PROGRAMMABLE CALCULATORS AND MINI-COMPUTERS IN HIGH SCHOOL MATHEMATICS:

A SURVEY OF POSSIBILITIES

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The value of a large-scale computer, complete with time-sharing terminals, in teaching high school mathematics in a large metropolitan school district has been proven. A computer has a twofold educational value: (1) Computer programming requires rigorous logical and mathematical thinking, and provides an arena in which mathematical abstractions become very concrete indeed; and (2) properly channeled, the motivation and enthusiasm generated by a successful response from a computer can greatly accelerate a student's mathematical growth.

Smaller school districts, however, may find it difficult to justify the acquisition of a full-sized computer system, even if they pool their resources with neighboring districts. On the one hand, the costs involved include not only the substantial initial outlay for the computer itself, but the additional expenses of telephone lines, CRT or teletype terminals, *service contracts* for all this equipment, and the ongoing costs of paper, ribbons and other supplies. On the other hand, for one or more small school districts to invest in a large-scale multiprocessing system capable of doing 10 times more than these districts could ever demand of it would be a wasteful misuse of the computer's capacity.

Technological developments of the past few years have created a wide range of possibilities involving computers and programmable calculators for small- to medium-sized school districts. Generally speaking, there are now three levels of calculating equipment available for educational uses: at the lowest level, there are pocket-sized programmable and non-programmable calculators capable of enhancing instruction in every area of mathematics; in the intermediate range, there are desk-sized programmable calculators with formatted printed output and substantial program and data memory; and, at the top level, there are mini-computer systems, programmable in BASIC or other widely-used computer languages, which can be expanded to meet a school district's growing needs. At Denver's George Washington High School, we have had the opportunity to experiment with the full range of equipment, and to examine the educational potential of each type.

A mathematics department with a restricted budget should invest in "scientific" or "slide-rule" calculators, such as Hewlett-Packard's HP-45 or HP-21, Texas Instruments' SR-50 or SR-51, or, if the money is available, the programmables: the HP-65 or HP-25, or TI's new programmable calculator, the SR-52. If a full class can have access to such calculators, they can be an indispensible aid at every level of high school mathematics. For example, perhaps the hardest concept encountered in intermediate algebra is that of logarithms. The presence in the classroom of a calculator with logarithmic functions can be an enormous help in getting that concept across. (The reservation should be made, however, that the presence of the calculator cannot justify omitting instruction in such matters as how to interpolate from logarithm tables; whether calculators are available or not, the assumption in teaching should be that they won't *always* be there.)

A slide-rule calculator can be particularly helpful in such a course as analytic geometry. If enough calculators are available so that no student is discriminated against by not having one, they can be used to speed up the necessary calculations, leaving teacher and students free to concentrate their attention on the concepts. Some hand-held calculators even come equipped with keys for instantaneous polar-to-rectangular (and vice versa) coordinate conversion.

The subject of statistics is presently struggling to find a place in the high school curriculum; one reason for the struggle is the tedium of calculation involved with most statistical analyses. The present generation of hand-held calculators has many statistical functions hard-wired. The availability of calculating machines makes statistics more teachable, and opens up the possibility of an alternative track for students who are interested in higher mathematics, but who don't feel they are able to handle calculus.

The specific keystroke functions available on a hand-held calculator becomes an issue of less importance if the calculator is programmable. The user is then in a position to program in his own functions. Hand-held calculators currently available provide enough programming capacity for any student to learn the rudiments of algorithmic thinking, so that he will have a head start when he is exposed to computer language programming later in his education. On any of the current models, it is easily possible to generate the algorithms to solve such problems as quadratic equations, systems of linear equations, or the production of prime numbers. The more expensive hand-held models even offer magnetic card program storage.

Hewlett-Packard's programmable model HP-25 has proven to be extremely popular in our school. Programming the calculator is easy (once the logic is understood), and it provides a congenial tool for teaching the conversion of mathematical algorithms into computer instructions. One measure of the usefulness of a hand-held programmable calculator like the HP-25 is the fact that many advanced-placement math and chemistry students have bought their own. Any high school could find ample justification for having a few of them around.

Of course, if a school is investing in small, pocket-sized programmable calculators, it must be conscious of the danger of theft. The availability of a security cradle for the calculator minimizes that danger; with security cradles, we have found that we can leave our hand-held calculators out in the open and accessible to all students with complete confidence. Hewlett-Packard offers security cradles for all its programmable and non-programmable calculators at a cost of about 30 dollars; Texas Instruments provides a security cradle for the new SR-52 only in conjunction with that machine's printer. The printer costs about 300 dollars.

If a school is more ambitious in its desire for programmable equipment, then the next step up is the desk-sized programmable calculator. Such calculators are offered by Wang Laboratories, Monroe, Hewlett-Packard, Canon, Tektronix and others. These calculators offer several advantages by comparison with the hand-held models.

With a desk-sized calculator it becomes fully possible to teach programming in its own right. Such a calculator typically has a sizeable amount of program and data memory, making possible larger and more sophisticated programs than on the hand-held models. While the calculator languages are not as easy to learn (or teach) as conversational BASIC, they are not hopelessly difficult; and once a student has learned to program the calculator, he can write programs of the same level of complexity as the BASIC programs featured in many math curricula which rely on a full-scale computer system. At the advanced-math level, programs performing such tasks as numerical integration or approximations to the derivative are not difficult to write for a programmable calculator; on a calculator with 64 data registers (which is practically the minimum available) it is possible to program a Gaussian reduction of a system of seven equations with seven unknowns. It is easy to use desk-size calculators in such introductory programming applications as the generation of "perfect numbers," Pythagorean triplets, or the solution of systems of linear equations.

The desk-size calculators have the added advantage of providing hard-copy printed output; the format of this output is usually, within the limitations of the machine's printer, formatible. And permanent storage of programs and data is possible, in the case of Monroe on magnetic cards, and on tape cassettes with Wang and Hewlett-Packard calculators.

If you decide that the desk-size calculator is the route that your school should travel, there are some cost factors you should consider in choosing the particular calculator you buy: for example, there is the questions of supplies - *thermal* printers are *very* much more expensive than conventional printers (although they are faster), so you would have to buy more paper; the cost of magnetic cards or cassettes varies from calculator to calculator, as does the cost of service contracts, and so on. The best choice of a calculator depends on the degree of frugality necessary for your school system, and on the specific uses you envision for the calculator. Before deciding, it is highly desirable to test the calculator out at work in your own school, and see if it suits your needs.

Certainly, in choosing a programmable calculator, a key factor is the system's capacity for expansion - that is, the availability of peripheral. Most calculators currently on the market are capable of powering such devices as typewriters and plotters. Some, in addition, can operate paper tape readers, porta-punch and mark-sense card readers, external tape drives and even disk drives. In terms of student motivation, the choice of peripherals is frequently as important as the calculator itself; and peripheral input devices such as mark-sense card readers can greatly increase the number of students having access to the calculator.

A most important peripheral for any calculating system is a mechanical plotter. A plotter is interesting to watch, and it can provide a graphic demonstration of such fundamental concepts in algebra as linear equations and conic sections; complex functions, which could take a student hours to visualize or a teacher hours to portray, can be presented by a programmable plotter in minutes. A plotter is one of the most effective teaching tools available in mathematics at the high school level; and a plotter is usually *not* available in conjunction with a large-scale system.

In ascending order of expense, Monroe, Wang Laboratories and Hewlett-Packard all offer analog flatbed plotters. In addition, Wang offers a large (42" by 31") digital plotter; this can be run by a moderately priced programmable calculator (the model 600).

The most ambitious level of entry into the world of programmable equipment is the acquisition of a mini-computer system, programmable in BASIC or a similar compiler language. Such systems are currently offered by Wang Laboratories, Hewlett-Packard and IBM; and the educational market may soon be entered on a large scale by the makers of "micro-computers," such as Altair.

We have had the opportunity to experiment with a typical mini-computer system, the Wang model 2200. The 2200's capabilities, coupled with its moderate cost, make it, in our opinion, an ideal educational computer system.

The basic configuration for a mini-computer system consists of a central processing unit (CPU), a CRT terminal and keyboard for input and output, and a tape cassette drive for storage. CPUs start at 4,000 bytes of core storage, and are expandable in increments of 4,000 bytes; an ideal size is 16,000 bytes. Such a configuration as this is available for under $10,000.

Programming in BASIC makes this system considerably more accessible to a wide range of students than a programmable calculator. We find it possible to use this system, for example, in the consumer math curriculum, with programs which simulate the processes of payroll deductions, the credit arrangements for buying a car, amortization, and so forth. The Wang 2200 and the corresponding Hewlett-Packard system also make available the programs created by the Huntington Project which cover a large number of areas of mathematics, physics, chemistry and earth sciences.

The chief advantage of a system such as the Wang 2200, however, is its capacity for expansion as the needs of the user grow. As funds become available, a school district might want to acquire an output typewriter to get printed copies of program output; another peripheral which could be added is a plotter, either of a small analog type or a large digital type. Programming can be made easier for the student by the addition of an editing package which greatly speeds up the correction of mistakes. Eventually, the system could be expanded to include program and data storage on disks; at this point, the mini-computer system would be fully usable for administrative as well as instructional purposes, and would rival in its efficiency the large multi-processing systems used by metropolitan school districts. In short, it is now possible for a school district, with a relatively small initial investment, to acquire a computer system which can be expanded virtually indefinitely to meet future needs.

Knowledge of computer programming in and of itself might well be an expendable educational goal; but its usefulness as a tool to increase the student's understanding of all levels of mathematics and the sciences has been demonstrated beyond dispute. At the present level of the art of computer manufacture, no school district can use the excuse of inadequate funds for depriving its students of some programming experience.

But we have learned one thing more in our past few years' experience with various types of equipment. If you don't feel you can afford to invest in a computer system, or even a small programmable calculator, now, wait a minute! The diversity of equipment available is increasing at a furious pace, and the cost at all levels continues to go down.