The computer in your briefcase*

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The object shown in Fig. 1 is a computer. It is the size of a ream of typing paper: about 9 x 12 x $\frac{3}{4}$ in. As you can see, it has a high resolution display screen and a typewriter keyboard. You can see neither the high-speed tape cassette in the back, nor the batteries that operate it, nor the circuit chips that contain the cpu and memory. There are also connectors in back so that it can be used over telephone lines as a terminal.

Unfortunately, the computer I have just described exists only as a cardboard mock-up: it is only a dream, not a reality. But according to its designer, Alan Kay¹ of the Xerox Palo Alto Research Center, it will exist soon enough that now is the time to plan for it. Kay calls this version the Dynabook, and he believes it to have the potential to change our normal educational process. Imagine, if you will, one of Kay's fondest dreams: children carrying their Dynabooks with them, sitting on the grass under the trees, skimming a history lesson. It is a book, but a book unlike anything you have seen before, for each history cassette soon becomes a personal record. With it you can flip through history in any order, not just the linear order implied by books. Start with any topic that interests you: the Dynabook presents the relevant text. If you find a section which you wish to study further, simply indicate so and the Dynabook displays that for you immediately, while still retaining a record of where you left off reading in your original section. Want to make a marginal note? Type it in, using the editing facilities which are always on-line. Want to find a previous marginal note? Simple.

Moreover, because this is a computer, it can keep tabs on your learning progress. If you wish to study a section that has prerequisites, the Dynabook could decide not to let you proceed unless it either already knows that you have studied the proper material or else satisfies itself, through a pretest, that you are ready. If you fail this test, no real harm is done except that the material in which you are deficient will automatically get presented to you. Moreover, before you are able to claim to understand the history tape, the Dynabook will check its records to make sure you have indeed covered sufficient material and performed with sufficient mastery on review checks. All the information about your course

and progress stays on your private cassette. Thus, you can simply have a library of tape cassettes and use any Dynabook that is handy. You can study a variety of topics or even play computer games—all in your cassette library. Central facilities will allow you to recharge your cassette with a new topic matter or new game or tool whenever you wish.

All this is a dream, but for those of you who have followed developments in the computer industry with any care, you can see that it is not really too idealistic. Look at Fig. 2. This is a mechanical calculator. A few years ago it was one of the best, costing somewhat over \$1,000. Today it is obsolete.

Figure 3 shows the Hewlett-Packard pocket calculator. It costs \$395 and is far superior to the mechanical version. It has four memory registers, scientific decimal notation so that numbers can be expressed in powers of 10 from 10^{-99} to 10^{99} . It has a button labeled Π and function buttons for taking sin, cos, and tan of angles (and the corresponding arc sin, arc cos, arc tan), logarithms to the base e or 10, and even the values of exponents and powers such as e^x and x^y .

Figure 4 shows another calculator, this one made by Compucorp. This is slightly bigger than the Hewlett-Packard machine (it doesn't fit into your shirt pocket). But enter a series of numbers and a single buttonpush gives their sum, their mean, or their standard deviation. Or, if you enter the numbers as pairs, you can push a simple button and get the linear regression line: slope, intercept, and the predicted y-axis value for any

Figure 1

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Figure 2

desired x-axis coordinate. In addition, there are a few other magical functions thrown in, such as t scores and normal deviates. Because this computer has parentheses, it is easy to use, unlike the Hewlett-Packard machine which requires an arithmetic expression to be entered in a somewhat awkward and unnatural Polish notation, and the numerical expression can be punched in exactly as it would be written on a piece of paper, from left to right.

These are all simply calculators, not computers. But, you all certainly must know about computers. Look, here (Fig. 5) is a picture of the computer-controlled laboratory that Dave Rumelhart and I supervise at our laboratories in La Jolla. Large, complex, expensive. These machines are indeed very powerful and indispensable to the operation of our laboratory, but in a few years they will be completely superceded by new developments.

Figure 3

For example, an advertisement arrived in my mail the other day. I do not mention it because it represents anything unusual, but rather simply because it came in the mail just as I was working on this paper. It is for a computer: 4,000 words of core, lots of registers, lots of instructions, I/O bus, etc. Its cost is \$1,450. To be sure, at the advertised price it is limited. It has no console display, no Teletype, not even a power supply. It has an 8-bit word (which can be concatenated to 16 bits). But it is an honest computer, a machine much more powerful than could even have been dreamt of some 20 years ago and certainly unbuildable 10 years ago. Despite its small size, most of its space appears to be taken up with mechanical supports and air passages. You could use a simple keyboard for input, a home television

Figure 4

display for output, a cheap tape cassette or even one of the new floppy disks for bulk storage, and forget about the console lights. Today, for around \$5,000 you can have a rather powerful machine.

SO WHAT

O.K. I have waved my hands and shown you the technical literature, sort of. What does it matter that the prices and sizes of computers keep coming down while the capabilities keep going up, except perhaps that everyone soon will be able to afford one?

I think it matters in several different ways. First, our laboratory equipment will suddenly become immensely more powerful and intelligent than it presently is. The memory drum, tachistoscope, psychophysical apparatus, and operant lab will change dramatically as a result—not always in desirable directions.

Second, the human S population which we

Figure 5

traditionally study will become more sophisticated of computers, having lived with them and used them as a matter of course. Will this affect their performance? Who knows—although it could easily lead to a deterioration of their arithmetic ability much as the invention of simple writing implements and paper led to a deterioration of the ability and desire to memorize long sections of prose and speeches. Third, our theoretical structure may well undergo radical change, as complex computational concepts become commonplace among all of society.

Effects Within the Laboratory

Let me speak to the first point: the changes in laboratory equipment. Suppose that today your new laboratory memory drum or operant apparatus or what-have-you came complete with a computer control (at no increase in price, of course). This will occur someday. Even now, it would be no difficult task to make a cassette-driven and television-set-display form of a memory drum. Moreover, it would cost about the same as today's expensive drums and have far more versatility and power, with the exception that it could only display at most a line or two of alphanumeric capital letters, in black and white. But this "memory drum" would be

programmable, would measure reaction time, and would be able to service several Ss at once. Suppose you had this device: what would you do with it?

On the whole and by and large, when all is said and done, the need for powerful control equipment is mostly a useful cliché, useful primarily in writing grant applications. I know, because I have taken part in both halves of the process: both writing (and receiving) grants for computers and evaluating (and recommending approval and disapproval of) grants for computers. "We need this computer," says the applicant, "because then we can make presentation of stimuli contingent upon responses." This is such nonsense that today most sophisticated applicants don't even bother with that line in their proposal anymore. It is not that the line isn't true, it is just that, on the whole, we psychologists don't know what to do with response-contingent presentations. It messes up our statistical analyses and makes the results harder to interpret. Moreover, it requires a cleverness in designing experiments that most of us both do not have and, moreover, don't even miss. It is primarily in the disciplines that do not do careful designs or use standard statistical assessments that response-contingent measures are used: in psychophysics and in operant learning. (I do not mean these comments

in a derogatory way—I simply mean that these people, including me, do not use Greco-Latin-square balanced designs or do analyses of variance, and in general do not much care about the complexities of experimental design as taught in the usual design course, but rather take care of the appropriate controls in other ways.)

The point is that the present experiments service our needs quite adequately. More complex experiments will certainly become possible when computer cpu's start becoming commonplace components in laboratory equipment, but these complexities may be detrimental: they may simply make the understanding of the experiments that much more difficult.

I, personally, have never understood the complexities or even the purpose of those yoked-linked-chained, contingent, timed-out operant schedules. My negative opinion of the field of operant learning stems in good part from the limited ability of my simple mind to comprehend what on earth they are doing. The concept that these small laboratory computers will make everyone's experiments in every field become as complicated as operant experiments frightens me. The fact that operant experiments will become even more complex doesn't bother me, because if I can't follow them now, it won't really matter that I won't be able to follow them then. But what about experiments in my own field? The only positive outcome I can think of is that as the experiments become more complex, I will save a lot of time that I now spend in reading the psychological literature: there just will be little literature left that I can understand—perhaps only the straightforward stuff that now gets published in the *Journal of the Acoustical Society of America* or in the *Journal of Mathematical Psychology*.

THE POSITIVE SIDE

I personally do not see much need for change in our experiments. I happen to be a firm advocate of the cognitive point of view in theorizing and in seeking information about the operation of mental functions, but the experimental aspects of cognitive psychology and the information processing approach to the study of mental life are limited by our knowledge and by our imagination, not by a lack of laboratory apparatus. In any event, there are now a sufficient number of large, computer-controlled cognitive laboratories around the country so that I do not believe that the computer advances of which I have spoken can make much of a change in the power of the laboratory environment. The major change will be in two directions: First, the laboratory apparatus now so closely tied down to the large computer facilities of the laboratory will become small and easily portable. Second, the lower prices will make the computer ubiquitous, available to all in some form or other, and not just limited to the relatively rich departments, as now.

Developmental Psychology

One of the major beneficiaries of the portability of

laboratory apparatus will be the developmental psychologist who will be able to bring reasonably sophisticated apparatus into the public school system and even into the home. This should increase the quality of experiments that are now performed, for it should be much more convenient than before to devise experiments that are performable on large numbers of children from different economic classes and cultural backgrounds at less of an inconvenience for all concerned: experimenter, child, parent, teacher.

Education

I expect the major change to occur in educational practices (see, for example, the recent Carnegie report on higher education: *The Fourth Revolution*). I see computers in the home, probably linked to the home television set as the display device and the cable television connection as the interconnection to the central computer. But as our sophistication with teaching increases, so too should our sophistication with learning theory increase.

To this date, the learning theories available in psychology are paltry, insignificant affairs, capable (perhaps) of handling only simple phenomena. We psychologists study the learning that occurs over periods of tens of minutes in our experiments. Real learning takes months, years, or even a lifetime. Our theories say nothing about the acquisition of a complete subject matter; rather they seem suited only for the learning of rather simple tasks or stimulus items. I make this criticism of all theories, including my own.

This point was most forcefully stated by Seymour Papert in an unrecorded talk. Papert reminded us that to learn even a simple subject matter (such as how to program a computer) can take months of study and practice. True, some understanding and simple proficiency can be acquired in a few hours, but expert programmers do not acquire their abilities in short time spans—they require months and, more often, years to acquire their expertise. What do learning theories say of all this? Very little. The important point to Papert's remarks is actually more in the fact that he had to make them at all than in their actual content.

Psychologists ought to play an important role in the development of educational materials, in the development of new curricula, and of new methods of teaching. Remember that as computer costs go down, as living standards go up and free time becomes more available, education will assume an even more important role in the world than it does today. But this will be a different education, an education of people who are studying because they wish to, not because they must or because they need a degree. So the consumer will become more selective and intelligent about the content of his courses. If psychology is to make any contribution, it had better start now.

Thus, one sidelight of the computer spread. I predict, will be increased requirement for some sophistication in

our theoretical understanding of the learning process. Of all the possible implications of the development of computer technology, I find the possible development of a sensible, intelligent theory of learning to be the most exciting and valuable of all.

SUMMARY

The computer will come to fit in your briefcase. It will become cheap and small enough that it will be a natural part of the laboratory, the school, and the home. All this is in the future, but for laboratory use of computers, the size and price of devices available today is almost low enough to cause a dramatic change in laboratory instruments.

It is my hope that this will simply cause experiments to become more convenient to do. I shudder at the thought that the power of the computer will come to rule our experimental design, so that experiments become so complex that only elaborate statistical analyses can ferret out the conclusions. In the face of much pessimism, I plead for simplicity of experimental design. Reaction time will blossom forth as an experimental measure, for if there is one thing a

computer can do simply and reliably, it is to collect response times. This is unfortunate, for our theoretical understanding of psychological processes is underwhelmingly impoverished when it comes to the analysis of response times—especially times from nonpsychophysical experiments, where it can be assumed that many complex operations are taking place for periods of time measured in seconds.

I hope that the computer will simply become a commonplace tool. Presumably some people will take advantage of its ability to present textual and pictorial matter and worry about the applied problems of education. But whatever happens, the computer should become our tool: do not let psychology become the tool of the computer.

REFERENCES

- Carnegie Commission on Higher Education. *The fourth revolution: Instructional technology in higher education*. New York: McGraw-Hill, 1972.

NOTE

1. Kay, A. C. A personal computer for children of all ages. Unpublished manuscript.