKE 34,0: HOME
122  VTAB 2: HTAB 9: PRINT "*****************"
124  HTAB 10: PRINT "COMMAND CENTRAL"
126  HTAB 9: PRINT "*****************"
128  PRINT : PRINT
130  RETURN
132  PRINT : PRINT : PRINT "   BEASTS HAVE BEEN DETECTED
LEAVING"
134  PRINT "THE WOODS HEADING TOWARD OUR CITY."
136  PRINT
138  FOR I = 1 TO 100:R =  RND (1): NEXT
140  PRINT : PRINT "   YOU, IN YOUR CAPACITY AS SCIENCE
142  PRINT "OFFICER, HAVE BEEN CHOSEN TO DIRECT"
144  PRINT "THE DEFENCE OF OUR COMMUNITY."
146  PRINT
148 S(0) =  INT (4 *  RND (1) + 1) * 2 + .8:P5 = 1
152 S(1) =  INT (4 *  RND (1) + 1) * 2 - .1: FOR I = 1 TO
8:C(I) = I: NEXT
154  FOR J = 1 TO 4:I = I - 1:R =  RND (1) * I + 1:W(J) = C(R)
+ .2 - .2 * (C(R) / 2 -  INT (C(R) / 2))
156 C(R) = C(I): NEXT
160  PRINT : HTAB 3: PRINT " DO YOU REQUIRE INSTRUCTIONS ";
162  INPUT Z$: IF  LEFT$ (Z$,1) = "N" THEN 210
164  IF  LEFT$ (Z$,1) <  > "Y" THEN  VTAB 20: HTAB 1: GOTO 160
166  POKE 34,7: HOME
168  PRINT "   FOUR GROUPS OF AGENTS ARE AT YOUR ": PRINT
"COMMAND. EACH GROUP IS LED BY A KNIGHT."
170  PRINT : PRINT "   COMMAND CENTRAL WILL INDICATE ": PRINT
"THE MOVEMENTS OF THE BEAST AND": PRINT "THE POSITION OF YOUR
AGENTS TO YOU"
172  PRINT "ON A HIGHLY SCHEMATIZED GRID SYSTEM."
```

```
174  PRINT : PRINT "   EACH GRID UNIT REPRESENTS A ": PRINT
"KILOMETER SQUARE OF TERRITORY. YOU": PRINT "WILL HAVE TO RELY
ON YOUR AGENTS' ": PRINT "FIELD REPORTS FOR DETAILS OF THE ":
PRINT "TERRAIN."
176  PRINT : PRINT "   TOUCH A KEY WHEN YOU ": PRINT "   ARE
READY TO CONTINUE. ";: GET Z$: PRINT Z$
178  HOME : PRINT "   WE ARE NOT SURE OF THE LEVEL OF": PRINT
"SOPHISTICATION OF THE DRAGONS SO": PRINT "WE ARE TAKING NO
CHANCES. EACH ": PRINT "KNIGHT LEADING A GROUP HAS BEEN "
180  PRINT "INSTRUCTED TO CHECK ALL COMMUNICATION": PRINT
"FROM YOU WITH COMMAND CENTRAL AS A": PRINT "PRECAUTION. IF
THE BEASTS BROADCAST": PRINT "MISLEADING DATA OR CONFUSING
ORDERS": PRINT "AGENTS WILL DISREGARD THESE ORDERS."
182  PRINT : PRINT "   THEY WILL NOT OBEY A COMMAND": PRINT
"TO RETREAT."
184  PRINT : PRINT "   TOUCH A KEY WHEN YOU ": PRINT "   ARE
READY TO CONTINUE. ";: GET Z$: PRINT Z$
186  HOME : PRINT "   IN COMPLIANCE WITH THE": PRINT
"FEDERATION'S NON-AGGRESSION PACT WITH": PRINT "OTHER SENTIENT
LIFE FORMS YOUR AGENTS"
188  PRINT "CARRY NO WEAPONS. "
190  PRINT : PRINT "   THEY ARE WELL SHIELDED (CODE NAME":
PRINT "SHINING ARMOR). YOU NEED ONLY TO ": PRINT "INSTRUCT
YOUR MEN TO BAR THEIR WAY": PRINT "TO DRIVE THEM OFF."
192  PRINT
194  PRINT : HTAB 3: PRINT "DO YOU NEED TO BE SHOWN THE ":
HTAB 3: PRINT "GRID VECTOR SYSTEM ";: INPUT Z$: IF  LEFT$
(Z$,1) = "N" THEN 210
196  IF  LEFT$ (Z$,1) <  > "Y" THEN  VTAB 18: HTAB 1: GOTO 194
198 IN = 12: GOSUB 806: GOSUB 328
200  PRINT "AS AN EXAMPLE": PRINT "THIS GRID": PRINT "POINT
IS":TIME = 1000: GOSUB 994
202  POKE 33,39: VTAB 8: HTAB 22: INVERSE : PRINT "X": NORMAL
: POKE 33,13: POKE 34,11: HOME : GOSUB 994: GOSUB 994
204  PRINT " (3,5)": POKE 33,39: VTAB 19: HTAB 1: GOSUB 994:
PRINT "IT IS EAST 3 KM AND FORWARD 5 KM.": GOSUB 994: GOSUB
994
206  PRINT : PRINT " TOUCH A KEY WHEN READY ";: GET Z$: PRINT
Z$;
208 IN = 0
210  GOSUB 120: VTAB 10: HTAB 12: INVERSE : PRINT " GOOD LUCK
": NORMAL
212 TIME = 1500: GOSUB 994
214  GOSUB 806
216  FOR M = 1 TO 4:C(M) = 0: NEXT
218  FOR M = 1 TO 4:I1 =  INT (W(M) / 2 + 0.5):C(I1) = C(I1) +
1: NEXT
220 I2 = 3
222 G = 0:I2 =  INT (I2 - 1):U = 0: IF ES > 8 AND I2 > 1.5
THEN I2 =  INT (I2 - 1)
224  IF ES < 6 AND ES > 3 AND I2 > 1.5 THEN I2 =  INT (I2 - 1)
226  IF I2 > 0 THEN B = S(0)
228  IF I2 = 0 THEN B = S(1):I2 = 3
```

```
230  FOR I = 1 TO 4: IF C(I) = 0 THEN G = I * 2: GOTO 234
232  NEXT
234  IF G = 0 THEN 280
236 B1 = B - 1.1: IF G > B THEN B1 = B1 + 2
238  GOSUB 250
240  IF K = 1 THEN  GOTO 316
242 B1 = B1 + 0.2: GOSUB 250: IF K = 1 THEN  GOTO 316
244 B1 = B1 + 1.8: IF G > B THEN B1 = B1 - 4
246  GOSUB 250: IF K = 1 THEN 316
248 B1 = B1 + .2: GOTO 300
250  REM
252 BH = 0:K = 1: IF B1 < 1.1 OR B1 > 8.9 THEN K = 0: RETURN
254  FOR J = 1 TO 4: IF  ABS (B1 - W(J)) < 0.05 THEN K = 0:
RETURN
256  NEXT
258  FOR J = 0 TO 1: IF  ABS (S(J) - B1) < 0.05 THEN K = 0:BH
= 1: RETURN
260  NEXT
262 L1 =  INT (I2 / 3): IF K = 1 THEN S(L1) = B1
264 T = B1 -  INT (B1): IF T > 0.805 THEN U = 9:K = 0
266  IF T < 0.2 THEN  GOTO 892
268 LS = 0
270  FOR J = 1 TO 4:T2 = W(J) -  INT (W(J)): IF T2 < T - 0.05
THEN LS = LS + 1
272  NEXT
274  IF LS > 1.1 THEN  RETURN
276  IF ( INT (B1) < 1.9 OR  INT (B1) > 7.8) AND LS > 0.5 THEN
RETURN
278  GOTO 892
280  REM
282 T = 2 *  RND (1): IF T < 1 THEN T = 1: GOTO 286
284 T =  - 1
286 B1 = B - 0.1 + T: GOSUB 250: IF K = 1 THEN  GOTO 316
288  IF B1 < B THEN B1 = B1 + 2: GOTO 292
290 B1 = B1 - 2
292  GOSUB 250: IF K = 1 THEN 316
294 B1 = B1 + 0.2: GOSUB 250: IF K = 1 THEN 316
296  IF B1 < B THEN B1 = B1 + 2: GOTO 300
298  IF B1 > B THEN B1 = B1 - 2
300  GOSUB 250: IF K = 1 THEN 316
302  IF U = 9 THEN 844
304  IF ES < 8 THEN TP$ = "TRAPPED": GOTO 320
306  IF (I2 < 3 AND BH <  > 1) OR I2 > 2 THEN TP$ = "TRAPPED"
307  GOTO 320
308  VTAB 2: HTAB 9: PRINT "*****************": HTAB 10: PRINT
" DRAGON PATROL ": HTAB 9: PRINT "*****************"
310 B$ = "           ": INVERSE : VTAB 7: FOR I = 1 TO 7: HTAB
12: PRINT B$: NEXT
312  FOR I = 1 TO 3: VTAB 10: HTAB (I * 3 + 9):TIME = 700:
PRINT "£*£";: GOSUB 994: HTAB (I * 3 + 9): PRINT "   ";: NEXT
314  NORMAL : RETURN
316  REM
318  GOSUB 746
```

```
320  IF ES < 6 AND ES > 3 THEN 324
322  IF I2 = 1 THEN 222
324 O1 = 0:O2 = 0:FC = 0
326  REM
328  POKE 33,13: POKE 34,0: HOME
330  PRINT "************"
332  PRINT "  COMMAND"
334  PRINT "  CENTRAL"
336  PRINT "************"
338  PRINT : PRINT
340  IF IN = 12 THEN  RETURN
342  IF TP$ = "TRAPPED" THEN  PRINT "CAREFUL. HE": PRINT "IS
TRAPPED.": PRINT "YOU MUST": PRINT "DRIVE HIM": PRINT "AWAY
!": PRINT :TP$ = " "
344  IF F > 0 THEN  PRINT "  WE ARE": PRINT "EXPERIENCING":
PRINT " FREQUENCY": PRINT " PROBLEMS.": PRINT " WE HAVE":
PRINT " LOST THE": PRINT " DRAGON!": PRINT
346  IF F > 0 AND FC < 1 THEN F = F - 1:FC = 2
348  IF O1 <  > 0 THEN  PRINT "WE HAVE LOST CONTACT WITH ";O1;
350  IF O2 <  > 0 THEN  PRINT " AND ";O2;
352  IF O1 <  > 0 THEN  PRINT
354  PRINT "WHICH KNIGHT"
356  PRINT "DO YOU WISH"
358  PRINT "TO CONTACT ": INPUT Z$:I =  INT ( VAL (Z$))
360  IF I = 9 THEN  GOSUB 806
362  IF I = 9 THEN 328
364  IF I = 0 THEN 328
366  IF I < 1 OR I > 4 OR I = O1 OR I = O2 THEN  POKE 33,39:
POKE 34,18: HOME : VTAB 20: HTAB 4: PRINT "££ NO CONTACT WITH
GROUP ";I;" ££": FOR TLOOP = 1 TO 1500: NEXT : HOME : GOTO 328
368  POKE 34,5: HOME : PRINT : PRINT "  GROUP ";I: PRINT :
POKE 34,0
370  PRINT : PRINT "TO WHICH": PRINT "GRID POINT"
372  PRINT "WILL HE BE": PRINT "SENT ";: INPUT X$,Y$:W1 =  VAL
(X$) +  VAL (Y$) / 10
374  GOSUB 726
376  IF K = 0 THEN  PRINT "  NO":TIME = 1000: GOSUB 994: GOTO
328
378  POKE 34,7: HOME : PRINT "    TO": PRINT " GRID POINT":
PRINT "   ("; INT (W1);","; INT (0.5 + 10 * (W1 -  INT
(W1)));")"
380  POKE 34,0
382  PRINT
384  PRINT : PRINT "************": PRINT "FIELD REPORT": PRINT
"   FROM ";I: PRINT "************"
386  POKE 33,39: POKE 34,18: HOME
500 R =  INT (5 *  RND (1) + 1): IF ES > 7 THEN R =  INT (7 *
RND (1) + 1)
510  IF R = 1 THEN  GOSUB 1000: GOTO 700
520  IF R = 2 THEN  GOSUB 2000: GOTO 700
530  IF R = 3 THEN  GOSUB 3000: GOTO 700
540  IF R = 4 THEN  GOSUB 4000: GOTO 700
550  IF R = 5 AND (F > 0 OR ES = 1 OR ES = 4 OR ES = 6) THEN
```

```
500
560  IF R = 5 AND F < 1 THEN  GOSUB 5000: GOTO 700
570  IF R = 6 THEN  GOSUB 6000: GOTO 700
580  IF R = 7 THEN  GOSUB 7000: GOTO 700
700  IF Q = 1 THEN  GOSUB 830:TIME = 750: GOSUB 994: HOME :
POKE 34,0: IF ES < 4 THEN 220
702  IF Q = 1 THEN 222
704  PRINT
706  IF UN$ <  > "WRONG" THEN 712
708  PRINT " UNITS OF ANSWER NOT STANDARD."
710 TIME = 750: GOSUB 994
712 R =  RND (1): IF R < 0.3333 THEN  PRINT " WE DISAGREE.
ORDERS ARE IGNORED.": GOTO 718
714  IF R < 0.66667 THEN  PRINT "       NO WAY ! à%": GOTO 718
716  PRINT " COMMAND CENTRAL DOES NOT VERIFY.": PRINT "
COMMUNICATION TERMINATED."
718  IF O1 <  > 0 THEN O2 = I
720  IF O1 = 0 THEN O1 = I
722 TIME = 1500: GOSUB 994: GOSUB 994: HOME : POKE 34,0
724  GOTO 326
726  REM
728 K = 1: IF W1 < 1.1 OR W1 > 8.805 THEN K = 0: RETURN
730  IF  ABS (W1 -  INT (W1)) < 0.005 THEN K = 0: RETURN
732  IF  ABS (W(I) + 1.1 - W1) > 0.05 AND  ABS (W(I) - 0.9 -
W1) > 0.05 THEN K = 0: RETURN
734  IF  ABS (W1 -  INT (W1)) < 0.005 THEN K = 0: RETURN
736  FOR M = 1 TO 4: IF W1 = W(M) THEN K = 0: RETURN
738  NEXT
740  FOR M = 0 TO 1: IF  ABS (W1 - S(M)) < 0.005 THEN K = 0:
GOTO 774
742  NEXT
744  RETURN
746  REM
748 X1 =  FN X(B):Y1 =  FN Y(B):X =  FN X(B1):Y =  FN Y(B1)
750  INVERSE : IF F >  = 1 THEN 758
752  VTAB Y: HTAB X: IF I2 < 3 THEN  PRINT "GRR": GOTO 756
754  PRINT "WUF"
756  FOR TLOOP = 1 TO 750: NEXT
758  IF P5 = 1 AND I2 = 3 THEN 762
760  VTAB Y1: HTAB X1: PRINT "   ": VTAB (Y1 - 1): HTAB X1:
PRINT "   "
762  IF F >  = 1 THEN 772
764  VTAB Y: HTAB X: IF I2 <  > 3 THEN  PRINT " £ ": GOTO 768
766  PRINT "   "
768  VTAB Y - 1: HTAB X: IF I2 <  > 3 THEN  PRINT " * ": GOTO
772
770  PRINT " * ":P5 = 0
772  NORMAL : RETURN
774  REM
776  POKE 33,39
778 XG =  FN X(W1):YG =  FN Y(W1):XA =  FN X(W(I)):YA =  FN
Y(W(I))
780 TIME = 350
```

```
782  IF M = 0 THEN SCRN$ = "£": IF F > 0.5 THEN SCRN$ = " "
784  IF M = 1 THEN SCRN$ = " "
786  INVERSE
788  FOR T = 1 TO 3: VTAB YG: HTAB XG: PRINT "GRR": GOSUB 994
790  VTAB YG: HTAB XG: PRINT " ";SCRN$;" "
792  VTAB YA: HTAB XA: PRINT "AHH": GOSUB 994
794  VTAB YA: HTAB XA: PRINT " ";I;" "
796  NEXT T
798  NORMAL
800 Z =  FRE (0)
802  POKE 34,20
804 R = 0: VTAB 23: HTAB 5: GOTO 714
806  REM
808  POKE 34,0: HOME
810  POKE 33,25: POKE 32,14
812  HOME
814 CL$ = "   "
816  FOR K = 1 TO 4: FOR J = 1 TO 2: FOR I = 1 TO 4: PRINT
CL$;: INVERSE : PRINT CL$;: NORMAL : NEXT I: PRINT : NEXT J:
FOR J = 1 TO 2: FOR I = 1 TO 4: INVERSE : PRINT CL$;: NORMAL :
PRINT CL$;: NEXT I: PRINT : NEXT J: NEXT K
818  POKE 33,39: POKE 32,0
820  IF IN = 12 THEN  RETURN
822 B = S(0):B1 = B: GOSUB 746
824  FOR I = 1 TO 4:W1 = W(I): GOSUB 830: NEXT
826 I = 9: VTAB 23: HTAB 4
828  RETURN
830  REM
832 X9 =  FN X(W(I)):Y9 =  FN Y(W(I)): INVERSE : VTAB Y9: HTAB
X9: PRINT "   ": VTAB Y9 - 1: HTAB X9: PRINT "   "
834  IF  ABS (W1 -  INT (W1)) > 0.875 THEN 838
836 X9 =  FN X(W1):Y9 =  FN Y(W1): VTAB Y9: HTAB X9: PRINT "
";I;" ": VTAB Y9 - 1: HTAB X9: PRINT " O ": NORMAL
838 I1 =  INT (W(I) / 2 + 0.5):I7 =  INT (W1 / 2 + 0.5):C(I1)
= C(I1) - 1:C(I7) = C(I7) + 1:W(I) = W1
840  NORMAL
842  RETURN
844 X1 =  FN X(B):Y1 =  FN Y(B): INVERSE
846 F = 0
848  POKE 34,6: POKE 33,13: HOME
850  NORMAL : IF ES < 4 THEN  PRINT : PRINT : GOTO 856
852  PRINT "THE OTHER": PRINT "  WILL"
854  PRINT " FOLLOW !"
856  INVERSE
858  POKE 33,39: POKE 34,0: VTAB Y1: HTAB X1: PRINT "   "
860  VTAB (Y1 - 1): HTAB X1: PRINT "   "
862  POKE 33,13: POKE 34,9: HOME
864  NORMAL
866 TIME = 1000: GOSUB 994
868  PRINT : PRINT "THE TOWN IS"
870  PRINT "SAFE. YOU"
872  PRINT "HAVE WON !"
874  GOSUB 994
```

```
876  PRINT : PRINT "YOU ARE A"
878  INVERSE : PRINT "  HERO   "
880  NORMAL
882  GOSUB 994
884  PRINT : POKE 33,39: POKE 34,0: PRINT : PRINT "  YOUR
EFFICIENCY RATING ": PRINT "  FOR THIS MISSION IS ";
886  GOSUB 984: PRINT  INT (EF);" %"
888  PRINT "  AT LEVEL "; INT (ES + .5)
890  PRINT : END
892  POKE 34,6: POKE 33,13: HOME : IF ES < 4 THEN  PRINT "HE
CANNOT": GOTO 898
894 F = 0
896  PRINT "THEY CANNOT"
898  PRINT "BE STOPPED!"
900 TIME = 1000
902  POKE 33,39
904  GOSUB 746
906  GOSUB 994
908  POKE 33,13: VTAB 8
910  PRINT
912  IF ES < 4 THEN  PRINT : PRINT " HE WILL": GOTO 916
914  PRINT : PRINT "THEY WILL "
916  PRINT "DESTROY THE"
918  PRINT "TOWN ! !"
920  GOSUB 994
922  PRINT : PRINT "YOU ARE "
924  PRINT "RELIEVED OF"
926  PRINT "DUTY. "
928  PRINT
930  GOSUB 994
932  PRINT "TRANSMISSION"
934  PRINT "TERMINATà& !"
936  GOSUB 994
938  POKE 33,39: POKE 34,0: PRINT : PRINT "  YOUR EFFICIENCY
RATING ": PRINT "  FOR THIS MISSION IS ";
940  GOSUB 984
942  PRINT  INT (EF);" %": PRINT "  AT LEVEL "; INT (ES + 0.5)
944  VTAB 23: HTAB 1: END
946 NM$ = " ":UN$ = " ":NN = 0: FOR T = 1 TO  LEN (Z$):AZ =
ASC ( MID$ (Z$,T,1)): IF AZ = 44 THEN NM$ = NM$ + ".":NN = T:
GOTO 950
948  IF (AZ > 47 AND AZ < 58) OR AZ = 45 THEN NM$ = NM$ +
MID$ (Z$,T,1):NN = T
950  NEXT T
952  IF  LEN (Z$) = NN THEN 958
954 UN$ =  RIGHT$ (Z$, LEN (Z$) - NN)
956  IF ( ASC ( LEFT$ (UN$,1)) < 65 OR  ASC ( LEFT$ (UN$,1)) >
90) AND  LEN (UN$) > 1 THEN UN$ =  RIGHT$ (UN$, LEN (UN$) -
1): GOTO 956
958 NM =  VAL (NM$)
960 NM$ = " "
962  RETURN
964 Z$ = " "
```

```
966  GET A$: IF  ASC (A$) > 31 THEN Z$ = Z$ + A$
967  IF  ASC (A$) = 4 THEN  PRINT : PRINT  CHR$ (4);"PR£1":
PRINT  CHR$ (9);"S": PRINT  CHR$ (4);"PR£0":A$ =  CHR$ (13)
968  IF  ASC (A$) = 13 AND  LEN (Z$) > 2 THEN  PRINT A$:
RETURN
970  IF  ASC (A$) = 13 THEN 966
972  PRINT A$;
974  IF  ASC (A$) =  ASC (";") THEN Y$ =  LEFT$ (Z$, LEN (Z$)
- 1): GOTO 964
976  IF  ASC (A$) = 8 THEN  PRINT " "; CHR$ (8);: IF  LEN (Z$)
> 1 THEN Z$ =  LEFT$ (Z$, LEN (Z$) - 1)
978  IF  ASC (A$) = 8 AND  LEN (Z$) < 2 THEN Z$ = " "
980  IF  ASC (A$) = 21 THEN Z$ = Z$ + " "
982  GOTO 966
984 EF = 100 + 60 * (S(0) -  INT (S(0)) - 0.8 + S(1) -  INT
(S(1)) - 0.8)
986  IF ES < 4 THEN EF = EF - 2 * (100 - EF)
988  IF EF > 100 THEN EF = 100
990  IF EF < 15 THEN EF = 15
992  RETURN
994  FOR TLOOP = 1 TO TIME: NEXT TLOOP: RETURN
995  REM
996  REM   PLACE QUESTIONS
997  REM   AT SUBROUTINE 1000, 2000, ETC.
998  REM
1000  REM
1010  PRINT "   ALL CLEAR. I'M MOVING OUT NOW."
1020 Q = 1:TIME = 750: GOSUB 994
1030  RETURN
1040  REM
2000  PRINT " COVER IS GOOD. THERE ARE NO": PRINT "OBSTACLES.
SHALL I MOVE THE": PRINT "GROUP NOW ? ";
2010  INPUT " ";Z$: IF  LEFT$ (Z$,1) = "Y" OR Z$ = "NOW" OR
LEFT$ (Z$,2) = "GO" THEN Q = 1: RETURN
2020 Q = 0: RETURN
2030  REM
3000 Q = 0:A1 =  INT (11 *  RND (1)) * 50 + 500:A2 =  INT (5 *
RND (1)) * 50 + 100
3010  PRINT " TO MOVE THERE WITHOUT BEING SEEN WE": PRINT "
MUST COVER ";A1;" M IN ";A2;" S."
3020  PRINT " WHAT AVERAGE SPEED IS THAT ?"
3030  PRINT "  SPEED = ";: GOSUB 964
3040  GOSUB 946
3050  IF  ABS (NM - A1 / A2) > .075 * A1 / A2 THEN Q = 0:
RETURN
3060  IF  LEFT$ (UN$,3) < > "M/S" THEN Q = 0:UN$ = "WRONG":
RETURN
3070 Q = 1: RETURN
3080  REM
4000  PRINT " I CAN'T SEE ANYTHING IN THIS THICK": PRINT
"FOREST. I'M NOT MOVING UNTIL I KNOW": PRINT "HOW FAR THE
DRAGON IS FROM ME. HOW FAR": PRINT "IS THE BIG ONE ? ";
4010 DS = ( ABS ( INT (S(0)) -  INT (W(I)))) ^ 2
```

```
4020 DS = DS + 100 * ( ABS (S(0) -  INT (S(0)) - W(I) +  INT
(W(I)))) ^ 2
4030 DS =  SQR (DS)
4040  GOSUB 964: GOSUB 946
4050  IF  ABS (NM - DS) > DS * 0.05 THEN Q = 0: RETURN
4060  IF  LEFT$ (UN$,2) <  > "KM" THEN Q = 0:UN$ = "WRONG":
RETURN
4070 Q = 1: RETURN
4080  REM
5000 A1 =  INT (11 *  RND (1)) * 5 + 10
5010 Q = 1
5020  PRINT " COMMAND CENTRAL INSTRUCTS ME TO": PRINT "SWITCH
TO THE ";A1;" M BAND. WHAT ": PRINT "FREQUENCY IS THAT IN MHZ
? ";
5030  GOSUB 964: GOSUB 946
5040  IF  ABS (NM - 300 / A1) > 0.05 * (300 / A1) THEN Q = 0
5050  IF  LEFT$ (UN$,3) <  > "MHZ" THEN Q = 0:UN$ = "WRONG"
5060  IF Q = 0 THEN F =  INT ( RND (1) * 2 + 1):FC = 2: IF ES
= 2 OR ES = 7 OR ES = 9 THEN F = 1: RETURN
5070  IF Q = 0 THEN  RETURN
5080 Q = 1:F = 0: RETURN
5090  REM
6000  PRINT " WE ARE IN A MOUNTAINOUS AREA. WHAT": PRINT "IS
THE DRAGON'S POSITION VECTOR": PRINT "(EAST,NORTH) RELATIVE TO
US ? "
6010  INPUT " ";Z$,Y$
6020  GOSUB 946:XE = NM:Z$ = Y$: GOSUB 946:YE = NM
6030 XC =  INT (S(0)) -  INT (W(I))
6040 YC = (S(0) -  INT (S(0)) - W(I) +  INT (W(I))) * 10
6050  IF  ABS (XC - XE) < 0.2 AND  ABS (YC - YE) < 0.2 THEN Q
= 1: RETURN
6060 Q = 0: RETURN
6070  REM
7000  PRINT " WE ARE IN A CLEAR, GRASSY AREA": PRINT "FLANKED
BY FOREST TO THE EAST AND ": PRINT "WEST."
7010 TIME = 2500: GOSUB 994
7020  PRINT
7030  PRINT " OUR CARTOGRAPHER REQUESTS THE "
7040  PRINT "    POLAR COORDINATES "
7050  PRINT "( DISTANCE ; COMPASS ANGLE )"
7060  PRINT "    NOTE SEMI-COLON !"
7070  PRINT "OF THE LARGE BEAST RELATIVE TO US."
7080  PRINT "  ";
7090  GOSUB 964
7100  GOSUB 946:TE = NM
7110 Z$ = Y$: GOSUB 946:RE = NM
7120 X =  INT (S(0)) -  INT (W(I))
7130 Y = (S(0) -  INT (S(0)) - W(I) +  INT (W(I))) * 10
7140 RC =  SQR (X * X + Y * Y)
7150  IF X = 0 THEN TH = 90: IF  SGN (Y) =  - 1 THEN TH =  -
90: GOTO 7180
7160  IF X = 0 THEN  GOTO 7180
7170 TH =  ATN (Y / X) * 180 / 3.14159265
```

```
7180 TH = 90 - TH: IF  SGN (X) <  - 0.5 THEN TH = TH + 180
7190  PRINT " ( "; INT (RC);",";  INT ((RC -  INT (RC)) * 10 +
0.5)" KM ; "; INT (TH + 0.5);" DEGREES )": PRINT
7200  PRINT
7210 TIME = 1500: GOSUB 994
7220  IF  LEFT$ (UN$,2) <  > "KM" THEN Q = 0:UN$ = "WRONG":
RETURN
7230  IF  ABS (RE - RC) < RC * 0.05 AND  ABS (TH - TE) < 15
THEN Q = 1: RETURN
7240 Q = 0: RETURN
```

Listing 7

```
50  REM
52  REM  ************************
54  REM  *     SIMULATION OF    *
56  REM  *                      *
58  REM  * OF WAVES ON A SPRING *
60  REM  *                      *
62  REM  *     CREATED BY       *
64  REM  *                      *
66  REM  *      TOM FORD        *
68  REM *                      *
70  REM *     MAY , 1984       *
72  REM *                      *
74  REM ************************
76  REM
78  REM
80  REM   MODIFIED BY B.MOFFAT
82  REM              JUNE , 1985
100  TEXT : CLEAR
110  HOME : PRINT : PRINT : PRINT : PRINT : INPUT "HOW MANY
POINTS TO MAKE UP SPRING        (ABOUT 25)   -> ";N
120  IF N < 2 THEN  PRINT  CHR$ (7): GOTO 110
130  IF N > 200 THEN  PRINT  CHR$ (7): GOTO 110
135  INPUT "K= ";K
140  HOME : VTAB 21: PRINT "USE JOYSTICK TO CREATED WAVE AT
LEFT"
150  PRINT : PRINT "'R' TO RESTART. 'ESC' TO QUIT."
160  HGR : HCOLOR= 7
170  DIM X(N),Y(N),XX(N),YY(N)
180  FOR I = 1 TO N
190 X(I) = I * 260 / N + 10:Y(I) = 80
200  HPLOT X(I),Y(I)
210  NEXT
220 Y(0) = 60 +  PDL (1) * 40 / 255:X(0) =  PDL (0) * 20 /
255: HCOLOR= 7: HPLOT X(0),Y(0)
230  FOR I = 1 TO N - 1
240 XX(I) = XX(I) + K * (X(I + 1) - X(I)) + K * (X(I - 1) -
X(I))
250 YY(I) = YY(I) + K * (Y(I + 1) - Y(I)) + K * (Y(I - 1) -
Y(I))
260  NEXT
270  HCOLOR= 0: HPLOT X(0),Y(0):Y(0) = 60 +  PDL (1) * 40 /
255:X(0) =  PDL (0) * 20 / 255: HCOLOR= 7: HPLOT X(0),Y(0)
280  FOR I = 1 TO N - 1
290  IF X(I) > 0 AND Y(I) > 0 AND X(I) < 279 AND Y(I) < 159
THEN  HCOLOR= 0: HPLOT X(I),Y(I)
300 X(I) = X(I) + XX(I):Y(I) = Y(I) + YY(I)
310  IF X(I) > 0 AND Y(I) > 0 AND X(I) < 279 AND Y(I) < 159
THEN  HCOLOR= 3: HPLOT X(I),Y(I)
320  NEXT
330  IF  PEEK ( - 16384) = 155 THEN  POKE  - 16368,0: GOTO 360
```

```
340  IF  PEEK ( - 16384) = 210 THEN  POKE  - 16368,0: GOTO 100
350  GOTO 230
360  TEXT : HOME : PRINT : PRINT : PRINT : INPUT "ARE YOU SURE
YOU WANT TO QUIT (Y/N)                -> ";A$: IF A$ = "N" THEN
100
380  HOME : END
```