Some Remarks on Computer-Based Educational Systems

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Abstract

This document is intended as an indication of the order of magnitude of commencing a realistic computer-based educational research program in Britain.

1 The Possibilities

The most important characteristic of the computer is that it is a general-purpose device designed to be capable of simulation the input/output behavior of virtually any other system. In this respect it is a *neutral* tool whose structure does not carry strong implications for its use, and its advantage is education is that it is non-restrictive-we can do anything we with, provided we are able to define out requirements in the form of a computer program.

This statement obviously requires some qualification—present computer technology, especially at the interface, does place some limitations, and considerations of cost may make these more severe. However, the state of the art is advancing so rapidly, and there is no technical reason why it should not continue to do so virtually indefinitely, that we have made very small inroads into the potential wealth of computing power as yet.

I would regard the state of our intentions in education and our knowledge how to implement them as being the main stumbling blocks to the advance of computer-based education systems, rather than the state of technology. This is not to say that present displays and input systems are adequate or that present computers are sufficiently low in cost, but rather that, by the time we know how to use these systems in education, the necessary technology will be available.

Whatever one's views on the purpose of education, it is clear that the present system of class instruction by a human teacher makes very inefficient use of the time when the brain is highly plastic, and information is being stored and behavior patterns established. Certainly the computer-based system should not be thought of, or evaluated as, a direct replacement of the human teacher. It is an entirely new venture which will be in a developmental and experimental state for a very long time. It offers the opportunity for far more freedom in the educational process than we have at present and this obviously requires enquiry into the foundations of this process. Such enquiry always taken place but it is too much philosophical reflection when the tools are not available to turn into an empirical science.

The most pressing need at present is research into education using a computer-based system as a research tool. The domain for such research is the entire educational system, and I would like to see the necessary facilities provided to any educational establishment that was prepared to experiment with their use. Any initial evaluation of these experiments in terms of 'improved learning' will be irrelevant, as have been those on teaching machines. Such an evaluation is equivalent to judging the first aircraft by their speed or passenger-carrying capability; computer-bases education must first take off. The mathematics teacher who provides his class with desk calculator facilities and then goes on the have the simulated calculators print out hints and pose new problems, and the geography teacher who provides a library of information and then goes on the have the simulated library question why information is required and provide comparative material—these, and others like them, will be the founders of computer-based education.

To summarize these first remarks, I feel that the computer offers the possibility of educational systems with far less restrictions than are placed by the present necessity for bulk teaching by a few localised individuals in a severely limited environment. The major problem in realising this possibility is not technology which lags a comparatively short time behind our requirements, but knowledge of education itself. This knowledge will be gained by putting the facilities offered into the hands of educators willing and able to experiment with their use.

2 The Problems

The outstanding problems are what facilities to place where, how to do it and at what cost. The difficulty about these last two considerations is that computer technology is in a tremendous state of flux, and that right decision today would most certainly be the wrong decision if implemented in two years time; very careful time-tabling of any development is essential and the necessary prediction is difficult.

2.1 Project must be very flexible

Thus, the first requirement is that any plan should be highly flexible with an inbuilt system of review and a capability for modification. This implies modularity in hardware and software, ease of physical re-location of equipment, and minimal capital expenditure on items which will be valueless when obsolete. It also implies that the facilities offered to experimental users will be changing and that some organisation is required to initiate, implement and oversee these changes. It will not be possible to progress by making equipment available at the start of a long-term program, and them waiting to see what happens.

2.2 Joint project with USA organisation?

Getting uncomfortably closer to details all the time, the problem of how to initiate this experimental use crops up. We have to decide very soon whether to go it alone, or to admit that the USA is five years ahead of us and co-operate closely with some organisation, or organisations, there. Could replica of the Plato III system, the successor to the IBM 1500, or one of the now many other CAI systems, provide us with technological foundations sufficient for rout educational research at a lower cost and in a shorter time than any we could develop ourselves? This certainly requires careful study and the decision is not clear-cut since varying degrees of co-operation are possible.

2.3 Small or large machines—users must be offered complete system

The question of many small computers or one large machine seems to occur in virtually every context. Whatever decision is taken, it is essential that the experimental users are offered a *system for education*, not just access to a computer whether large and remote or small and local. The task of the central organisation in up-dating this system will be much the same whether it is located centrally as one machine or distributed peripherally as many. Ultimately the small-versus-large question will cease to have a meaning since most small machines twill be in communication with large central facilities, and multi-access large machines will have multiple processors, especially for input/output, which may be regarded as small machines in their own right.

2.4 Plan for cost/effectiveness in R and D

This is a research and development phase and routine use of computer-based educational systems in some years away. We cannot specify the hardware configuration for that use at present and it is irrelevant to our current requirements. Any system development must be implementable on machines of any of reasonable range of sizes. Thus, providing we are not forced into incorporating ineradicable machine-dependent features, especially restrictions, the criterion for selecting machines is overall cost/effectiveness (i.e. that which give the greatest R and D return for a given cash flow over the planned period of research).

2.5 The breakdown of costs

The overall costs of the R and D program may be broken down into the following for the purposes of comparison:

(i) Capital cost of computing system—i.e, processor(s), backing stores and standard peripherals.

(ii) Capital cost of student terminals—i.e, visual display units and keyboards.

(iii) Running cost of communication links between peripheral terminal systems and central system.

(iv) Development cost of operation and system software.

(v) Development cost of educational software.

(vi) Running cost of administration and maintenance.

2.5.1 Capital cost of computing system

A CDC6600 with mass-core backing would cost £2m. It could run 4,000 student terminals (from Bitzer's figures of 4 seconds mean response time; 2,000 CPU operations per response; 250 nanoseconds per operation; and statistical queuing factor of 2) . A DDP516 with disc backing would cost £50, 000 and could run 100 student terminals. The distribution of this cost per student terminal is the same for both systems, £500 per terminal; amortised over 5 years this is £100 per annum.

The effectiveness of both these systems in terms of overall computing power would be identical. The CDC6600 would also be suitable for large-scale statistical evaluation of results off-line at night, and could be run as a commercial batch-processing service at night. This might be an important advantage provided it could be utilised. On the other hand, multiple small systems offer the advantage in initiating a program with a far lower capital outlay on computing equipment than £2m.

2.5.2. Capital cost of terminals

The terminals required are ill-defined and poorly developed at present. They will be subject to up-dating throughout the R and D phase, whereas the computing system can remain fairly static over the next five years. minimal terminals are a teleprinter at £500 or random-access film projector at the same cost. Neither is adequate although both may be useful: the teleprinter is a factor of 10 too slow and has a limited and inflexible display; the projector adds a pictorial capability, but again and inflexible one. At the next stage, a character display with memory (Ratheon DIDS400) costs £3,000 and, further still, a full graphic display costs £20,000. A colour version of this last system would be expected to cost about £40,000. A random-access audio device costs £2,000. A monitor/control unit for connecting other equipment to a terminal would range from £1,000 to £10,000.

A reasonable student terminal with film-strip, limited character/graphics, audio and hard-copy would cost between £5,000 and £10,000 at present. This is over an order of magnitude greater than the corresponding computing system cost—a very sobering consideration. Extensive terminal development is being carried out and costs will fall dramatically in the future, but for some years they will be at this level.

The most reasonable solution to the terminal problem at present is to provide a range form the absolute minimum to a highly flexible and comprehensive system, aiming at a mean terminal cost of £4,000 or £800 per annum; expensive ones should be readily relocatable.

2.5.3. Running cost of communication links

The information content of visual displays is very high and when terminals are remote from the computer the cost of the links transmitting this information can be very high. A 60 mile link with a data-rate of 1,2000 bauds costs £2,500 per annum. As high-speed PCM links become more common the data-rate will go up for the same cost, but this figure is typical for the next few years.

A 1,000 line colour-graphic display refreshed at 30 frames/second requires data at a rate of 3×10^8 bauds. This is fantastically high but only corresponds to a very good quality movie; it is what we might reasonably expect to have as a general-purpose visual display. Transmitting this information over a data link is out of the question, and a local random-access movie projector will have to be used. This constraint continues t apply to the other end of the graphic display scale; a black-and -while, 500-line, still display requires data at a rate of 6×10^4 baud. This data-rate is still too high for both the (time-shared) computer and communication links. Selection of one film-strip or frame form one million requires a data rate of 5 baud only. A 1,200 baud line could control 50 such terminals using a multiplexer system costing £4,000. Assuming that 100 terminals are located in center and that the mean distance between centres is 60 miles, the cost per annum of communication links is £65 per terminal, applicable to the large computer (servicing 40 centres) only.

Pictures stored only in the form of complete units are not adequate for many requirements. A teleprinter offers amore flexible character display at 60 baud, but is rather slow, and a better facility is a CRT character display with storage, requiring a data-rate of 1,500, respectively, per terminal per annum for the large computer only. A reasonable mean communication cost is £1,000 per annum.

2.5.4 Development cost of operating and system software

This is a very difficult figure to estimate, but a reasonable guess, which tallies with experience in the USA, is 100 man-years at a cost of £4000,000, or £80,000 per annum. This would be £20 per annum per terminal for a 4,000-terminal system, or £200 per annum per terminal for a 400-terminal system.

2.5.5 Development cost of educational software

This figure depends on how much effort is devoted to the educational research, but since this is the major purpose of the project it should be substantial. A large secondary school with a five-year course, sixteen options, five streams, and a three-term year requires 1,200 ten-hour courses. Each ten-hour course (which will take up thirty hours of student time) will consist of 9,000 units of educational material ('frames' in the teaching machine sense, but obviously not so well delimited). Hence the total number of frames for minimal coverage of normal secondary education is 10^{7}. At £10 per frame, this is a cost of £100m; alternatively it may be viewed as 1.5 man-days per frame, or a total of 25,000 man-years of effort.

This gives an estimate of the total effort and cost involved in computerising secondary education. Assuming that there is a build-up of an equivalent amount of R and D expenditure and the work is funded at a mean rate of £10m per annum the project would take 20 years. A fifteen-year program split into three five-year periods with an initial investment of £2m per annum building up to £25 m per annum would be reasonable. The expenditure of £25 m in the first five years would be expected to generate about 100 complete ten-hour courses.

The expenditure of a quarter of a million pounds on one 'ten-hour course' might seem very large; it is based on the assumption that all the material the student requires is available to him and that the course has been developed to a very high standard. A typical teacher would teach twenty-five such courses per annum and hence the comparative cost of the course amortised over 10 years is 200 teachers; i.e. if the program is utilised in 200 schools it balances the cost of conventional teaching.

I feel that the cost of development of educational material is very easily underestimated, and that the devotion of substantially less effort per course than that proposed would fail to generate material of adequate standard.

To estimate the expenditure which reasonable uses the computing facility purchased, we may suppose that a 100-terminal local system serves four classes of students taking twenty courses per annum. Eighty courses would then be required at a total cost of £20m, or £4m per annum. If the local system were restricted to a single class then £elm per annum would be adequate.

2.5.6 Running cost of administration and maintenance

Thus are again costs which it is easy to underestimate; the terminals, especially, are electro-mechanical devices with a high failure rate. An engineering staff of four pr 100-terminal local system, or two per 25-terminal local system, with one administrator at the control computer would be required for a system based on the large computer, whilst the small computer would require a local staff of four and a total central administration of twenty people.

Thus a 4,000-terminal system based o a large machine requires 200 staff at a cost of £800,000 per annum; a 1,000-terminal system with forty 25-terminal local units would cost £500,000 per annum; a 45,000-terminal system using the small machine would cost £7000,000 per annum; a 100-terminal system with eight 25-terminal local units, using the small machine, would cost £2000,000 per annum.

2.6 Summary of Costs

The cost of terminals, and the cost of communication links to a central machine, stand out as the major factors in expenditure. Taking the two together, the costs are £9,000 per terminal for the large machine, and £4,000 per terminal for the small machine. Thus, a 4,000- terminal system would involve expenditures of £36m and £16m, respectively. With a dedicated large machine a minimum reasonable number would be 1,000 terminals at a total cost of £9m. With background batch-processing on the large machine, and with the small machine, eight units of 25 terminals might be a reasonable level for the development phase, at costs of £1 8m and £800,000 respectively.

The educational material is the next most expensive item. A high proportion of it could be generated by use of present manpower in educational establishments. A team preparing a course might consist of thirty-two people, thrifty of whom would be teachers devoting 20% of their time to the work, and the remaining two would be additional full-time staff; thus, only 40% of the development costs are required.

The costs of eight centres with 25 terminals, over a five-year period, can now be summarised.

2.6.1 Cost of five-year R and D programme

For eight local units of 25 terminals each:

	Large machine	Small machines
Computing system	2	0.4
Terminals and communications	1.8	0.8
System software	0.4	0.4
Educational material	2	2
Administration (50 staff)	1	1
	————	————
Totals	£7.2m	£4.6m
	————	————
Cost per annum	£1.5m	£1m

2.6.2 Effect of background service with large machine

It is reasonable to assume that the background commercial computing service on a large machine might recoup the cost of the computing system and extra administration.

The figures then become:

	Large machine	Small machines
Totals	£5.2m	£4.6m
Cost per annum	£1m	£1m

Thus the overall cost/effectiveness of one system does not differ appreciably from that of the other.

2.7 Staff and Accommodation

From the figures given previously, the administration of the system based on the large computer requires 32 people centrally and 16 at the local centres (two at each); for the system based on the small machine, comparable figures are 20 centrally and 32 locally. The educational material development requires 40 full-time staff and 20% of the time of 600 teachers. A reasonable organisation would be eight groups of ten schools each, with 25 terminals in one of the schools in the group. Seven of the teaching staff at each school would be involved in the project; liaising with five full-time workers.

The development of the operation and system software requires a different form of organisation. It would best be carried out by a commercial organisation, and only 30% of the staff involved need be employed directly on the project. This would be a staff of five system analysts overseeing the work of the commercial firm and liaising with the educational administrative staff.

2.8 Scheduling of the Program

It would be reasonable to allow one year for contract specification and negotiations, and a two-year run-up period in which the hardware and operating system were developed and commissioned, and the administration established. This it would be threw years from the decision to go ahead to the start of the main five-year program. Assuming that the decision to go ahead might be made in eighteen months time, then the R and D program would be completed at the end of 1978.

2.9 Organisation

The overall conclusion on cost/effectiveness is that it makes very little difference whether one goes for the small computer or large computer. The organisational structure for the two will differ in some respects. In both cases ad consortium of private firms together with government agencies if indicated. No one firm is in a position to supply computers, communication links, terminals, and the system software. Both the Ministry of Technology and the Department of Education and Science are clearly involved in the running of the project.

No British computer firm can supply the large machine. CDC Philco-Ford or Univac are obvious contenders;; IBM and RCA are possibilities. Amongst small machines the American DDP516 by Honeywell is outstanding, but two British firms are contenders—Ferranti with the Argus 500 and Computer Technology with Modular 1.

The terminals do not exist as standard items and it is essential to have al local organisation to fabricate them in close liaison with the staff of the project. It is possible that a British communication company, such as Marconi, Plessey or STC, might be prepared to take system responsibility for both communication links and terminals.

The system software development might possibly be done by the firm supplying the computer, but the use of and organisation specialising in software is preferable. Much depends here on whether the educational system is to remain completely nationalised, or whether the DES would be prepared to buy time on an educational computing system operated commercially. This is not so far away from buying books produced commercially as to the inconceivable, and would be the most economical approach (the Post Office Corporation might offer the services as a compromise). In this event there would be very much greater commercial interest in the overall systems aspect of the project.

3. Conclusions

The proposal for an expenditure of £lm per annum on a five-year R and D program on the use of computer-based educational systems is the minimum that will give any useful return. Twice as much would be better; with less, we might just as well watch the developments in the USA and buy in when appropriate. This program is the necessary precursor of a twelve-year, full-scale development program giving us computerised secondary education in 1990.

It is probable that tat least one America firm will be involved in the project, and advantage should be taken of this to establish close ties with work in the USA. Certainly the hardware development performed here should be minimal with the main emphasis on the development of educational material. At present, it is not possible to buy even the main computer plus operating system off the shelf, but it is probable that something suitable will be available by 1973.

Whether the system is based on a small machine (£50,000) or a large machine(£2m) makes very little difference to cost/effectiveness.

The proposed level of effort is a five-year program commencing in 1973 with eight local centres each having 25 terminals. The aim would be to develop twenty complete courses, of nominally ten hours each (taking the average pupil some 30 hours at the terminal). Each course would be prepared by a team of thirty teachers working on the project for 20% of their time plus two full-time staff.