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ABSTRACT

This monograph on the cost and use of computers in education consists of two parts. Part I is a report of the President's Science Advisory Committee concerning the cost and use of the computer in undergraduate, secondary, and higher education. In addition, the report contains a discussion of the interaction between research and educational uses of computers, the education of the faculty in the use of computers, and the role of the large university computing facility. Examples of computer usage in instruction in both the sciences and humanities are cited. Part II of the monograph contains (1) an overview of the selection of a media system, and a discussion of (2) its methodology, (3) cost estimates, (4) cost-saving and considerations, and (5) regulatory implications of electronic systems. (LC)

EDUCATION AUTOMATION MONOGRAPH

COMPUTERS IN EDUCATION:

THEIR USE AND COST

Part 1 – Report of the President's Science Advisory Committee

Part 2 – Michael G. Sovereign

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PART I

I. INTRODUCTION, FINDINGS, AND RECOMMENDATIONS

After growing wildly for years, the field of computing now appears to be approaching its infancy. Recent revolutionary technological advances will eventually take us far beyond our newest, biggest, and best computers. Yet computers and computing have already fantastically increased our power to know as well as to do. They have made masses of data which were previously completely intractable accessible to analysis and understanding. They have made it possible to trace the consequences of theories and assumptions in a wide diversity of fields.

As computers and computing have become more powerful, they have invaded wide areas of industry, government, and the professions. Computers launch and guide missiles and antimissile missiles. Computers aid in engineering design, they control machine tools and chemical processes, they keep books, control inventories, and make out payrolls. In the production of newspapers and books, computers are used in alphabetizing and correcting text, and in justifying and hyphenating lines of type. Computers are used in the retrieval of medical information and in the analysis of voluminous business, social, and historical data. Indeed, it seems that the social and economic gains which can be made through the use of computers and computing may be limited chiefly by the availability of people who are able to apply these tools in new and useful ways.

In the field of scholarship and education, there is hardly an area that is not now using digital computing. Section XIV of this report cites examples from instruction in linguistics, business and social sciences, as well as mathematics, physics, engineering, geology, and biology. Use of computing in scholarly research ranges even more broadly, and includes the analysis of literary texts and the analysis, composition, and playing of music. Computing is a new resource in learning. It enables the student or the scholar to deal with realistic problems rather than oversimplified models. By lessening the time spent in the drudgery of problem solving and in the analysis of data, it frees time for thought and insight. Partly, it enables the student to do old things more easily, but more important, it enables him to do things he otherwise could not. Computing increases the quality and scope of education.

The widespread use of computing in scholarship as well as industry and government has come about not just because of a general enthusiasm for computers, but because this new tool has found vital and increasing use in each field in which it has been applied. Computers and computing are simultaneously an American resource and a challenge to America. Here indeed we have a lead on the world, a lead which gives us an intellectual as well as an industrial advantage.

If we are to exploit our opportunity fully, students in colleges and universities must see for themselves what a powerful tool computing is, and learn to use it. No matter what his specialty, the student must be given the opportunity of using computers in learning and in doing, and the faculty member must be able to use computers in teaching. Both the individual's opportunities and the progress, well-being, and stature of our society can be increased by adequate computing facilities for our colleges and universities.

Further, both in providing the necessary facilities and in meeting scientific and industrial requirements, we need more men who are deeply trained in computer science. While computers and computing supply all of scholarship and education with a new resource and a new opportunity, they also tax education and educators with new problems. It has been estimated that in January 1965 $7.2 billion worth of computers had been installed in this country, and the annual growth rate was estimated as 25 percent. About 185,000 college graduates were needed to use the Nation's computers. A projected annual growth of 20 percent in this number roughly equals annual engineering baccalaureates and exceeds those in mathematics or physical sciences. Computing must be available which is adequate for education in computer sciences as well as for education in other fields.

Happily, at some fortunate and forward looking colleges and universities the educational use of computers is widespread and effective. But this does not apply to the majority, where computing facilities are often absent or inadequate, or where their use is confined to a few specialties.

Can this deficit be remedied, so that no American need have second-rate education in this respect?

Because of the extremely rapid rate of change in the computer art, it is impossible to make useful long-range predictions, extending beyond the era of the new generation of powerful computers which are just coming into use. But, it is possible to estimate the cost of providing by means of these efficient new computer systems the high grade of educational use that is <u>now</u> available in <u>some</u> colleges and universities to <u>all</u> of our colleges and universities. One of the chief aims of this report is to estimate the cost of making up the deficit in educational computing and to show how the deficit can be made up while still supporting leadership and innovations in educational computing.

The recommendations we make are expensive, but if they are not carried out there will be a different kind of cost. Today, the best and richest institutions are able to carry part of the burden of educational computing. As time goes on, these institutions will improve the service they give their undergraduates, while smaller and poorer institutions will be trying to catch up. Many of them will be able to catch up to today's best in 10 or 15 years instead of the 5 years we recommend. If the deficit in educational computing is not made up quickly, millions of students who will have attended these institutions in the 1970's will be poorly prepared for the world of the 1980's and 1990's.

The answers we have arrived at are intended to apply over the period from late 1968 to late 1971. The new generation of large computers which is just coming into use will be predominant during most of this period. It will be a period during which techniques and apparatus which are now available and in limited or experimental use will become widely used. Although general computer technology will improve, we believe that during this period there will be no widespread revolutionary effects due to such advances as "microelectronics" and ultra-large memories.

The cost of providing adequate computing turns out to be large in overall magnitude, but the estimated cost of $60 per student per year averaged over all college students is comparable to the $50 to $200 per student per year for college libraries and an estimated $95 per chemistry student per year for a single chemistry laboratory course in a 4-year college. The total cost for adequate computing in connection with training in computer sciences will be a small part of the total cost of adequate computing for undergraduate education, so the average of $60 per year should provide for adequate educational use of computers in colleges and universities (exclusive of graduate research).

While the average cost of $60 per student per year is a small part (around 4 percent) of the overall educational cost per student per year, there is no place for it in the already tight budgets of America's colleges and universities. Further, the cost is growing rapidly compared with other expenses, and it must grow even more rapidly if adequate service is to be provided for all students. We believe that it is in the national interest to have adequate computing for educational use in all our institutions of higher education by 1971-72. We believe that this can be achieved, but we believe that it can be done only with government assistance.

The cost and use of computing in colleges and universities will and should be a small part of the total cost and use of computers in industry and in government.* But these major economically and socially productive uses are dependent on educational computing not only for the training of manpower, but for stimulation both in new and productive uses of computing, and in advances in computers and their software. Adequate

*In 1965 the capital value of college and university computers was $300 million, or one twenty-sixth of the total of $7.8 billion for the United States and the cost of computers used in instruction $35 million, or one-two hundred twentieth of the U.S. total, according to the report "Digital Computer Needs in Universities and Colleges," (Rosser report), publication 1233, National Academy of Sciences.

support of computing as a part of education is essential for a rapid and full realization of the social and economic benefits of computing.

While an investigation of the cost of and means for remedying our computer deficit in undergraduate education by 1971 is a chief purpose of this report, other purposes are to cast light on various opportunities and problems in the educational use of computers.

The report is divided into four main sections. The first is primarily concerned with computers and undergraduate education. The second considers education in computer sciences, mainly at the graduate level. The third discusses the interaction between research and educational use of computers. The fourth comments briefly on computers and secondary education.

The major findings and recommendations of the Panel are:

1. Approximately 35 percent of college undergraduates are enrolled in curricula in which they could make valuable use of computers in a substantial fraction of their courses. An additional 40 percent are in curricula for which introductory computing training would be very useful, and limited computer use should be part of several courses. The remaining 25 percent could make some use of computers in one or more courses during their college education, but computer training is not now important in their major studies.

In 1965 less than 5 percent of the total college enrollment, all located at a relatively few favored schools, had access to computing service adequate for these educational needs. However, it is practical to supply adequate computing service to nearly all colleges by around 1971-72.

> We recommend that colleges and universities in cooperation with the Federal Government take steps to provide all students needing such facilities with computing service at least comparable in quality to that now available at the more pioneering schools.

2. One of the major problems in providing the necessary educational computing is the cost. The yearly cost of providing this service will rise to a total (for baccalaureate programs and 2-year colleges) of about $400 million per year in 1971-72 in addition to the relatively smaller costs required for faculty training and associated research. It is beyond the capabilities of our colleges and universities to bear all of this cost in this time period.

> We recommend that colleges be encouraged to provide adequate computing through government sharing of the cost. Such governmental cost sharing should include special grants to cover transient costs when service is being initiated or larger facilities are being installed. It should also provide a portion of the annual cost of continuing service.

3. Government accounting practices have made it very difficult for colleges and universities to utilize fully that Federal and private support for computers or computer service intended for unsponsored research and education (as distinguished from research paid for by grants and contracts).

Treatment of a grant for educational use of a computer as a reduction in total cost reduces the hourly charge for computer time paid by all users and has the effect of shifting research costs to educational users. The Department of Defense has recognized this and now has an agreement with the National Science Foundation not to treat NSF educational grants for operating expenses as a reduction in sponsored research costs.

Many schools cannot now afford to pay for educational and unsponsored research use of computers by students and faculty even though there is time available on their computers. Consequently, some college and university computers now available for educational and unsponsored research use are standing idle for major portions of the operating week.

> We recommend that the present DOD-NSF agreement be extended to other government agencies and private supporters and include both capital and operating cost grants. Additional Federal funds should be made available immediately for support of computing service used for education and unsponsored research activities at institutions presently having the required facilities.

4. We find that any expansion of the educational use of computing depends heavily on increased knowledge of computing by faculty in most disciplines. Such knowledge usually can be provided by intensive 2- to 6-week periods of faculty education. The extensive activity of the National Science Foundation in sponsoring summer institutes provides a useful model.

> We recommend an expanded faculty training program to provide adequate faculty competence in the use of computing in various disciplines.

5. There is a great need for specialists trained in the computer sciences at the bachelor's, master's, and doctorate level. The whole success of educational computing and continued improvement in its use depends on expanded education and research in computer sciences. This education requires a good faculty and access to very good computing facilities for both course work and research.

> We recommend that the Federal Government expand its support of both research and education in computer sciences.

6. The cost of computing is a continuing expense, like light or water, rather than a capital investment, like the initial cost of buildings.

> We recommend that the Government agencies which support computing allow the schools to be free to apply the funds either to the purchase or rental of equipment and the support of staff, or to the purchase of service.

7. The optimum mechanism for providing computers will differ from campus to campus. However, in many cases it appears economical and effective to supply adequate and dependable service from large computing centers.

> We recommend that universities and the Government cooperate in the immediate establishment of large central educational computing facilities capable of serving several institutions.

8. Because of inconsistent Government and university accounting practices, the great variety of sources of computing support, and the experimental nature of computer use, some universities have had difficulty in determining and controlling their computer costs. Informed decisions regarding expansion and/or budgeting for current operations cannot be made without accurate cost information. Errors made at this stage can only lead to the diversion and dissipation of university resources needed for other educational purposes.

We recommend that universities and colleges develop and use accounting procedures which accurately measure the cost and utilization of computer services. With such information the allocation of computer time for research and education and the anticipation of associated costs should be made on a realistic and measurable basis.

9. Proper introduction of computing into secondary education is desirable and growing. Not enough is known about the best ways for introducing computing and we were not able to consider this adequately in the time available.

We recommend that NSF and the Office of Education jointly establish a group which is competent to investigate the use of computers in secondary schools and to give the schools access to past and present experience. Cooperation between secondary schools and universities, and particularly providing service to secondary schools from university centers, should be encouraged.

10. There is inadequate information about the number and level of skills of personnel now employed in the field of computers, and there are no meaningful forecasts.

We recommend that the Federal Government collect meaningful data concerning computers and the jobs, personnel, and educational facilities associated with them, and endeavor to make useful annual forecasts.

II. COMPUTERS AND UNDERGRADUATE EDUCATION

Computers in colleges and universities

Computers were first introduced into universities as rare and special pieces of equipment used for a few specialized sorts of research by small groups of people. Today, many universities and colleges have centers which serve most of the students, faculty, and administration both by providing training in programing and by meeting computing needs for undergraduate education, for research, and often for administration.

Where adequate computing facilities have been available, the faculty has made increasing use of computing in both research and education, and computing has become a part of more and more undergraduate courses, including business subjects, social sciences, biological and health sciences, psychology, geology and other disciplines, as well as mathematics, physics, chemistry, and engineering. This is consistent with the rapidly growing use of computing outside the schools in small as well as large business enterprises, in government operations and national defense facilities, and in almost all technology -- those many fields of endeavor where most college graduates will find their places. Computing is not an esoteric or specialized activity; it is a versatile tool useful in any work with a factual or intellectual content. Computing is becoming almost as much a part of our working life as doing arithmetic or driving a car.

Computers find a widespread use in education only when well-run facilities are easily available to all students and faculty members, with rapid service for all users. Under these conditions there are a number of instances (including, for example, Dartmouth and Texas A. & M.) in which a majority of all undergraduates learn programing and use computing in some part of their course work. While computing has not yet become an important part of undergraduate work in such field as English, linguistics, languages, history, music, and art, faculty members in some of these fields are making increasing use of computers in research, and computing is beginning to find its way into undergraduate instruction.

In all fields where computing has been used, it has added a new dimension to education, and has led the students to better comprehension of complex problems and greater insight into the meaning of quantitative expressions. In these areas undergraduates have learned, through preparation of and experimentation with computer programs, of the care required to define a problem logically and fully, and the assumptions needed to obtain answers to complex problems. We predict that in the future almost all undergraduates will use computers profitably if adequate computing facilities are available. There may be a few students in some fields who will not use computers at all, but they will be a small minority.

Using a computer is easy

It is possible to make effective use of computers without programing training. "Computer aided instruction" systems and some information retrieval systems (Medlars, for instance) are examples of uses which do not require appreciable programing knowledge. There are many other examples for which the user need only supply data to existing programs.

However, acquiring some knowledge of programing is easy, and it greatly extends the scope of the educational use of computers. This is particularly true when special student-oriented programing languages are used. Ten to thirty student hours spent in learning programing enable a student to use computers profitably in course work. This contrasts strikingly with the time needed to acquire a useful knowledge of mathematics or of a foreign language; it is more comparable to the time spent in learning to drive a car. It is the universal experience of all those with whom we have talked that students spontaneously made use of computers in solving problems or handling data even when this was not intended. A further evidence that learning to program is easy is that in many places programing training is extending down into secondary education.

Of course, when time permits, it is desirable to introduce computer use as part of a comprehensive basic course which includes more than just the elements of programing. In many colleges this is a one-semester introductory course with about 3 class hours per week. Such a course typically includes some elementary numerical analysis, a discussion of computer organization, an exposition of algorithms, and an introduction to several programing languages. But there is often effective use of computing without such a course.

The nature of educational computer use

The earliest educational use of computers provided instruction in programing followed by student use in solving assigned course-work problems adapted to computer solution. This procedure has been in effect for a number of years at the University of Michigan, at the Carnegie Institute of Technology, at Washington University, and a number of other universities, particularly in engineering. Examples of specific problems which are now being used by some of these schools may be found among the examples in Section XIV.

Continued familiarity with the computer allows students to use it in courses in which no such use is specifically required -- reducing data obtained in laboratory courses, or making statistical evaluations in sociology courses, for instance. Familiarity of faculty as well as students with computing leads to the assignment of computer-oriented special problems, and even to undergraduate student research projects which could not be carried out without computing. Such student work is valuable education and highly desirable.

It has been proposed that computers be used for "computer-assisted instruction" in which the student interacts with the computer during a learning period. It is clear that much of this will involve more than passively following a previously prepared routine; it will involve data analysis and data presentation. Whether or not computer-assisted instruction using a computer becomes widely used is an educational and economic problem. Surely, however, the cost of trying it to find how it works is a legitimate educational expense.

It is of the utmost importance to keep in mind that computing should not be thought of primarily as a new subject to be taught in addition to all the other important material now in the curriculum. Teachers who make use of computers in a wide variety of subjects have found that their material can be taught more rapidly, more thoroughly, and more meaningfully with the aid of computers. The examples given in Section XIV include comments by the instructors which specify why solving these problems with the aid of a computer has particular educational value.

We have second class education for the majority

Adequate computing is not available today in many fine small colleges. Further, even in many larger colleges or universities which have reasonably powerful computers, the computers are not accessible to the majority of undergraduates, either through lack of an appreciation of the usefulness of computing on the part of the faculty, or lack of suitable instruction, or lack of suitable computer languages, or through the way in which facilities are administered or financed. Yet these institutions train undergraduates of excellent ability. Many of these graduates will go out into the business world where they will need to understand and use computers. As evidence for this fact, in 1965 about $2.4 billion were spent for new computers and it is estimated that the salaries of the programmers and operators and associated overhead costs for installed machines more than equaled that amount. Consequently, the total expenditure for computers was more than $5 billion in 1965. These figures are even more impressive when we consider the rapid growth of computing. The freshman enrolling in 1966 will be employed in 1970 in a world using more than twice the computing capacity now available.

Many others of these undergraduates will go on to a wide variety of graduate work unequipped with a simple but vital skill in problem solving, and unaware of its power and versatility. The handicap of a lack of understanding and skill in the use of computers is extremely severe in all areas in which data analysis is vital, in learning as well as in practice -- in business, in the social sciences, in psychology, in geology, in the health sciences, for example. In a very real sense, students who have not learned to use computers are badly equipped for the postbaccalaureate world.

Based on the estimates for all university computer expenditures (research and education) contained in the Rosser report,* less than $25 million was spent on educational use of computers in 1965. Because of the large variety of computers and the uncertainties as to actual costs, it is difficult to interpret this figure. However, if all of this money had been spent for computing service from the largest and most efficient university centers (for example, using an IBM 7094 II at a cost of $300 per hour of processing), about 1 minute of computing was available per undergraduate for the entire year. Put another way, about 5 percent of the students could have received adequate computing service (about 20 minutes of processing for the year). In practice, this money undoubtedly was not used this effectively since it was necessarily distributed very unevenly.

We believe that undergraduate college education without adequate computing is deficient education, just as undergraduate education without adequate library facilities would be deficient education. At present, deficiency in computing is widespread. We believe it to be vital to the national interest as well as to the welfare of the individual student to remedy this deficiency quickly. How can the deficiency be remedied and what will the remedy cost?

What is adequate service?

What is adequate college computing service today, in 1966? Several things are essential even to the most modest user if the aim is education rather than hard knocks:

*"Digital Computer Needs in Universities and Colleges," publication 1233, National Academy of Sciences.

1. Adequate instruction in and consultation concerning computing. Besides a good introductory course, the student should have available adequate supplementary material, and someone available to help him when he has trouble. It is desirable that the operating system be kept up to date, but any changes in the system must be documented and users given help in adapting.
2. Adequate software. The writing of programs should be made as simple as possible. Failure to run should lead to good diagnostics. Various languages, and facilities for adding new languages, should run as part of the operating system without delays or changes in operation.
3. Reliable operation. Interruptions are bound to occur because of equipment failure, and there will be occasional interruptions because of hardware or software changes. However, if students and faculty are expected to use computers routinely, operation of a center must not be interrupted significantly by computer science experiments, unusual scientific or accounting jobs, or when examination time takes away those students who help to run the center. As far as is physically possible, the computing center should be open to users on a regular schedule.
4. A fast turn-around time. Instantaneous response is an ideal. Overnight delay is hardly tolerable. A delay greater than overnight is not acceptable for most purposes.

This is what can be called adequate in 1966. Other desirable things are available now and will be essential before 1971. These include:

a. Interactive remote consoles. Those who have used them in undergraduate education are convinced that interactive consoles are superior to batch-processing operation. When using these consoles the student types a program and special commands to the computer and then receives a response from the computer while still seated at the typewriter. The response either points out errors or inconsistencies in the program or presents the results of the requested computation. This reduces the time required to prepare a correct program or presents the results of the requested computation. This reduces the time required to prepare a correct program and provides immediate reinforcement to his learning process.
b. Graphic output. In many cases, graphs or scatter diagrams or drawings are more desirable than tabular printouts as output. Present equipment can produce such plots on 35 mm. microfilm negatives cheaply, quickly, and without laborious programing. The negatives can be used in a reader or large prints can be made if desired.
c. Visual displays. The immediate presentation of graphic data on a cathode-ray tube is an extremely powerful tool in teaching a large variety of subjects. It is used currently in many applications.
d. New forms of input. Many new applications or modes of operation require special input devices such as the following. (1) Direct connections allow data to be transmitted directly from experimental apparatus rather than by reading meters and typing the values into the computer. (2) A character recognition scanning device makes some typed or printed

material available as input without requiring laborious keypunching. (3) A "light pen" combined with a cathode-ray tube allows one to give directions to the computer by pointing at a selected portion of a display and allows one to draw input graphs.

Who should use computers?

We have outlined features of good computing service which are now available, and indicated others which will be available soon, to a small percentage of students at a few colleges. What portion of the undergraduate enrollment has immediate need for such service?

This question was approached by classifying the needs of major curriculum divisions as substantial, limited, or casual. In the first category (which includes all engineering students, for example), an introductory course in the freshman year would allow the students to make routine use of the computer in many courses throughout their undergraduate career. Students in the second category (many business students, for example) will probably take an introductory programing course at an early stage of their education and then make some use of the computer in three or four other courses during their 4 years as an undergraduate. Students in the third category -- such as English majors -- may not make any use of the computer as part of their major study, although it is quite likely that even they will be exposed to it and find it useful in a few courses.

By sometime in the 1970's it is doubtful that more than a few percent of the students will graduate without having made some use of computers. A rough guess of the portion of the undergraduate enrollment in each of these categories as of about 1972 suggests that approximately 35 percent will make substantial use, 40 percent will make limited use, and 25 percent will make casual use.

Problems to be overcome

If good quality service is to be made available on a large scale there are four primary problems which need to be faced: First, how are the required funds to be obtained? Second, how can the necessary facilities be provided? Third, what faculty education is necessary? Fourth, how can the costs be controlled?

Problems of paying for computer service

It is reasonable to ask why the use of computers and the implementation of computer techniques in undergraduate education is singled out in this report for such extensive Federal support. Our colleges and universities clearly have a central responsibility to pioneer in and to adopt new educational techniques and methods. What is so special, then, about the use of computers in education?

The answer lies in the extremely rapid growth rates in computer-related costs which are being experienced by many universities (and should be experienced by more of them). Universities and colleges, whether public or private, are all faced with rising costs and a precarious balance between income and outgo; the public institutions are overwhelmed by the tidal wave of student enrollment, whereas the private institutions are struggling to provide improved student services and to keep pace with rising faculty salaries in an enterprise dependent upon relatively fixed income sources.

Many of our institutions of higher learning have already responded to the significance of computers for all aspects of their programs by establishing new departments of computer sciences. Such a step is a major one for any university, involving new long-range commitments to faculty tenure and to providing building space. Yet, in addition to these very substantial financial loads, the universities also face the very high cost of hardware and manpower to generate and use software. And these total costs are mounting at incredible annual growth rates -- figures as high as 45 percent per year are given in the Rosser report -- which are an order of magnitude larger than the budgetary growths universities are used to providing from their own funds, with great effort, to academic divisions.

Rightly or wrongly, the long range commitments and relatively fixed income components of American institutions of higher learning simply do not allow rapid turnoff of existing programs nor rapid generation of substantial new non-Federal sources of income. The colleges and universitites face an explosively advancing technology in a technique which very likely will have revolutionary implications for undergraduate education and for the Nation -- with institutional financial resources which may permit response at only one-tenth of the rate adequate for keeping pace with the developments.

The sources of computers and of funds for computers and computing service at universities and colleges have been various and confusing. For example, IBM supplies machines and service free and shares operating costs at the Western Data Processing Center at UCLA. IBM uses half of the computer time and the other half is used without charge by UCLA and over 100 other participating institutions. The latter pay only for either wire transmission costs if terminal facilities are on their campuses, or for the mailing of programs and data. The equipment and operating costs of computing at the Irvine campus of the University of California are at present a part of the educational budget. At one college visited, a wealthy benefactor had recently given money for a computer which was hurriedly chosen and purchased without adequate advice or consultation with the faculty. The computer had inadequate hardware and software and no adequate provision was made for its operation, but due consideration was given to the benefactor's dislike for paying rent.

Great good has been done through donated computers, obsolescent computers, huge educational discounts, grants for the purchase of computers, and the struggles of enthusiastic men with inadequate machines. However, computers that are both free and useful will in the future be available to very few users. Further, the operating costs of a computing center are substantial and easy to underestimate. Computers become obsolescent in a few years, so that money spent in buying a computer provides for only one generation of students. Computing is rather a continuing expense than a capital investment. Obtaining computing is not like buying a building, it is like paying, year in and year out, for light or water.

In seeking efficient and effective computing, a school should choose wisely among various options. (1) It can purchase service from a commercial service center. (2) It can obtain service from a university service organization such as the Western Data Processing Center at UCLA. This requires only card punches and a printer, or perhaps consoles, on its own campus. (3) It can run one or more of its own computing centers which are generally accessible to users. (4) It can provide various departments with computers for limited or restricted use.

The last is almost certainly the most costly, for it tends to lead to low usage or to careless, noncompetitive and unevaluated usage; in one guise or another it calls for a greater total number of maintenance, operating, and programing consulting personnel, and it makes it hard to keep software and hardware up to date. Further, the rental cost per unit operation will be higher.

To the unwary, the third alternative can easily seem to be more economical than paying for computing service. It is easy to forget the inevitable cost of expanding, replacing, and updating both hardware and software. It is easy to underestimate the cost of computer time used in updating the center and making it serve with high efficiency various different needs, old and new, including the running of undergraduate educational programs and the running of powerful research programs. It is easy to underestimate the cost and the difficulty of obtaining and holding personnel who are adequate to keep the center current.

With all these alternatives available, it is very desirable to allow a school to choose that one which best suits its needs and circumstances. Consequently, we strongly recommend that the Government agencies which support computing allow the schools to be free to apply the funds either to the purchase or rental of equipment and the support of staff, or to the purchase of service.

Estimation of cost of adequate computing for undergraduate education

Universities get computing at bargain rates compared with industry. Either there is no charge for space, or the charge is much lower than in industry. Reasonably skilled student help is available at as low as $1.25 an hour, and salaries for professional help appear to be lower than in industry. Educational discounts have reduced machine costs. Certainly, those who pay for campus computing get it at a bargain rate.

Even though educational computing seemingly comes at bargain prices, adequate computing can be a backbreaking burden for an institution which has no place for it in an already tight budget. We find that some of the most advanced institutions with the best computer services are the hardest pressed for funds. Those who are least hard pressed for computing funds are those which have no computing to trouble their budgets. These institutions which stand most in need of computing will have the greatest difficulty in finding funds for it. We do not believe that adequate educational computing can be established throughout American higher education in the near future without some new source of funds. It is, of course, important that colleges demonstrate conviction and earnestness by bearing what burden they can -- in manpower and enthusiasm as well as in dollars. But to succeed they will need financial help.

In Section XII we estimate the cost of providing in all our colleges and universities educational computing at a level of a relatively advanced school in 1965-66; e.g., Dartmouth. Costs per student per year depend on the field of study, and range from perhaps zero to at least as much as $120 per year. The estimated total cost averages approximately $60 per student per year. To meet this goal by 1972, the cost for all colleges would rise from $100 million per year in 1968-69 to $414 million per year in 1971-72.

Although this is a small fraction of the total yearly cost of student education in colleges and universities (about $9 billion* in 1971-72), it is still a large cost. But it is not large compared with the costs of many other facilities which are deemed essential. Let us, for instance, compare the average cost of $60 per student per year with some other costs.

Perhaps the most direct comparison can be made with the library. A sampling of college and university libraries indicated that operating costs range between $50 and $200 per student per year. According to the 1965 Digest of Educational Statistics the average current fund expenditure for libraries in 1963-64 was about $48 per student. This is probably an underestimate of the real costs since it is unlikely that it properly allows for donations and depreciation. Thus, the computing expenditure being considered is roughly comparable to that for a minimal library.

Another comparison can be made with the cost of a laboratory used for specialized training. A freshman chemistry laboratory, for example, is estimated to cost $95 per year per <u>chemistry student</u> taking this laboratory course. This includes the depreciation for building and equipment, cost of expendables, salaries for laboratory staff, but not faculty salaries.

The average total cost per student per year is difficult to determine from the accounts kept by most universities. However, it has been estimated to range from a low of $900 at some small liberal arts colleges to more than $4,500 at the best technical schools. From the Digest of Educational Statistics the current-fund expenditure for all institutions in 1963-64 for educational expenses was $5.5 billion. The total plant value was $17 billion and if we estimate depreciation and interest at the low value of 5 percent, total educational expense was $6.3 billion or $1,250 per student. Thus, the computing expenditure we are considering is about 4 percent of present annual cost.

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*This does not include organized research or expenditures for auxiliary enterprises or student aid.

We wish to make it clear that the figures cited above, though they may seem large, represent only the money needed for all our schools to get where some are now. However, the facilities on which the calculations are based are able to meet the needs of very advanced computer users for either research or educational purposes. This will open the way to even more imaginative and computationally demanding educational use of these systems. Such experimentation should be encouraged wherever possible even though it may require additional expenditures.

Providing the funds

Several government agencies have been supporting the growth of computing in colleges and universities. The NSF, ARPA, NIH, and AEC have all recognized the needs even though they could provide only modest support and that mainly for research. We are now urging large scale support of computing for educational purposes. Several government agencies have been supporting the growth of computing in colleges and universities. We do not wish to make detailed recommendations as to which agencies should provide this support and how they should implement a program. However, it seems desirable that the Office of Education should be much more active than it has been. For this reason, we recommend that the Office of Education, in cooperation with other government agencies, actively encourage colleges to provide adequate computing through sharing of the cost. Such governmental cost sharing should include special grants to cover transient costs when service is being initiated or larger facilities are being installed. It is particularly important that the Government be prepared to provide a large fraction of the annual costs of this service. Such support should be planned and administered on a long term basis.

Problems of providing facilities

We believe that even if money were available, adequate educational (or research) computer centers could not be staffed in all the colleges and universities that need them in the next 5 years. There are simply not enough able, experienced people available to the colleges to do this.

It would be practical, however, by enlarging and modernizing well-run university computing centers to give adequate remote service to a considerable number of other colleges and universities in their geographic areas. If the distance between the center and the school served is not excessive, communication costs would be tolerable. Such expansion and modernization of centers would have an additional benefit in providing experienced universities with improved facilities for their own computer science education and research. In some cases it will be necessary to set up new centers (run by groups of colleges organized for this purpose or by private companies) to provide this service.

Large computing centers can provide high quality remote service while using a batch--processing type of operation. The system in use at Case Institute of Technology furnishes a particularly good example of this. However, present experience tends to show that immediate access to computers through interactive remote consoles will be practical and desirable, rather than a luxury. It is a conclusion, rather than a recommendation, that a large part of the necessary computing service will be provided by systems of this sort.

Extensive use of large computing centers providing remote service to several schools should alleviate the staffing problems and help reduce costs, but it does lead to some other problems. First, although there is some experience with the management of such joint centers, much more will be needed. In Section XII it is suggested that many such cooperative arrangements can be initiated immediately using standard batch-processing systems in order to provide experience as rapidly as possible. Second, different schools have differing characteristics and it is not easy to achieve the necessary cooperation among the participating schools. It is important that the computing service be designed to meet the needs of all the schools insofar as possible. Third, the transmission costs can be excessive if suitable facilities and tariffs are not provided. However, aggressive action on the part of the universities, the Government, and appropriate industry can overcome these difficulties.

Many of the larger schools will need the entire capacity of one or more of the largest computers available to provide for their own research and educational usage. However, wherever possible, it is desirable that these schools also supply computing service to smaller nearby schools. In a few cases this may even justify and require the use of more than one large computer at a center. We recommend that universities and the Government cooperate in the immediate establishment of large central educational computing facilities located and equipped so as to be capable of serving several institutions. In particular, it would be desirable that the funding procedure encourage the development of such centers. Provision should be made for supporting the centers while usage builds up, or in the face of temporary fluctuations in usage.

In making the cost estimates cited above, it was assumed that service would be provided from (in 1971-72) hundreds of advanced computer centers, using the best new-generation machines provided with remote consoles. We are convinced that this is an economical way of supplying service. It was for this reason that we made this assumption as a means for estimating total cost. While we expect that much of the service will be provided from such centers, we do not intend to specify any single means for supplying service. Some day it may be possible (though this seems to us very unlikely) for one computer to serve all of the Nation's users, but that is not yet. Some day it may be possible to obtain the best grade of service from a small computer on each campus without problems of operation, maintenance, or obsolescence, but that day is not yet. Today, it takes several large machines, which may use remote consoles as well as batch processing, to serve the various needs of a very large university, while one machine can serve the needs of a smaller university or of a number of colleges. Certainly, colleges will not obtain educational computing in a completely uniform and entirely predictable way.

It seems desirable and likely that in many, if not most, cases educational computing will be supplied from university centers which are also used for research and perhaps for administrative computing. In some cases small colleges may be so remote from existing or new centers that they may have to establish and use limited computer facilities of their own. Finally, as we have noted, some needs for educational computing may be met through centers established by groups of universities, or through private services.

Problems of educating faculty

Obviously, the faculty plays an important role in determining the rate at which computing is introduced into undergraduate courses. We feel that an intensive effort will be required to show the faculty the advantages and importance of computing and to help them to learn to use computers effectively. A number of suggestions to this end are contained in Section IX.

There are basically two types of faculty education required if educational computing is to find a useful place in a college. First, the campus must have at least one faculty member who can teach a good basic programing course. This faculty member can be in any department -- his prime attribute can be enthusiasm. Many young faculty members are already reasonably well qualified to teach such courses; others will need to participate in summer institutes or other special programs.

The second type of faculty education which is needed is more difficult to provide but is not unfamiliar. It is the basic education associated with any substantial revision of course material. To take maximum advantage of the computer it is frequently necessary to integrate new problems into a reorganized course. Planning problems and preparing the course revision require a large amount of time and effort from the faculty members involved and a consequent reduction of available teaching staff. Once done, of course, the normal amount of effort required from faculty members to keep abreast of a field is sufficient to make such courses generally useful by all members of the department. The examples in Section XIV illustrate the results of this kind of problem planning at several schools. The final report on "The Use of Computers in Engineering Education"* contains a list of 66 problems for various engineering fields. The rate at which problem planning and course revisions can be carried out depends heavily on faculty interest and on their understanding of the power of the computer as well as on the availability of facilities.

Because of the great importance of this faculty education, we recommend an expanded faculty program of education to provide adequate

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* "The Use of Computers in Engineering Education," final report of project supported by the Ford Foundation, College of Engineering, the University of Michigan, Ann Arbor, Mich., Jan. 1, 1963.

faculty competence in the use of computing in various disciplines. The Government should provide all funds necessary to support such a program.

The problem of controlling computing

It has often been proposed that computing should be an overhead item -- that it should be supplied to students and faculty without any formal procedure of allocation, as is library service. We believe this to be unrealistic.

It is perfectly possible for one user to write one program which justifiably (although more often unjustifiably) will run one or more days on the most advanced computer available. Such a monopolization or pre-emption of a university library never occurs and thus does not pose a comparable problem.

Although most computer runs are short (less than a minute), to arbitrarily limit the time any program can run would preclude some important and legitimate uses of computers. Further, in the absence of adequate control, students can fritter valuable time away in meaningless computer use even when the running time is short. Therefore, control cannot be exercised by just limiting the maximum length of any run, but instead requires that cumulative use records be maintained for each user. We find that institutions which have a well-run computer center keep careful records of computer costs, and keep careful records of computer usage by assigning job numbers and charging computer time against jobs. This accounting will be more complex but no less essential for remote consoles.

Some universities (Michigan, for example) allocate computer usage among various departments on the basis of time. Others (Harvard, for example) allocate computer usage on the basis of dollars. We believe that measurement in dollars is more meaningful to users and is more useful in comparing the value of computing the value of, say, laboratory apparatus or special-purpose computers than is measurement in terms of computer time. Regardless of whether the unit is time or money, it is important that some allocation procedure be used which provides effective control.

Measurement of computer usage in dollars need impose no extra burden on faculty members, and might indeed eliminate the burden of arranging or begging "free" computer time here and there, as some faculty members must do at present. For example, faculty members can have budgets (the source may be university department funds, contract or grant funds) from which their students' computer costs for basic instruction, course problems, or research work can be supplied.

Keeping just account of costs of computing can be a powerful tool in university and agency hands in avoiding unprofitable research programs. The cost of extremely lengthy computations in various fields, including medicine, information retrieval, and artificial intelligence, should at all times be clear to the research worker, the university administration, and the funding agency. This does not mean that a uniform accounting system should be imposed on universities, but merely that the accounting system used by each university should be clear and should apply to all computing services.

We recommend that colleges and universities develop and use accounting procedures which accurately measure the cost and utilization of computer services. With such information, the allocation of computer time for research and education and the anticipation of associated costs should be made on a realistic and measurable basis. This should encourage a more balanced allocation of funds for research and educational uses.

III. THE COMPUTER SCIENCE STUDENT

We have noted in the introductory section of this report the magnitude and rate of growth of computing in this country and the need for more men trained in computer science.

Computer science advances and changes as rapidly as all of the computer art. Thus, it would be futile as well as highly undesirable for us to try to describe or prescribe in detail what computer science is or should become. That is a matter best left in the hands of the academic community, to evolve through interaction with the computer industry and users of computing, academic, and nonacademic.

Computer science had its academic origins in designing and building computers in universities. Indeed, the very first electronic digital computer, the Eniac, was built at the Moore School of Electrical Engineering at the University of Pennsylvania. Today, it is no longer appropriate for a university to build a large-scale machine to provide its routine computing service. We also believe that the time is rapidly passing when it is appropriate for every university to develop a large-scale system program for its routine computing center. These aspects of hardware and software will be largely the province of commercial enterprises because the great effort involved in such developments cannot be carried out without excessive delay in the universities.

Yet men must be educated to understand hardware and software very deeply. By providing such education, the universities cannot only supply the computer industry with needed expert manpower; they can strongly influence progress in both hardware and software. Progress requires both university research and commercial enterprise. In general, universities will work on special hardware and software necessary to exploit computers in new ways for new or more efficient uses. This will include the design and construction or adaptation of special peripheral equipment, the development of the necessary software, the devising of new program languages, and the derivations of special procedures or algorithms for obtaining desired results.

Education for such research in computer science includes theoretical studies of machines and machine organization, the study of software and languages and their relations to a wide variety of disciplines, the study of hardware, and appropriate background work in mathematics, physics, and other fields of engineering and science.

This work calls for access to and interaction with a good computer center.

Since many computer science departments also grant a master's degree, it is difficult to separate the undergraduate use from use at the master's level. Graduate work in computer science calls for substantial use of computer time in carrying out research on software and toward new computer applications. Such time may often more appropriately be paid for out of research project funds rather than as an educational expense.

The demand for people trained in computer sciences exceeds the supply. In fact, we have noted previously that one argument for supplying educational computing remotely from centers which serve many schools is that there is not enough trained manpower to establish and staff good computer centers in all colleges. In trying to evaluate the needs, we have been unable to find adequate data on the number of men with various skills now employed in the computer field in industry, government, and schools, or any meaningful estimate of the number who will be needed in the future.

We strongly recommend that the Federal Government collect meaningful data concerning computers and the jobs, personnel, and educational facilities associated with them, and endeavor to make useful annual forecasts. We caution that because of the rapid evolution of the computer art and its highly technical nature, useful studies must rely on well-informed and astute knowledge of the state and evolution of the art as well as on statistics.

Despite the importance of instruction in computer sciences, the total amount of computing connected with such instruction will certainly be small compared with the total amount of undergraduate educational computing which we have estimated earlier in this report because there are so many fewer computer science students than there are college undergraduates. Thus, if the deficit in undergraduate computing is made up, as we propose, an adequate amount of computing would be available for computer science education. It is of course important that such use be recognized as a part of the educational use of computing.

We must not, however, overlook the quality of computer facilities necessary for good education in computer sciences. In order to provide the computer experts who are needed to produce the new computers and computing techniques which are so vital to our national defense, to increasing our productivity, and to improving our standard of living, we must have excellent computer science departments at a number of schools. Though computer science education and research need place only modest demands on a large computing center, the quality of the center is of utmost importance.

It is hard to see how a master's program in computer science can be conducted without use of a center of such quality that costs would be about $1 million a year. Of course, most of the yearly cost of the center would be covered by charges for uses other than computer science education. For first-rate doctoral work, a center at the forefront of the art is desirable. We estimate the annual cost of operating such a center to be around $3 million. This, for instance, is the yearly expenditure of Project MAC at MIT.

We recommend that the Government expand its support of research and education in computer sciences. Such support should encourage the development of "centers of excellence" in computer science.

IV. INTERACTION BETWEEN RESEARCH AND EDUCATIONAL USES OF COMPUTERS

This report is addressed primarily to the use of computers in education. Nonetheless, we have clearly expressed our belief that the best and most efficient computing is most likely to be obtained from large computing centers with the most modern equipment. These centers can provide for educational uses, but they can also be used for all kinds of research.

It seems very desirable to favor large, up-to-date university centers which can serve a variety of needs, including research and administration as well as education. This is particularly desirable in that the educational load may be more seasonal than the research load, so that a system serving educational needs alone might be nearly idle in the summer. Though the funding of research and administrative computing costs may well be different from the funding of educational costs, it is only reasonable to ask that educational needs as well as research needs be taken into account in establishing and operating large computing centers.

Government accounting practices have made it very difficult for colleges and universities to utilize fully that Federal and private support for computers or computer service intended for unsponsored research and education (as distinguished from research paid for by grants and contracts). Treatment of a grant for educational use of a computer as a reduction in total cost reduces the hourly charge for computer time paid by <u>all</u> users and has the effect of shifting research costs to educational users. The DOD has recognized this, and now has an agreement with the National Science Foundation not to treat NSF educational grants for operating expenses as a reduction in sponsored research costs.

We recommend that the present DOD-NSF agreement be extended to other Government agencies and private supporters and include both capital and operating cost grants.

There is another way in which research computing may seriously affect the educational use of computers. We believe that unless computers used in research are managed wisely and effectively, money which might be used to advantage in education may be wasted.

We have observed that most colleges and universities have no adequate provisions in their budgets for educational computing. For research computing, funds are often available through project grants from various Government agencies. Yet even here the Westheimer report* shows that in the field of chemical research, in 1963, of $4.2 million value of computation, only $0.56 million, or 13 percent, was paid for under research contracts, while in 1964, of $6.4 million only $0.72 million, or 11 percent, was paid for out of contracts. The difference represents "manufacturers discounts, grants made to computer centers by the Government, and hidden support of chemical research from the universities themselves."

The Westheimer report anticipates a very rapid growth in computing in connection with chemical research, just as a rapid rise in all research computing is to be expected. Unless adequate provisions are made for the support of research computing, the very resources which are needed for educational computing, and indeed, for the rest of education, may be drained away by unforeseen research needs.

Thus, it is extremely important that in planning for support of research, Government agencies plan for adequate support of necessary computing. It is equally important that universities keep adequate account of the cost of computing and allocate computing services, measured in either time or dollars, so as to provide for their educational needs. It is particularly important that universities do not carelessly allow overruns in research computing to penalize the education of their students.

V. THE COMPUTER AND SECONDARY EDUCATION

Training in the use of computing and in the nature of computers and computing is rapidly but randomly invading secondary education. We have felt it impossible to approach the problem of computers and secondary education quantitatively both because of the sheer magnitude of the problem and because of the lack of quantitative information. However, through personal experience and the testimony of others we have formed some preliminary opinions concerning the problems involved.

The advantages of introducing the use of computing into course work and of teaching something about the nature of computers and computing in secondary schools can be considerable, either as a preparation for college work, as a preparation for semiprofessional or vocational training, or as a preparation for employment. Such training in secondary schools will increase rather than decrease the amount of educational computing required in colleges and universities.

There can, however, be real disadvantages to an unwise introduction of computer training in high schools. Detailed and narrow training

*"Chemistry: Opportunities and Needs," National Academy of Sciences, Washington, D.C., 1965.

in commercial programing languages and the operation of commercial computers has apparently led some able young people to accept dead end jobs in a market hungry for people with computer knowhow, when they might better have gone on to college and fitted themselves for more productive and rewarding places in our economy.

Vocational training in computers and computing has a legitimate place in terminal secondary education, but this may not be the chief contribution which computing has to make to secondary education. Secondary-school students should be taught what computers and computing are. In addition, it may be that computers can be used to improve the teaching of many courses. Computers may be useful in stimulating the interest of students who cannot be reached in other ways.

Computing is best used in secondary schools by means of convenient facilities, such as remote consoles, and simple instructional programing languages. Instruction in the nature of computers and computing can be by means of special texts supplemented with specially designed experimental equipment.*

Unfortunately, this approach is contrary to much that is now being done in secondary education. Sometimes the computer used is one which is used for administrative purposes, which may be ill adapted to proper introductory instruction. Sometimes the computer used is a small machine purchased or rented primarily for instruction, but awkward to use and of limited computing power compared with a remote console attached to a large modern machine -- or even compared to job shop operation by courier or mail on some accessible more powerful machine.

This is not to deny that good and useful secondary-school instruction can be carried out with less than optimal facilities. But we believe that money is often spent, and financial obligations incurred (through the purchase of computers which will be expensive to replace when they become obsolescent and expensive to maintain at all times) which could be better applied in securing service from a more suitable source. Indeed, many secondary schools may, for want of guidance, reexperience all the difficulties that universities and colleges have already gone through in coping with computers and computing.

As to financing computing in secondary education, there is some evidence that some communities and school boards have been liberal in financing computers and computing in secondary schools. Thus, the lack in many cases may be one of guidance rather than of funds. This will not, of course, be true in remote or underprivileged areas.

We urge that the Office of Education and the NSF jointly establish a group which is competent to investigate the use of computers in secondary schools and to give schools access to past and present experience.

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*Such as the material in the text, "The Man Made World," and the associated experiments being prepared by the Engineering Concepts Curriculum project under the auspices of the Commission on Engineering Education.

Cooperation between secondary schools and universities, and particularly providing service to secondary schools from university centers, should be encouraged.

Computers and computing are already invading junior high schools and elementary schools, and this same recommendation should be applied to junior high school and elementary education.

VI. COMPUTERS IN HIGHER EDUCATION

Introduction

In attempting to assess the educational need for computers in colleges and universities, we find ourselves compelled to believe that within a decade essentially all university and college students will require some basic understanding of digital computation. We believe this will require all institutions offering collegiate level instruction to have on campus sufficient input-output facilities to permit students to prepare problems for digital computation and to receive results; the actual computer may, in many cases, be remotely located. Every such institution will also require, on its staff, enough faculty with computer experience to teach computer use and provide computer experience in the various disciplines.

In short, we believe that the computer and computing are rapidly coming to have an impact on the life of practically every member of our society. Most people educated beyond the high school level will have occasion to make use of these tools, and all will need sufficient understanding of their possibilities and limitations realistically to appraise the new opportunities now available for information processing.

While many of the arguments which compel us to believe in the desirability of very widespread acquantanceship with computers are spelled out in the Rosser report, we wish to emphasize a few key points.

The rapidly increasing use of digital computers in this country is documented. A $2.5 billion industry with a 25 percent per year growth rate in capacity and a similar growth rate in people to develop and operate the computers is significant in itself, especially since the numbers do not include the large number of military or special purpose industrial computers now in use.

In all parts of education, government, or industry, digital computer use has come about because it is an effective tool. Each new use leads to several more -- like bookkeeping, inventory control, airlines reservations, on-line control of manufacturing processes, design of structures, diagnosis of disease, market analysis and forecasting, design and analysis of experiments in the social and natural sciences. It is a new tool with unusual implications.

Suddenly, it seems, the computer and its many applications has opened a new technical field to women. Of all technological fields the computer area shows the greatest growth in the employment of women, largely those with baccalaureate degrees in mathematics. And the large growth in mathematics degrees is a major factor in the total increase in science and technology baccalaureates in recent years. At a time when technical "manpower" is in ever shorter supply, the almost 50 percent addition possible through the use of "womanpower" is a boon indeed. It is a boon both for the numbers available and for the breaking down of traditional attitudes which discouraged women from entering technical fields.

In national defense computers are the unique ingredient. No airplane can fly without one; no missile guided or defended against. Effective materiel procurement requires them. Transport of supplies by ship or rail is planned by them. Space exploration could not be done without them. Nuclear reactors require them. But every use demands people who are at home in the computer world. People must have understanding of computers which varies from that of the highly specialized Ph. D. designer to the crucial technician maintainer and operator. Now to mechanical know-how most Americans must add computer know-how. We need to encourage the same love affair with the computer that we now have with the automobile.

In every day life the computer problem looms equally large. Automation is the usual name for the problem. It means using computers to control machines and processes previously carried out by human labor. A threat perhaps, but equally an opportunity. Many people can be relieved from jobs of mental or physical drudgery. With additional training they can carry out more complex jobs using computers than their abilities allowed before. How many checkout clerks in supermarkets could add well enough to hold their jobs without a computer -- the cash register?

Clearly some acquaintance with digital computers will be as essential to the next generation as is now familiarity with the automobile and the radio. It will need to know what a computer is, its uses and limitations. For college and university students the time required to get such familiarity may be about that to learn to drive a car. Unfortunately, parents can't teach about computers so the colleges and universities must.

An estimate of needs

A quantitative estimate was made by classifying the needs of major areas of study as (1) substantial, (2) limited, and (3) casual. Category 1 includes primarily all the biological and physical sciences and engineering and roughly half the social sciences, mathematics, and business and commerce. Category 2 contains the other half of mathematics, social science, and business plus three-quarters of education. Category 3 includes mostly the humanities.

In category 1 an introductory course in the freshman year would allow students to make routine use of the computer in many courses -- probably more than 50 percent -- throughout their undergraduate career. Students in category 2 will probably take an introductory programing course at an early stage of their education and then make some use of the computer in three or four other courses during their 4 years as an undergraduate. Students in category 3 need not make any use of the computer as part of their major study although it is quite likely that even they will find it useful in a few courses. By sometime in the 1970's it is doubtful that more than a few percent of the students will graduate without having made some use of computers.

A rough guess of what percent of the undergraduate enrollment will be in each of these categories as of about 1972 is based on 1963-64 data given in figure 1. Assuming that the relative enrollments in these major areás of study will not change substantially from these figures, about 35 percent of the students will be making substantial use, about 40 percent limited use, and 25 percent only casual use of computers in their undergraduate education.

A common characteristic of both the general and professional education in computers is that the student is gaining understanding of and facility with a tool. Such instruction is often best given, in terms of motivation and of drill, in connection with the study of the discipline for which the tool is important. Thus we would expect that students of education might learn digital computation in connection with analysis of educational statistics. Introductory physics students might find digital computation a powerful tool for reduction of experimental data or in simulation of experiments.

Institutions will differ in the way in which they introduce students to digital data processing, and this is healthy. But if the most is to be made of limited time -- and every new subject introduced into the college curriculum now faces rigorous competition from other subjects which can make excellent claims on the student's time -- it is important that computers be used to extend rather than displace the student's grasp of other subject matter. The problems listed in Section XIV, and the faculty comments on their use, indicate that this principle is already understood and applied on campuses now making the most use of computers.

In undergraduate education the computer offers especially exciting possibilities in teaching the formation of hypotheses or theories. Physics, for example, has been very successful in describing and explaining the physical world because theories could be constructed and results calculated on the basis of fundamental principles. Yet it still is sometimes hard to separate the logical from the empirical content of our knowledge of physics.

As Prof. W. M. Huggins of Johns Hopkins University has pointed out, computer methods now permit us much more readily to examine the logical consequences of a given set of assumptions in nearly any discipline without turning to analogous systems in the real world which imperfectly realize the assumptions. In these situations, the implications of theory may be examined with a "pure" system in which a prescribed sequence of operations can be performed precisely as specified without any uncertainties or irrelevancies from the real world contaminating the investigation.

This manmade world of the computer will enable all disciplines to a greater or less degree to generate an idea, hypothesis, or theory, and test its value completely independent of its practical realization. Added to this possibility is the computer's ability to handle data with all the complexity that exists in the real world. Such powers have never existed so extensively before and have tremendous potential at all levels of the educational process.

An important plus

We have discussed the need for and cost of education in the use of computers as a tool in solving problems in various disciplines. This seems to us the most direct route to knowledgeable use of computers by students and faculty. But the presence of a computer, or its input-output terminals, on a campus creates an additional opportunity with equally great rewards.

These rewards could come in the form of assistance in the teaching-learning process itself. Many exciting new experiments have the student interacting directly with the computer through typewriter, visual, or audio presentations. With competent and careful programing of the computer, one finds it helping the student to construct answers rather than picking them from a list; to learn as he would from a teacher.

The potential rewards to the student and increased effectiveness of the teachers merit intensive development of computer assisted learning at all educational levels. With large computers, more faculty experienced in their use, and better input-output devices, this teaching process can be explored and developed toward the end of the period we are considering. It is possible that productivity gains will provide much better education at very reasonable costs.

The educational value of computing

Obviously, it is not possible to establish definitely the value of computers in the educational process. Not only is there inadequate experience as yet, but the entire educational process involves many intangibles. It is possible, however, to compare the estimated cost of $60 per student per academic year with the costs of some other educational facilities to allow a judgment as to whether the balance is reasonable. A sampling of college and university libraries indicated that operating costs range between $50 and $200 per student per year. According to the "1965 Digest of Educational Statistics" the average current fund expenditure for libraries in 1963-64 was about $48 per student. This is probably an underestimate of the real costs since it is unlikely that it properly allows for donations and depreciation. Thus, the computing expenditure being considered is roughly comparable to that for a minimal college or university library.

Another comparison can be made with the cost of a laboratory used for specialized training. A freshman chemistry laboratory, for example, is estimated to cost $95 per year per <u>chemistry student</u> taking this laboratory course. This is the marginal cost of this course; i. e., it includes the depreciation for building and equipment, cost of expendables, salaries for laboratory staff, but not faculty salaries nor general university overhead expenses.

The average total educational cost per student per year is difficult to determine from the accounts kept by most universities. However, it has been estimated to range from a low of $900 at small liberal arts colleges to more than $4, 500 at the best technical schools. From the "Digest of Educational Statistics" the current-fund expenditure for all institutions of higher education in 1963-64 for educational expenses was $5. 5 billion. The total plant value was $17 billion and if we estimate depreciation and interest at the low value of 5 percent, total educational expense was at least $6. 3 billion, or $1, 250 per student. Mr. Harold

Figure 1. --Classification of Computing Needs by Major Areas of Study (Based on bachelor's degrees conferred in 1963-64)

	USAGE		
	Substantial	Limited	Casual
Agriculture			4, 600
Architecture		600	
Biology	23, 000		
Business and commerce	28, 000	28, 000	
Education		84, 000	28, 000
Engineering	33, 000		
English and journalism			35, 000
Fine and applied arts			16, 000
Foreign language and literature			12, 000
Forestry		1, 300	
Geography		1, 200	
Health	1, 000	10, 500	
Home Economics			5, 000
Library science	500		
Mathematics	9, 500	9, 000	
Military	2, 500		
Philosophy			4, 700
Physical sciences	17, 500		
Psychology	7, 000	6, 500	
Religion			3, 600
Social sciences	38, 000	38, 000	
Others			12, 000
Total (460, 000)	160, 000	179, 000	120, 900
100 (Percent)	35	40	25

Howe, U.S. Commissioner of Education, has stated (New York Times, Mar. 27, 1966) that costs to undergraduates in public institutions now average $1,560 a year and in private colleges the present annual average is $2,370. Thus, the computing expenditure we are considering is about 4 percent of present annual cost.

Finally, a collective assessment of the value of computing to the national economy and welfare is represented by the expenditure of business and government for acquiring and using computers. It is estimated that the salaries and related overhead of the programers and operators for existing computers more than equals the approximately $2.4 billion spent in 1965 for new machines. Consequently, total expenditure was more than $5 billion in 1965. Thus, the educational expenditure estimated for 1971-72 is less than 8 percent of all 1965 computing expenditures. The growth rate projected guarantees that the educational expenditure will be much less than 8 percent of the actual computing expenditure in 1971-72.

What we are saying, then, is that university and college administrators must recognize education in computers as a pressing need and opportunity. It is an opportunity that can be grasped successfully for about a 4 percent increase in their operating budget. This is no mean feat in times of rising costs in all other areas of operation. But a 1 percent rise might be possible if the other 3 percent came from Federal support. Certainly such a joint effort is essential if computer education appropriate for this country is to come about.

VII. SOME FACTS OF LIFE ABOUT COMPUTERS

The mode of using computers has changed steadily through the years. In the earliest days of computers, each user took his program individually to the machine and used the computer either until his problem was solved, or until he ran out of assigned time. This is no longer feasible except in the use of obsolete computers which have been replaced but not discarded, and when one considers maintenance and space for such machines, it is of dubious merit. One can learn something about hardware and diagnostics by maintaining a computer, but one learns nothing about computer usage by having the computer physically accessible.

One of the first advances in adapting computers to easy use was the open shop together with batch processing. Open shop operation means that anyone who follows specified rules can get a program run, not just a selected group of programers. By batch processing we mean that the programs and data for a lot of jobs which various people want done are put on a magnetic tape and run through the computer in sequence. This means that all programs to be run must conform to certain rules, and use the input and output facilities which are provided for all. All these functions are implemented by a small amount of additional hardware and a large executive or system program to manage the operation automatically.* Batch processing can cut down the turnaround time, the time between handing a job in at a computer center and getting an answer back, to one or two hours.** As computers have come to be used by more and more people for a greater variety of jobs, even this may be too long to wait for an answer.

A recent development which makes computers more efficient and more flexible in use is called multiprograming. The flexibility is obtained by having the computer take up tasks in order of their ease or brevity. This is similar to a garage mechanic's having a 5-hour job but taking on easier 5- or 10-minute jobs as they come in. By interrupting the larger job periodically, more customers are satisfied and no one must wait for a very long time. In multiprograming the computer can leave a long job partly done to take on other, shorter ones, then return. This procedure also leads to greater efficiency. Without multiprograming, the entire expensive computer system can be held idle if processing is delayed for any reason; for example, if a new input tape must be mounted during the course of computation. This wastes both time and money, and computer time can be worth as much as a thousand dollars an hour. With multiprograming, another job, or part of a job, can be started (or even completed) during these necessary interruptions.

With multiprograming it is possible to use in one computer many controls and many arithmetic units. This is called multiprocessing and permits many users to have access to the machine simultaneously. This is called multiple access. Instead of having one line of jobs coming in one door, there are many doors with jobs coming into whichever doors are most convenient. The computer now cannot stand by one door, but must look all around. Thus there are many input terminals. For instance, at Dartmouth and in Project MAC at MIT, a number of computer users have keyboards by means of which they can call on one central computer.

When there is multiple access to a computer, the computer must decide which input to attend to. This depends not only on what the computer decides is efficient, but on the requirements of the inputs themselves. In some cases, for example, those involving data transmission from distant cities, the information must be handled when it is received. In other instances semiautomatic readout of information (as from satellites) must be handled periodically in order to avoid storage overload, but the computer is more or less free to choose the time. In yet other cases, high-volume inputs such as punched card readers must be serviced very frequently in order to avoid pileup.

*Programs of this kind become an integral part of the computer to users, and so are often called "software" as a contrast with the hardware. The other computer operating schemes mentioned in the remainder of this section are also implemented by a hardware-software system, not by hardware alone.

**By use of a special system at the Case Institute of Technology, turnaround time for simple student problems has been reduced to 5 minutes or less.

It is possible to have multiprograming without multiple access, but providing multiple access efficiently requires multiprograming as well. Most computers do not yet have multiple access, but the newest generation of large machines is well adapted to multiple access. Both multiprograming and multiple access permit increased efficiency of computing facilities and produce better service for more users. We do not yet know what the increase in efficiency will be.

Another rapidly changing feature of computer usage is in input and output equipment. In analyzing data, computers must be able to accept input in forms other than magnetic tape. In some cases they must be able to pick up readings from measuring instruments. In processing photographs of the tracks in bubble chambers or photomicrographs of human chromosomes, computers must be equipped with something like a television pickup device. Using this, the computer must be able to pick up data from different parts of the picture at different times, parts chosen on the basis of what the computer has laready found in the picture.

Modern computers have also been equipped with special output devices which can draw pictures as well as with special input devices which can read data from pictures. By programing a computer to draw a sequence of pictures, each differing a little from the previous one, a computer can be made to produce animated movies.

Sometimes it is desirable to obtain a diagram from a computer output without taking a picture and waiting for the picture to be developed. This can be done by storing the output numbers from the central computer in the memory of a small auxiliary computer. This auxiliary computer can then draw pictures on a cathode-ray tube (which is like a TV picture tube), pictures specified by the numbers stored in its memory.

The interaction between man and machine is an essential element in many modern uses of computers. The computer types out a text, or draws a picture, or places packages for minimum wire length, or calculates the deflections in a mechanical structure, and a man observes the result and makes alterations to correct defects or to improve performance. Multiprograming, multiaccess, and peripheral computers and visual displays are important elements in making such interactions between man and machine quick, easy, and efficient.

VIII. COMPUTER LANGUAGES

Any computer is built to respond to a repertory of instructions which cause the machine to perform arithmetical, logical, and input and output operations. These instructions, which are built into the computer, are called the machine language of the computer. The machine language of the computer may consist of two or three hundred (or even more) instructions or words.

The machine language of early computers was simpler though less powerful than that of present computers. And all programing was done in machine language.

Today, the majority of people who use computers do not use or know machine language. They write programs in some symbolic, simplified language which is adapated to the problem they wish to solve. The computer is then used to compile a machine language program, which is then run on the computer. The computer operates under a complicated systems program which controls the programs used to translate from symbolic, user-oriented languages into machine language, provides diagnostic printouts when a program fails to compile, and makes it easy to handle input and output.

The best known symbolic language is FORTRAN (formula translation) which is adapted to numerical computation. FORTRAN is unnecessarily complicated for student use. Several special simple languages have been developed for student use, including MAD (University of Michigan), BASIC (Dartmouth), and CORC (Cornell). These are easy to learn. Perhaps even more important, they take less compiling time, and hence cut down on computation costs.

A large computer with a good operating system will handle programs in many special-purpose languages: languages to simulate economies or machines, languages to do algebraic manipulations, languages to design bridges and electrical networks, languages to produce musical sounds and motion pictures.

The provision of appropriate, adequate, and efficient languages is one of the most vital ingredients in the wider and more effective use of computers. This is a strong reason in favor of providing students and faculty with access to a large and powerful computer, rather than a small computer of limited flexibility and capability.

IX. EDUCATING THE FACULTY IN USE OF THE COMPUTER

This section focuses on training the faculty in computer methods. If the rapidly expanded use of the computer creates financial problems for the colleges and universities, so does it pose a problem for faculty members most of whom were educated prior to the present computer revolution. How can they become adequately conversant with computer methods, and how much effort does it involve?

The greatest initial effort to aid faculty members should probably be for disciplines which are already making substantial use of the computer. Engineering comes to mind immediately as an outstanding example. Statistics is another good example of an important computer application; it touches many areas of the social sciences, biological sciences, and physical sciences. It is probable that many faculty members may have their first occasion to consider use of the computer in connection with statistical problems.

Younger faculty, who are closer to their graduate student days, may have greater awareness of the growing importance of the computer, and they may, therefore, be among the first to bring pressure on the computation center staff to learn about the computer. But it has been pointed out that a relatively short interval of intense training can prepare a faculty member to make effective use of the computer, and it is clear that many faculty members from all age groups will -- and should -- want to become conversant with the computer.

Need to solve a particular set of problems or to keep current in one's field provides an important motivation for a faculty member to seek instruction in use of the computer. This instruction should be followed by self-teaching and learning by doing. Another motivation for the faculty member is his desire to keep pace with his students who have found the computer fascinating and useful. These motivations are present to varying degrees for most faculty members, and the proper response of the institution is to make it as easy as possible for faculty to respond to the urge to learn more about computers. Such learning cannot nor should not be forced.

Here the role of the administration is in providing opportunities. It can also be helpful if, as new faculty are recruited to various departments, individuals knowledgeable in computer techniques are added. These men can be extremely helpful to their departmental colleagues.

Instruction at no monetary cost to the faculty should be offered in a variety of ways; for example, short courses during the academic year, seminars between regular semesters or quarters, and longer courses during part of the summer. Some of the courses should be so general that a faculty member from any discipline can attend and gain something from the discussion. Others should be discipline-oriented and present special techniques that have been advanced to solve particular problems.

It is very important for the faculty to recognize that the time needed to cross a significant threshold of understanding so that one may begin to do useful work for oneself and his students is very low compared to a discipline such as mathematics or operations research or languages. A 1-week laboratory-oriented course of instruction on computing will enable a motivated faculty member to solve some problems in his own field and provide for him a basic knowledge from which he can advance on his own.

There is evidence, from experience at schools such as Dartmouth, that a nearby console and simple programing languages, if available, make it especially easy for a faculty member to learn and to experiment with the new tool in spare moments and in private. But whether or not this especially ideal arrangement for learning is present, the statement emphasized in the preceding paragraph is valid.

For faculty members who have been contemplating that one of these days they ought to get around to learning something about using computers, the advice is simply: start now. Nearly every college and university computing center has knowledgeable individuals who are delighted to help their faculty colleagues discover this powerful new tool.

X. THE LARGE UNIVERSITY COMPUTATIONAL FACILITY

The pattern of the past

In the past, computation has usually come to colleges and universities through a proliferation of computers around the campus, each computer assuming a single role such as teaching, research, or university administrative data processing. While this "solves" the problem of administering computers, albeit in a costly and redundant manner, it generally begs the question of how the computation might best serve the needs of education, and it establishes artificial boundaries which tend to stifle the healthy growth of university computer use.

Not long ago computational devices and the data processing devices were different. Each had a different set of operations and different mode of operation. This made several installations about the campus not only desirable but necessary. The so-called third generation of data processing devices has tended to join the two divergent path trends.

The place of the computer in the university

The advent of time sharing, terminals of many types, and the modular computer makes computation more flexible and powerful, but it makes the administration of computation more difficult. In the past a computer has often been administered by some special group which uses it the most, has the money to support it, has the space to house it, or sometimes merely has had the courage and energy needed to obtain the device. While all of these reasons were probably valid at the time the computer was obtained, the passage of time and changing conditions will almost certainly invalidate the original reason for control of the computational facility by a single department or specialized group.

The one thing certain about computing devices of today is that their uses will continue to evolve rapidly. Through such evolution the use of the device spreads through all departments of the university, and will probably become heaviest in data processing rather than in numerical computation.

In order to permit the use of the computers to transcend the normal boundaries of the various university disciplines it is prudent to establish a facility to serve all and sundry areas of the university.

A proper global view by its management enables the computation facility to react to the combined needs of the whole university rather than just the particular needs of a single department or group.

The ultimate administration of the facility should rest in the hands of an administrator so placed as to be cognizant of the total needs of the university. Due to the leadtime necessary to obtain additional or replacement computational equipment, the administrator of the computational facility must be aware of the long- and short-range plans of the university in order to have time to react to planned changes.

It is essential that the management of the facility have sufficient independence so as not to be dominated by any one division of the university and that there be enough intellectual leadership in the center so that it can understand the educational goals of the administration and be competent to work with the faculty and students. Caution should be exercised to make certain that all users have a forum in which their needs and dissatisfactions can be heard. When communication ceases, the usefulness of the facility decreases. This is particularly vital in the field of computer sciences. The computer sciences faculty should not be burdened with the administration of a computer center. Nor should their research and teaching interfere with the continuous and effective operation of the center in providing service. However, computer science people should have a strong voice in the introduction of new hardware and software and in adapting computers to new uses.

Facility orientation

The chief reason for existence of a computation facility is to provide computation, whether for teaching, or research ranging from history to computer sciences. As long as the facility operates with this goal in mind it should prosper and will probably grow. If, by design or accident, the primary goal of the facility changes from service to some other pursuit, there is a high probability that the facility will falter and probably fail.

In view of the large dollar value associated with computer devices and staffs, it would seem reasonable that all campus computational facilities should be coordinated through one person having the responsibility for the total computational and data processing needs of the campus. If this needed coordination is not provided, it is possible that computational facilities will spring up in several areas and attempt to provide overlapping services. The costs of data processing are high enough at best without further increases due to inefficient management.

The most critical need in university computation is that of a long-range plan. Since the average life of a computer is on the order of 3 years, and the time between order and delivery of the device is on the order of 2 years, it is readily evident that a 5-year plan is the minimum tolerable. In order to plan 5 years ahead, we must peer over the computer designer's shoulder in order to see far enough ahead to have the needed lead time.

Since the universities are training the men of the future, it seems obvious that the men should be trained on the most modern equipment available today in order to have a fair chance in the world of tomorrow.

In view of the proliferation of computer languages and dialects it might behoove the university community to sort through these languages and begin to select the ones which should live and prosper, and through teaching and use attempt to standardize a very chaotic situation.

Facility operation

In order that the facility provide adequate quality service, it must be user directed. While one computer can work in practically all areas of problem solving, it is rather doubtful that one person can work in all areas. This situation requires that problem-oriented people serve as an interface between the user and the computer. Many of these problem-oriented people will be administratively outside of the facility; some may be within it. The number of interface people will vary widely with the number of user areas served by the facility and the extent of experience and capability of the interface personnel.

In general, the staff of the facility will fall into four categories: (1) administrative, (2) operational, (3) software oriented, (4) user oriented.

The administrative personnel should concern themselves with the long- and short-range plans of the facility while continually coordinating the efforts of the other three groups.

The operational personnel should be concerned with the daily operation of the facility and should attempt to maximize through-put and minimize turnaround time.

The software-oriented personnel should concern themselves with the operating systems of the facility, ever conscious of the needs of both the user and the operations staff. The availability of good software is probably more important than good hardware. It is not necessary or desirable for most schools to write large operating system programs since they will be available from other sources. However, it is important that software-oriented personnel be available to interpret, modify, update, and add to these programs.

The user-oriented personnel are the outward face of the computer facility. They should serve as the buffer and interpreter between the user and the facility. A failure in the first line of defense can well make the rest of the facility ineffectual.

The proliferation of terminals will cause the staff of the facility to be more widely dispersed. The operational staff will have to stay with the computer hardware but the remainder of the staff can go wherever communication lines permit. In general, the user-oriented personnel will follow the terminals. In most cases this will be a short distance from the computer, but in others it could be to other campuses some distance away. As this move occurs it will become necessary to frequently return these people to the mother house for upgrading and rejuvenation.

The machine

If we accept the premise that all computing gravitates to the largest possible machine, small machine proliferation becomes untenable. While this does not preclude the use of small special-purpose devices for special tasks, it does seem to preclude the need for each user group to have its own machine and appropriate staff.

An unfortunately common first step into the computing field is the acquisition of one or more small machines with complete open-shop operation. While this type operation is rewarding to the user, it is somewhat difficult to justify on a cost basis, and the user soon becomes disillusioned by the limited size and speed of the machine.

At this point most of the users are willing to forego some of the freedom of small machine operation in order to acquire size and speed. The next step is the acquisition of a large high-speed machine to be operated in the batch processing mode. In most instances the small machines remain.

Thus begins the migration from machine to larger machine, in an effort to get the computing capability needed.

Each machine change leads to an anguished period of problem restatement, reprograming, and reorientation. Each machine change brings glee to some and pain to others. One cannot start with the small system and go to the large system without major upheavals or major discontinuities.

The third generation of modular computers with their building-block design and complete upward compatability may make future increases in computing capacity less painful.

If we can assume that the present concepts of a modular computer are to be in vogue for a reasonable length of time, then a progressive plan with incremental steps can be outlined in such a way as to reduce the alternate feast and famine of computational capability brought about by the discrete computers of the past generations.

The advent of the time sharing systems with the provisions for terminals, shared memories, shared peripherals, shared processors, and teleprocessing, should permit the university to lease or purchase just the amount of computing needed and be able to react quickly to changing requirements.

When the terminal is mentioned, one normally visualizes a typewriterlike device with someone operating the keyboard at a poor typing rate. The term terminal should be taken to mean any input-output device available. One can visualize not only typewriterlike terminals in using areas, but also high-speed readers and printers, graphical display devices, and small peripheral computers which store data and process it to some extent but call on the central computer for difficult processing and computation. Such terminals, and problem-oriented languages and compilers open a whole vista of possibilities for university computation utilizing a central processor and time sharing.

XI. WHAT COMPUTER FACILITIES ARE APPROPRIATE

The larger college or university

A college or university large enough to utilize the computational capacity of a typical computer system would probably decide to operate such a system within its own walls. In the past, this has been supported by a combination of manufacturers' discounts, a Federal grant (usually from the NSF), and funds from the university itself. In some cases complex arrangements with manufacturers have been worked out so that the institution itself bears a relatively small portion of the total cost. In most institutions, the presence of Federal grant money for related projects is used, and in some cases actually sought, to offset part of the operating expense. The extent to which this additional support is available will vary widely, but it cannot be expected in the future to be used to offset costs of educating students. Furthermore, it would be difficult for many predominantly teaching institutions to attract the amount of research funds needed to make any sort of dent. Thus, it would appear that the methods by which colleges and universities have equipped themselves with computers cannot be counted on to supply future educational needs on a broad scale.

Smaller colleges

There are two ways in which smaller colleges can begin to provide computing power for educational needs. The first is through the acquisition of a "small" computer, such as has been done quite often in the past with the help of matching grants from the NSF Undergraduate Instructional Equipment Branch. This has, in the past, been an effective means for introducing computing to a large number of small colleges, those that were able to present a convincing argument to the National Science Foundation. The small computers provide a good mechanism for the training of a corresponding small number of students, many of whom have been in the past headed for further training in computer science. However, the inability of a small computer to present a truly sophisticated software system for the user will prevent this method from becoming an important vehicle for mass training and indoctrination in elementary programing and principles of computing. Further, the financial burden of this course is high. Manufacturers' discounts have been lowered, and the housing of a computer may pose significant financial hardships on many colleges.

Small colleges

Perhaps the most sensible way for small colleges, and many larger institutions, to provide educational computing service to their students is to obtain one or more teletypewriters or similar consoles connected to a very large and very sophisticated computer system through telephone or telegraph lines. This approach has several advantages. First, the amount of computing power to be supplied to a given school can be easily tailored to the amount of funds that are available. Second, the institution does not have to assume the task of administering, and sometimes developing, a large-scale computer system. Third, every student has the advantage of being able to call on the most sophisticated software systems, something that most institutions could simply not supply on their own.

Actual experience has shown that a single teletypewriter can expose computing to hundreds of students during the course of an academic year. Naturally, a deeper involvement in computers with more frequent exercises will require additional teletypewriters.

One small college has actually used this method to get started in computing. Harpur College in Binghamton, N.Y., has been connected to the Dartmouth Time-Sharing system for almost a year. They plan to obtain their own large computer, but would also be quite happy to hook into a "New York Educational Data System Network."

The ability of a time-shared computer system to provide computing power flexibly, quickly, and in a wide range of quanta, permits a wide variety of administrative structures for providing this service. Large schools, of course, can have their own private computer system. They would be able to experiment with various aspects of computer science and should do so. Components of a state university system could expect to obtain whatever specific computing they needed by tapping into a statewide network.

Secondary schools

The argument for obtaining service from a time-shared computer system is even stronger in the case of secondary schools than it is in the case of small colleges.

In general, the purpose of secondary-school education in the use of computation should be to enable the student to understand the nature, ease, and power of computation, and to use it in course work in a variety of subjects. This is best done through the use of simplified languages which are not available on small computers.

Any instruction in the nature and organization of computers is best done through special laboratory equipment and experiments, not through operating a computer designed to perform useful calculations.

Teaching technical skills in standard programing languages and in computer operation may indeed divert very able and enthusiastic students from an academic career. Such skills, which now have a ready market, may well be rendered obsolete by future rapid developments in hardware and software. However, such training is necessary now, but it is not appropriate as a part of a college preparatory secondary education.

XII. ESTIMATION OF REQUIRED COMPUTER CAPACITY AND COST

Introduction

Estimating the required computer capacity and its cost is difficult because of the complex interrelationship of the needs, the variety of available facilities, and the uncertainty in the possible rate of growth. All of these factors are complicated by the fact that large time-sharing systems for which we have limited experience will be widely available during this period. On the basis of available data and experience we believe that the simple programing languages, convenient terminals, and rapid access of time-sharing systems will lead to a faster growth rate and a more widespread use than with older batch-processing systems. For example, at Dartmouth, within 2 years after installing a time-sharing system, usage grew from essentially zero to the point where more than one-half of the students used the computer each quarter. Further time-sharing systems appear to be an economical means of providing high quality computing service to almost all schools. Purchasing such service is particularly attractive to the large number of schools which do not now have well-trained computer center managers.

Consequently, even though many schools may find it feasible and as economical to use another approach; e. g., a very good batch-processing system such as the one at Case Institute of Technology, we decided to base our estimates on the capacity and cost of computing provided by large time-shared centers. We believe that the costs arrived at in this way are close to those for any other efficient and effective means for supplying service; the use of less efficient computers could, of course, lead either to higher cost or inadequate service.

Estimation of needed capacity

The basic unit in the calculation was chosen to be the average number of hours each student is at a console in each week. This figure was estimated as one-half hour per student per week. (Very roughly, this would be equivalent to one-half minute of processing per week on a large batch-processing computer.) It was obtained by estimating that those students making substantial use of the computer would total 130 hours at a console during their 4 years, those making limited use would total 46 hours, and those making casual use would total 18 hours. The average use during a 4-year curriculum, based on the estimated classification according to major areas of study, is then 0.35(130)+0.4(46)+0.25(18)=69 hours. This is 17.25 hours per year or about one-half hour per week of the school year. The total hours of use in each category might be made up as follows:

Substantial	Hours	Limited	Hours	Casual	Hours
Introductory course	10	Introductory course	10		
10 other courses, 12 problems per course	120	4 other courses, 6 problems per course	36	3 courses, 3 problems per course	18
Total	130	Total	46	Total	18

Many commercial computer manufacturers will be able to deliver suitable time-sharing systems in the interval from 1968 to 1972. To be specific, approximate calculations were made based on approximate costs of two similar systems soon to be available -- the IBM 360-67 and the GE 645. As nearly as can be determined at this time, one of these (dual-processor) systems should be able to service approximately 150 active consoles for this type of use. Although service could be available nearly 24 hours a day, 7 days a week, a practical maximum of 100 hours use per console per week is more reasonable. This means that one such center can provide 150 x 100 = 15,000 console hours per week.

Combining the estimates of use per week and console hours available, one center can serve $15,000/\frac{1}{2} = 30,000$ students. This calculation does not depend on the distribution of the students; i.e., one center is needed for a single 30,000 student university or for 30 colleges each having an enrollment of 1,000. In order to get the total computing capacity needed for any year, the estimated enrollment is divided by 30,000. Thus, in 1971-72 the estimated enrollment of 5.5 million students in baccalaureate degree programs would require the capacity of 183 such centers. Forty additional centers would be needed to provide for a 2-year college enrollment of 1.2 million.

Estimation of costs

The cost of providing this service includes three components: (1) the cost of operating the center, (2) the cost of the consoles, (3) transmission charges for connecting the consoles to the center.

Cost of operation center

This cost component was calculated by using approximate rates for the 645 and 360-67 and reasonable guesses for actual costs at a university of the operating staff, space, and consumables. These latter costs are about the same as those for large batch processing systems now being run at such schools as Michigan, Berkeley, Texas A. & M., etc. No allowance is made for educational discounts since these are uncertain and, in any event, should be considered as outside educational support rather than reduced costs. In order to consider costs on an academic year basis, it is assumed that the computer can be used for research or special summer programs during summer months so that only nine-twelfths of the yearly cost should be charged.* It is possible that some research use could be provided during the academic year in the 68 hours of the week not accounted for by the operation assumed above, but this will depend on time-sharing systems achieving a reliability which is yet to be demonstrated so this possibility is ignored. The cost of the first component is then obtained as follows:

Annual equipment rental	$1,500,000
Annual staff, space, consumables	300,000
Annual total	$1,800,000

Academic year total 3/4 x $1,800,000 = $1,350,000
Cost/student $1,350,000/30,000 = $45

* Special consideration would have to be given those cases in which greatly reduced summer usage would cause financial problems.

The annual equipment rental assumed in this calculation is actually somewhat below the actual cost of a well-balanced configuration which would probably be used in all centers also providing for research work. However, accounting methods will probably take account of the simpler requirements for student programs and therefore reflect a reduced rental reasonably close to that assumed in the calculation. The annual cost for staff, space, and consumables could go as high as $700,000 per year which would add $10 per year per student to the cost. However, many universities seem to be operating at a rate close to that assumed so we shall use that figure.

Cost of the consoles

To average 150 active consoles and still avoid long queues, and to provide for faulty equipment, it is necessary to have more than 150 consoles available. The number needed depends on the distribution of the students since a rather small excess would suffice in case all 30,000 students were using consoles in one room but 100 percent excess is probably needed in the extreme case of 150 small 200-student groups. Therefore, the number of consoles needed for each center will vary between 150 and 300. A reasonable estimate of their cost is $125/month. Since most students are in schools needing at least 10 consoles, it is assumed that about 25 percent excess is adequate. The cost per student per academic year is then 125 x 9/200 x 1.25 = $7.

Cost of transmission

The transmission costs are very difficult to estimate since they depend on the geographical distribution of the centers and the students. Our calculation does not really specify the number of centers, let alone their distribution, since it is based on educational use only. It is likely that the number of centers will be at least two to four times greater since the research use will continue to exceed educational use. Three cases might be representative.

1. University -- 15,000 students, a research load about equal to the educational computing load. In this case the transmission charges are essentially zero since the center could be supported on this one campus and local line charges are negligible.

2. College -- 1,600 students, 100 miles from computing center. Need an average of 8 active consoles, assumes that 12 will be provided. The 12 transmission channels can be supplied with one Telpak A facility which has 12 terminals. Line charges ($15 per mile per month for 12 channels)
   $15 x 100 miles = $1,500 per month
   $1,500 x 9 months = $13,500 per academic year
   Terminal charges ($30 per terminal per month)
   $30 x 12 terminals = $360 per month
   $360 x 9 months = $3,240 per academic year

Total charges per academic year = \$13,500 + \$3,240 = \$16,740

$$\text{Cost per student per academic year} = \frac{\$16,740}{1,600} = \$10$$

3. College -- 400 students, 200 miles from computer center.
   Need an average of 2 active consoles, assume that 4 will be provided.
   Line charges (\$2 per mile per month per channel)
      \$2 x 200 miles x 4 channels = \$1,600 per month
      \$1,600 x 9 months = \$14,400 per academic year
   Terminal charges (\$24 per terminal per month)
      \$24 x 4 terminals = \$96 per month
      \$96 x 9 months = \$864 per academic year
   Total charges per academic year = \$14,400 - \$864 = \$15,264

$$\text{Cost per student per academic year} = \frac{\$15,264}{400} = \$38$$

Considering these calculations as reasonable limits, the cost of transmission can vary between \$0 and \$38 per student per academic year.

A sampling of the 1964 college enrollment figures shows that about 13 percent of students are enrolled in schools with less than 1,000 total enrollment and about 37 percent are in schools with more than 10,000 total enrollment. We assume that the latter group is typified by the first college, the former by the third college, and the remaining 50 percent by the second college. A rough estimate of the average transmission cost per student per year is then 0.13 x \$38 + 0.50 x \$10 + 0.37 x \$0 = \$10.

Total costs

The total of these three components of cost in 1971-72 is summarized in the table below.

ANNUAL SUPPORT NEEDED IN 1971-72

	4-year colleges (in millions)	2-year colleges (in millions)
Enrollment	5.5	1.2
Computing, \$45/student	\$247	\$54
Consoles, \$7/student	38	8
Transmission, \$10/student	55	12
Total	\$340	\$74

How the transition can take place

Assuming that adequate support is provided to reach this level by 1971-72, how can the transition take place?

By the 1968-69 academic year, manufacturers will be able to install from 2 to 10 powerful, high-capacity time-sharing systems at universities with a staff able to manage them. In addition, there are likely to be at least another 10 to 20 simpler and smaller systems, such as the one at Dartmouth, in use at universities. However, the bulk of educational computing will still be provided via batch-processing (but multiprogramed) systems. Between 80 and 120 colleges and universities which now have large computing centers (using machines classified in the Rosser report as type A, B, or the larger members of type C) will have increased their capacity by changing over to the larger, faster, and cheaper machines now being installed by many manufacturers.

These installations (in particular the more than 50 schools having centers based on type A or B machines in 1966) will have the facilities and skilled personnel to be able to provide service remotely to several hundred other colleges. This service will be provided via special terminals which provide card punching, printing, and card reading; e.g., the IBM 360/20, UNIVAC 2000, GE 115, or others. Such terminals will make reasonable computing service available to many campuses without requiring large numbers of skilled operational personnel to begin operations. At the same time it speeds the development of the competence of computing center personnel at both ends of the scale. The large centers providing the service will gain experience in the problem of running centralized services; the smaller schools obtaining the service will become familiar with the requirements for providing and using good service.

By the 1969-70 period some 20 to 40 other schools should be capable of managing time-sharing systems and by 1970-71 an additional 40 to 80 will have caught up. Thus, it appears to be possible to develop the competence to manage large centers of this sort at the same rate at which manufacturers will be able to deliver such systems during this period. To maximize the development of this management ability, the larger colleges and universities should be encouraged immediately to increase the size of their computing centers and to use the extra capacity to provide remote (batch-processing) service to other campuses.

Support during the transition

How much support will be needed during the interim period? In the Rosser report approximately $60 million (including almost half of the computer science use) was projected as the cost of educational computing in calendar year 1968. This projection was based on a 1965 survey and a conservative 20 percent growth rate. If we assume that this is approximately correct for the academic year 1967-68 and apply the conservative 20 percent growth rate used in the Rosser report, $72 million would be the cost for 1968-69 assuming that no special measures are taken to accelerate the educational use of computing. This is about 20 percent of the support level that we recommend for 1971-72.

If a special effort is made prior to mid-1968, it should be possible in 1968-69 to take a significant step beyond the growth projected in the

Rosser report. One portion of this step would be represented in the additional educational use made of the (between 2 and 10) large time-sharing systems installed by this time. Assuming five such systems installed, the total cost for that academic year would be about $8 million. However, these systems would all be located at schools which now have well-developed computing centers and a portion of this cost, say 75 percent, is already represented in the Rosser report projection. Thus, the additional support represented in these systems is only about $2 million.

Another portion of the step would be represented in the additional remote terminals connected to the larger batch-processing centers that will exist in 1968-69. One of these terminals can be provided for about $40,000 per year ($20,000 for equipment rental and transmission costs, and $20,000 for personnel and space). Providing such service to 200 colleges in this year would increase costs by about $8 million and should make reasonable quality computing service available to an additional million students.

The final portion of the step would be represented in an accelerated growth rate in educational computing use at schools where good computing service is available. By providing funds so that no available facilities must be idle, by supporting faculty training programs so that interest is stimulated, and by using the remote terminals to make service available to more students, the growth in this year could be brought to 50 percent rather than 20 percent. Thus, instead of the growth from $60 million to $72 million projected in the Rosser report, the increase would be from $60 million to $90 million. (This increase includes $6 million of the $8 million costs projected for time-sharing systems.)

Combining all these elements, the total level of expenditures which we believe to be attainable and efficiently usable in 1968-69 would be $100 million. Of this, $8 million might be used for large time-sharing systems, $8 million for remote terminals connected to batch-processing systems, and $84 million for computing centers primarily using batch-processing systems.

In order to achieve the desired level of computing service by 1971-72, a 60 percent growth rate would be necessary. This would imply a support level of $160 million in 1969-70 and $260 million in 1970-71.

XIII. THE COMMUNICATION PROBLEM

Everything points to an increasing use of powerful central computers connected to remote consoles of a variety of types. When all consoles are on a single campus, the cost of communication between consoles and computers is small. However, it is highly desirable to provide service to colleges and secondary schools which may be tens or even hundreds of miles from the central computer. In this case the cost of data transmission may be a major obstacle to the educational use of computation.

Various suggestions for cheaper communications have been made. In the case of an integrated system -- a State university system, for instance -- the State university could operate its own private data transmission network, in which case the educational computing power could be transmitted along those lines. This network might consist of long lines or perhaps microwave relay or coaxial cable. Or, a small piece of an educational television circuit could be used. The data requirements for a teletype machine are small and could be handled by a very small band in the TV circuit.

However, the only communication facilities which are immediately available to interconnect all schools, wherever they may be, are common-carrier communication facilities. It seems possible that common-carrier communication could be provided for substantially less money, both through technical improvements in the use of present facilities, and through providing classes of service more appropriate to present and future needs.

There are present service offerings in which the messages for a group of from 10 to 20 teletype consoles are multiplexed electronically for transmission over a single telephone channel. However, these services are not available in all areas as a standard offering. Work toward improving and reducing the charge for such service might prove highly valuable.

The introduction of new service offerings is more difficult, for it requires both action by the common carriers and approval by State regulating bodies and/or the FCC.

Present services are ill adapted to many computer uses, which call for connections longer than is common in telephone calls, but only a fraction of the time provided by a private line.

A determined study seems called for, involving common carriers, and those knowledgeable in the educational use of computers (the Association for Computing Machinery is a possibility), to seek out ways for meeting the needs of American education.

XIV. EXAMPLES OF THE USE OF COMPUTING IN COURSE WORK

A chief point of this report is that at a number of colleges and universities computing has become an integral and indispensable part of course work in a wide variety of subjects. Computing has extended the range of material that students can understand and make use of. This is best illustrated by a few examples drawn from various fields of study and from various institutions. These examples consist of problems, groups of problems, and in one case an undergraduate research project. The examples vary widely from field to field. The computer is a universal tool; the nature of the work is dictated by the field of study. Since there is nothing like a consensus as to "best" examples, this sampling is for purposes of illustration only, and is in no sense intended to represent the best that can be done.

The examples are presented in various degrees of detail. In the case of some examples we have obtained very brief comments from the instructor indicating why he thinks it advantageous to be able to use a computer in solving this problem. Of course, in most cases the significance of the computer is not in the solving of any one problem but in its use for a whole set of problems.

Business

1. B. A. 133, Investment Principles and Policies, School of Business Administration, UCLA

The students collect data from the financial statements of two companies (different for each student) that are then analyzed by a previously prepared computer program to form the basis of an investment analysis and recommendation.

Instructor's comments: The computer does analysis computations that would take over 100 hours on a desk calculator. Without it, the analysis would be simplified to eliminate many important aspects; with it, more time can be spent on the interpretation and meaning of the analysis.

2. B. A. 140, Elements of Production Management, School of Business Administration, UCLA.

Students program a subroutine decision rule to establish production levels and raw material orders for a manufacturing process with known costs and unknown demand. This subroutine is then used as part of a previously prepared program to simulate the operation of the concern over a period of time.

Instructor's comments: The computer enables students to explore the process with 10-12 cases, each with 10-12 time periods. It takes the exercise out of the realm of arithmetic and makes it a real learning experience in the management of a process. Emphasis is placed upon heuristic decision-making and the dangers of suboptimization.

Biology

Application of computer modeling in biological instruction at the University of California, Irvine.

1. A model of a reproducing population of organisms has been used to illustrate the interaction of natural selection and random drift in one laboratory exercise designed for the beginning biology course. Because of the size of this class (10 laboratories of approximately 24 students each) it was impractical to have the students interact directly with the computer. Therefore, the experiments were set up and run on the computer prior to the time for the laboratories. The data output from the experiments were supplied to the students along with descriptions of the experiments. Then, at the time of the laboratory period, by using multiple-parameter sets and replications of runs on the computer each student at a given laboratory table could be supplied with a unique data packet. This was done to give the student the impression that he

was working with genuine experimental data, as was indeed the case. He then answered certain questions about the results of the experiment, these questions also being supplied by the laboratory syllabus.

2. A second laboratory exercise based on this same model of evolutionary dynamics was devised for a class in human genetics. The class contains both biology and nonbiology majors. For the purpose of this laboratory period it was divided into two groups of about eight students each. Each group met on separate occasions with the instructor in the computer terminal room. There, as a group they selected for modeling several genetic systems known in humans. With the help of the instructor they chose values for the input parameters necessary for the model. This data was then fed via an IBM 1050 terminal and university-leased telephone lines to an IBM 7094 computer located at the University of California at Los Angeles. Within 2 to 10 minutes the experimental results were returned from the computer and printed out on the printer at the terminal. The students then immediately analyzed their results either graphically or numerically, and made changes in the input parameters if desired for the next run. In this case, obviously there was a much greater opportunity for participation on the part of the students in the experimental design. It is anticipated that in the future this computer/student interaction will be extended from the group to the individual by means of multiple terminals and input/output interpreters with plain language capabilities operating in a true time-sharing mode.

Instructor's comments: Biological concepts from the disciplines of population genetics and population dynamics are particularly hard to illustrate to the student because of the time and cost barriers. The computer is used to overcome these difficulties. It should be pointed out that the language and the concepts involved in these laboratories were biological in nature and not computer oriented. The problem of the experimental design and parameter specification was put in biological terms and the entire exercise was made as real as possible, except for a vast compression of the time scale which is possible only with the aid of a computer.

Mathematics

Numerical analysis courses at Rensselaer Polytechnic Institute.

Two undergraduate courses in numerical analysis require extensive use of the computer. The basic mathematical material is standard work in numerical methods, such as solutions of equations, differential equations, and linear algebra, and there are separate courses at the institute in computer programing and data processing. However, the students are assigned "problems by the bushel" on the computer. In addition, in a successful recent experiment, half the students were required to undertake a major project of preparing a program for a pretty complicated big problem. The total enrollment in these courses is about 700 students and the IBM 360/50 system is used roughly 6 hours a day, 5 days a week for homework.

Instructor's comments: George Handelman, chairman of the Mathematics Department at RPI, expressed himself roughly as follows about the introduction of the computer into the numerical analysis courses: "It's so fantastic it's almost impossible to say how much better the course is. The amount of practice the students get is up by one to two orders of magnitude."

Engineering

1. CM 341, Rate Processing I, College of Engineering, University of Michigan.

As a problem, students analyze the flow in a pipe network. A network consists of a number of horizontal pipes, of specified diameters and lengths, which are joined at n nodes numbered $i = 1, 2, \ldots, n$. The pressure is specified at some of these nodes. There is at most a single pipe connected directly between any two nodes. The students write a MAD program which will accept information concerning the above and which will proceed to compute (a) the pressures at all remaining nodes, and (b) the flow rate, and direction of flow in each pipe.

Theory. The flow rate Q_{ij} from node i to node j is related to the corresponding pressures p_i and p_j by

$$|p_i - p_j| = c_{ij} Q_{ij}^2 \tag{1}$$

in which Q_{ij} is plus or minus for low from i to j or vice versa, respectively. In the following version, Q_{ij} will automatically have the correct sign:

$$Q_{ij} = (p_i - p_j) \sqrt{\frac{1}{c_{ij}|p_i - p_j|}} \tag{2}$$

Here, c_{ij} will depend on D_{ij}, L_{ij}, the diameter and length of the pipe connecting i and j, and also on a friction factor f. At any node where the pressure is not specified, the sum of the flows from neighboring nodes must be zero:

$$\sum_i Q_{ij} = \sum_i (p_i - p_j) \sqrt{\frac{1}{c_{ij}|p_i - p_j|}} = 0 \tag{3}$$

When applied at all "free" nodes, equation (3) yields a system of nonlinear simultaneous equations in the unknown pressures. Such a system can be solved by Newton-Raphson iteration, but the following method is perhaps simpler conceptually. Note that $(p_i - p_j)$ is more sensitive than $(p_i - p_j)^{1/2}$ to variations in p_j. Thus, if an approximation to p_j is known, a new (and hopefully better) estimate p_j^* is suggested from (3) as

$$p_j^* = \frac{\sum_i a_{ij} p_i}{\sum_i a_{ij}} \tag{4}$$

in

$$a_{ij} = (c_{ij}|p_i - p_j|)^{-1/2} \tag{5}$$

Equation (4) can be applied repeatedly at all nodes until the computed pressures show little further change, or until a preassigned number of iterations has been exceeded. It is understood that the most recently estimated values of p_i will always be used in the right-hand side of equation (4).

Notes

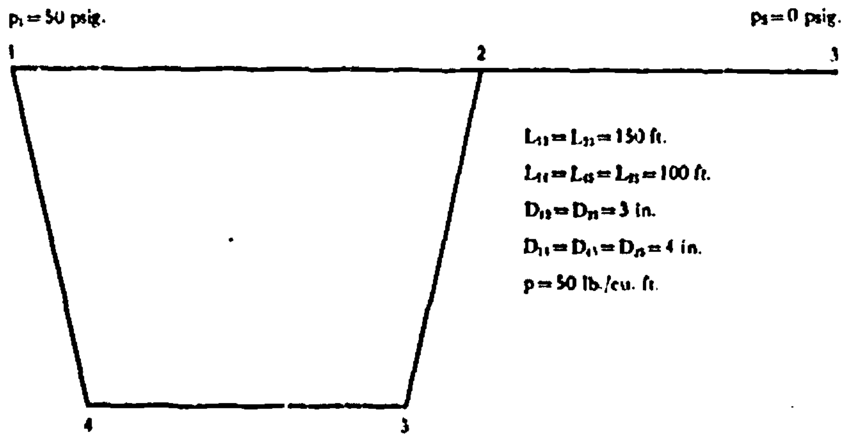
(a) Students may collaborate as far as discussing methods of attacking the problem, questions of fact about MAD programing, general principles, etc. However, each student must individually write his own program and prepare a written report.

(b) Execution time estimates should be kept to no more than 10 seconds (*10 in columns 52-54 of I. D. card) unless <u>after</u> consultation with the instructor there appears to be a definite reason for increasing it.

(c) Liberal use of blank spaces between words, variables, operators, etc., and occasional use of remark cards identifying key computational steps will make it <u>much</u> easier for the instructor to understand your program.

Data

Your program should solve the following network and also one of your own choice. Assume a Moody friction factor of 0.056.



<u>Instructor's comments</u>: CM 341 is an undergraduate fluid mechanics and heat transfer course taken during the junior year. Most of the students have previously taken an introductory computer course (Math. 273).

Before a computer was made available to the students a problem of this sort could not be assigned because the calculations would have required too large a portion of their study time. Now they are able to do several such problems which provide a good base for considering more complex and realistic systems later. The students have reacted very enthusiastically to its introduction into the course.

2. Aerospace engineering 320, College of Engineering, Texas A. & M. University.

A sounding rocket is launched in a vertical direction. It has a burn time of 5 seconds. During this 5 seconds the mass is being reduced. The forces acting on the rocket are thrust, drag, and weight. The thrust varies slightly with altitude; the drag varies as the square of the velocity and slightly with altitude; the mass varies with time. Using the given FORTRAN program, calculate and print out t, y, m, T, D, V and a at time increments of 1 second, starting with t=0 and continue through t=10 seconds. However, you should calculate values of y using h-0.01 second (i. e., Δt t=0.01).

The governing equations are:

$$\text{D.E.} \qquad F=\frac{d}{dt}\left(m\frac{d}{dt}\right)$$

$$\text{Mass:} \quad m=(7-t)\frac{40}{32.2} \text{ for } t=0 \text{ to } 5 \text{ sec.}$$

$$m=\frac{80}{32.2} \text{ for } t=5 \text{ to } \infty$$

$$\text{Force:} \quad F=T-d-m(32.2)$$

$$\text{Thrust:} \quad T=520+0.00005y \text{ for } t+0 \text{ to } 5 \text{ sec.}$$

$$T=0 \qquad \text{for } t>5$$

$$\text{Drag:} \quad D=(1-0.000005y)(2.6\times10^{-5})\left(\frac{dy}{dx}\right)^2$$

Instructor's comments: This problem requires the numerical solution of a basic type of equation and demonstrates the relative ease of solving a problem on the computer that is very difficult to solve otherwise. The realistic problem made possible by the computer relates the material covered in the mathematical treatment of numerical methods to a "real" engineering problem and gives students confidence in their ability to solve real problems.

3. Civil engineering 1.51, Structural Analysis and Design, Civil Engineering Department, M. I. T.

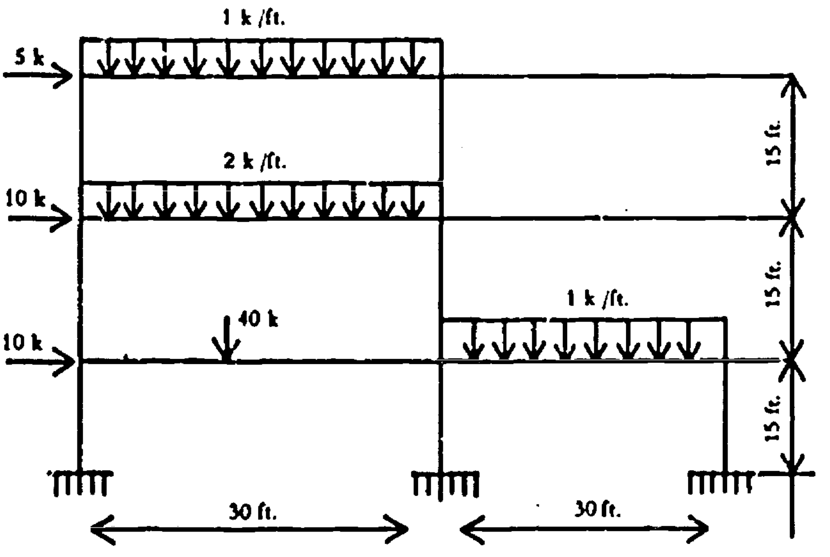
Problem. Given the two-dimensional building frame and loading shown in the figure, execute a design by selecting standard steel sections for all members of the structure. Stresses must satisfy the AISC Specifications. For simplicity, assume all members to be laterally supported. Attempt to optimize the design based on minimum weight.

Procedure. The student first makes an approximate analysis of this indeterminate structure by making behavioral assumptions (e. g., location of points of contraflexure, distribution of story shears between columns, etc.). He then analyzes this trial structure using STRESS, a general purpose program for structural analysis which uses a problem-oriented language for input. After checking stresses against allowable values, he recycles by selecting new members as required, modifying the computer input, and obtaining a new analysis. The cycling operation is continued until the student has achieved what he believes to be both safe and an optimum design.

Instructor's comments. The purpose of this problem is to provide experience in the design of steel frames and to develop understanding of the behavior of such structures. The preliminary analysis and design is important since it permits the student to evaluate the validity of his intuitive feeling for the structural behavior.

The input may be written in 10 or 15 minutes and subsequent runs require only changes in member properties. A typical student might therefore obtain five or six runs in the course of the design, for which the equivalent of two homework exercises is normally allowed. During this process the student learns a great deal about the effect of changing member properties on the gross internal forces and the problems associated with optimizing a design.

Given structure and loading



Portion of Students Program

```
STRUCTURE 1.551 FRAME ANALYSIS BY NEVINS AND LYNN
TYPE PLANE FRAME
NUMBER OF JOINTS 10
NUMBER OF SUPPORTS 3
NUMBER OF MEMBERS 11
METHOD STIFFNESS
JOINT 1 COORDINATES   0.     0.
JOINT 2 COORDINATES 360.     0.
JOINT 3 COORDINATES 720.     0.
MEMBER 1 FROM 1 TO 4 PRISMATIC 14.40 0. 0. 0. 0.    272.9
MEMBER 2 FROM 2 TO 5 PRISMATIC 27.94 0. 0. 0. 0.   1063.5
MEMBER 3 FROM 3 TO 6 PRISMATIC 14.40 0. 0. 0. 0.    272.9
```

Portion of results for students program

Structure 1. 551 frame analysis by Nevins and Lynn, loading one

Member	Joint	Axial force	Shear force	Bending moment
1	1	48. 8660450	2. 2492919	298. 6059227
1	4	-48. 8660450	-2. 2492919	106. 2666206
2	2	95. 9773693	14. 9974674	1530. 4982605
2	5	-95. 9773693	-14. 9974674	1169. 0458984

Linguistics

Harvard linguistics 104. Computation techniques for linguistic analysis.

Linguistics 104 was given in 1965-66 and is schedules to be given in alternate years henceforth. The enrollment this fall was 50 students of whom 40 were undergraduates. Topics discussed included: introduction to computers and programing; concordance and index preparation; authorship identification; computational techniques for historical linguistics; generative grammars; syntactic analysis by computers; discourse analysis; theories of semantics; information retrieval and question-answering systems.

Computers were used throughout this course both for demonstration in which the students played an essentially passive observer role and for active laboratory exercises. For example, a concordance system developed at the University of California was used to illustrate techniques and problems of concordance preparation. Each student was required to become familiar with operating procedures for these programs and to submit a short text of interest to himself for concording.

In addition, each student was asked to prepare a small English grammar and dictionary for a text of his own choosing and given an opportunity to test the operation of the grammar and the dictionary by means of the predictive syntactic analyzer developed at Harvard.

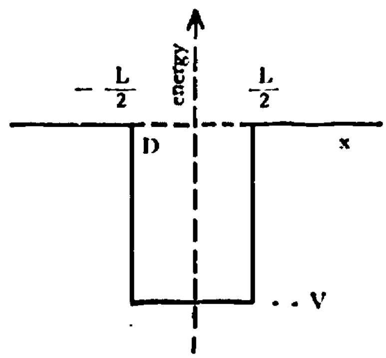
Instructors' comments: For both of these examples it would be impossible to avoid the use of a computer unless a roomful of dedicated monks were available. However, with the aid of the computer the students are able to look at patterns and see interesting phenomena that otherwise would be masked by unbearable tedium.

Physics

Physics 24, Dartmouth College.
The square-well potential: A computer assisted exercise --

A. Theory of the square-well potential.
The one-dimensional square-well potential is defined by the following function:

$$U(x)=\begin{cases} V, & -\frac{L}{2}\le x\le\frac{L}{2}, \\ O, & \text{elsewhere} \end{cases}$$



Where V is a negative number for a well and positive for a barrier. The Schrodinger Equation in one dimension is

$$-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2}+U(x)\psi(x)=E\psi(x)$$

Exercise 1. We wish to transform this equation to dimensionless variables so that the essential parameters will become obvious. Show that if we let

$$x=\rho\frac{L}{2},\qquad E=\epsilon\frac{2\hbar^2}{mL^2},\qquad U=u\frac{2\hbar^2}{mL^2},\qquad V=v\frac{2\hbar^2}{mL^2}$$

then the Schrodinger Equation becomes:

$$\frac{d^2\psi(\rho)}{d\rho^2}=(u-\epsilon)\psi(\rho) \tag{1}$$

A program has been written which integrates numerically the differential equation, equation (1), step by step starting from the center of the well, p = C, and proceeding in the positive sense. You must supply to the program a trial value for and information as to whether it is an even or an odd function you are looking for. The depth of the well is already set at -36, in our units. The program will then plot a graph of the solution, and you may observe whether or not it is a physically acceptable solution. If not, try to improve the solution with a new energy. Keep the process up until you have established the acceptable energy eignevalue to an accuracy of four decimal places. Then look for a different acceptable eigenfunction, and repeat the process. Your objective is to produce the eigenvalues and graphs of the eigenfunctions for all of the physically acceptable bound states of this well. (Hint: There are four such states; it is easiest to start looking for the state near the top of the well.)

After you have found the four eigenvalues and graphs of the eigenfunctions, answer the following questions:

1-1. In what order do the even and odd functions appear?

1-2. Numbering the states from the <u>bottom</u> of the well, what is the relation between the number of nodes ($\psi = 0$) and the number of the state? (Remember that the graph shows only the positive values of p; the other half of the graph may be inferred from the symmetry of ψ.)

1-3. In which state is the particle most likely to be in the classically forbidden region and in which state is it least likely to be there?

(The problem is then broadened to discuss the analytic solution for the eigenvalues and the calculation of the eigenfunctions. Two more computer exercises are included in addition to the theoretical analysis.)

<u>Instructor's comments</u>: The one-dimensional square-well is studied as a model quantum-mechanical problem because it displays m many features of mathematically more complicated systems but is itself soluble in terms of elementary functions. The purpose of this exericse is to have a close look at a variety of features of this problem without having to go through the laborious work of plotting graphs of wave-functions and solving by hand the transcendental equations which arise even in this elementary problem.

The square-well exercise on the computer was intended as a counterpart, not a replacement, for laboratory experience. It afforded the student an opportunity to "experiment" with the theory involved, experimentation which would be difficult at best if computations and plots had to be hand produced. It was selected to permit a strong interplay between the theoretical or analytical solution on the one hand, and the consequences of that solution on the other hand. Not only did the students solve the square-well problem, but they saw "shapes and patterns" as well.

The students themselves felt this effort produced more learning per hour than a conventional experiment would have. The problem could also have been presented as a homework exercise, and here again would have an advantage because it was structured instead of being a random isolated exercise as is usually the case. In fact, most of the textbook material on this problem could have been skipped. This exercise required about 4 hours of console time plus about 2 hours in preparation, though some students spent up to 12 hours. This exercise had the highest response rate of any in the course.

as a very simple model of river systems, investigate the relationship of stream order to drainage area, stream length, and number of streams.

The computer was used to calculate and draw examples of river systems using this simple model. The drainage basins were then determined and analyzed by visual inspection. Tabulation then indicated empirically that stream order was linearly related to the logarithm of drainage area, stream length, and number of streams and that the size of the biggest basin in each of many independent drainage systems follows Gumbel's distribution.

Instructor's Comments: The classic work on this subject is by Luna B. Leopold, chief hydrologist of the U. S. Geological Survey; and a notable lecture by Dr. Leopold, in Claremont during the winter of 1965, was the immediate stimulus to this project. Although the student involved had only a limited time to devote, I believe that he gained an appreciation of Leopold's work that would have not been so easily achieved in any other way.

Social sciences

Examples of computer use in the Social Science Division at the University of California, Irvine.

1. Psychology I, introduction to psychology.

   Psychology I is a one-quarter introductory course for both majors and nonmajors. It provides an overview of the basic facts, principles, and theories in general psychology. As an exercise in applied educational psychology, students are taught the coursewriter language and write small programs covering limited topics which are then tested on several of their fellow students.

   Computers are also used to provide review tests that the students may use to guide their reading and check their comprehension. For example: "psymiller", 658 instructions, covers George A. Miller's Psychology the Science of Mental Life; "psymotivl, 2, 3", 655 instructions, is based on Edward J. Murray's Motivation and Emotion; "psypers1", 337 instructions, tests concepts of Leona E. Tyler's Tests and Measurements; and "psypers2", 420 instructions, is based on Richard S. Lararus' Personality and Adjustment. A word association experiment has also been programed, consisting of 464 instructions.

2. Economics I, introduction to principles of economics.

   Economics I is a one-quarter introductory course for both majors and nonmajors. It will concentrate on the essentials of price theory in the context of partial and general equilibrium analysis. Subject to this constraint, it will be problem oriented with emphasis on problems taken from the area of economic growth and development of comparative economic systems as well as more standard topics; e. g., theory of the firm.

As an example of the use of the computer, the student will be given the role of a trader in a highly organized market. After being introduced to the rules of market functions, he will then work in a game where he must make production decisions. In this manner a complete general equilibrium model can be constructed and the student can acquire a strong intuitive knowledge of the model.

The introduction to the market game follows. The dialogue is carried out between a student and a computer over a typewriter terminal.

This chapter is the first of several which are designed to aid you in learning economics. Each will describe a situation to you and you are then to respond with either questions or answers -- the computer will in turn respond to you. You may ask any question (or give any answer) that you believe to be appropriate.

You are a resident of a small agricultural village that is almost completely self-sufficient. The major crop is wheat, grown by the villagers both for their own consumption and to sell in a nearby market. The villagers sell the wheat that is left over after they have provided themselves with a sufficiency. They use the money that they get from the sale of wheat to provide the village with things they do not themselves produce.

You have been selected by the village to act as its trader in the market where wheat is bought and sold. (This selection is an honor, since the trader does no other job for the village.) In order to continue as trader, however, you must be a good one, or you will be replaced.

You begin your trip to the market with 1,700 bushels of wheat to sell. Upon your arrival, you find that the market place is well organized and you learn the following rules that apply to all participants.

Rule 1. Buyers (there are four of them) are required to stay in a fixed location; they may talk only to sellers and must answer seller's questions truthfully.

Rule 2. Sellers (and there are a lot of them) may roam freely and may talk to anyone, but may not conspire.

Rule 3. There is a brief initial period of 1 hour during which no sales may be consummated (called the Nodding period). At the end of this period final sales are made and the market is closed.

NOTE.--This does not mean that you need work at the terminal for 1 hour. Since the computer is simulating the world, it will tell you just before the "hour" is up.

You have arrived a few minutes before the Nodding period. You see to it that your 1,700 bushels of wheat are safe and begin to walk around the market square just as the bell signals the beginning to the Nodding period -- you're on your own now. What would you like to know?

Instructor's comments: The main advantage of the computer's use in introductory courses is in the organized feedback to the instructor. In addition, the computer provides a modifiability not present in other methods of program organization -- courses can be readily changed or adapted as the need arises.

PART 2

I. SELECTION OF A MEDIA SYSTEM -- AN OVERVIEW

Estimating the costs of purchasing, installing, implementing, and operating a media system is not an isolated activity. Rather, it is part of the broader overall process of media system selection.

Cost estimation, the subject of this study, must be preceded -- and followed -- by certain other necessary activities to insure optimum results from the use of a media system. These activities, while outside the scope of this study, are examined briefly here to show their relation to cost estimation.

The major steps in media system selection appear graphically in Fig. 1. Although the component activities are presented and discussed

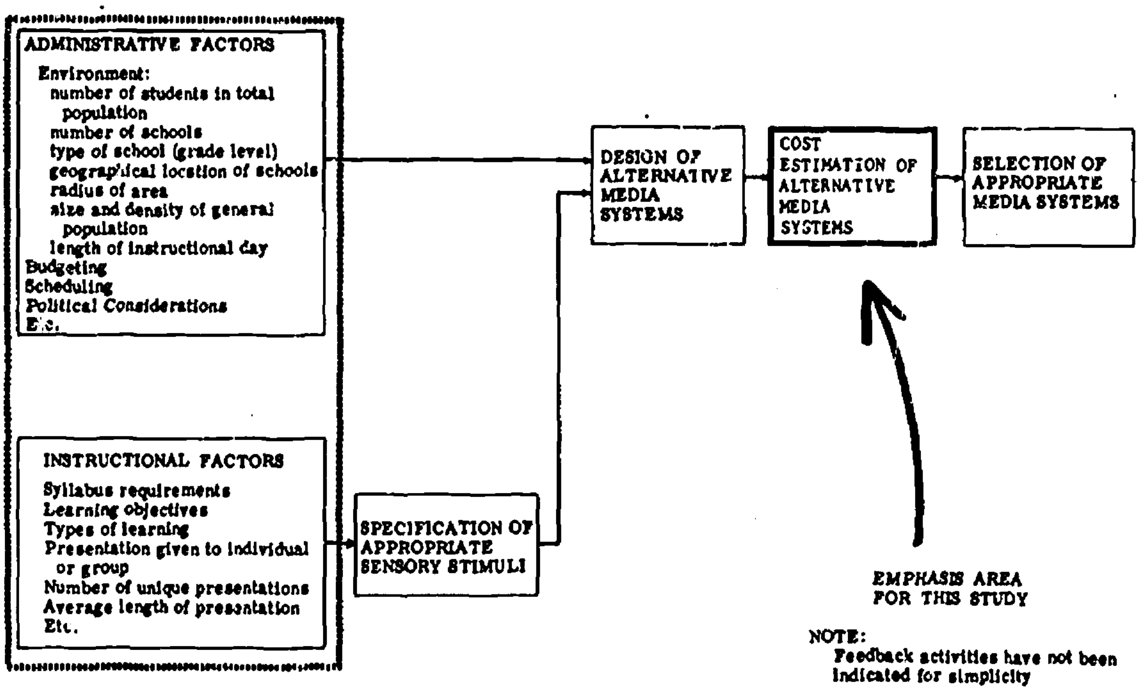


Figure 1 -- Selection of a Media System -- An Overview

sequentially, it should be emphasized that the steps in media selection are interactive. The results of an activity or activities in one step may not only provide data for a subsequent activity, but may also modify activities that have gone before.

The selection process begins with an examination of the educational setting in which the chosen media system is to function. Most educators agree that this setting consists mainly of an administrative component and an instructional component. Each component contains limiting factors which shape the specific data used in later stages of the selection process, namely specification of appropriate sensory stimuli, design of alternative media systems, cost estimation of the alternative systems and, ultimately, selection of the appropriate system.

Final selection of a media system is followed by the customary procedures of contract specification, review of bids, and award of a contract for equipment and installation. Two other "post selection" activities are essential at this point -- implementation (training and operation) and evaluation. Logically, planning for these activities should be completed well before this time. Some of the groundwork should already have been laid at earlier stages of the selection process. Staff acceptance of new media is more likely if teachers have participated in the selection process and have received instruction in how the new media are to be used. Operating procedures which allow for a period of adjustment must be carefully planned and introduced.

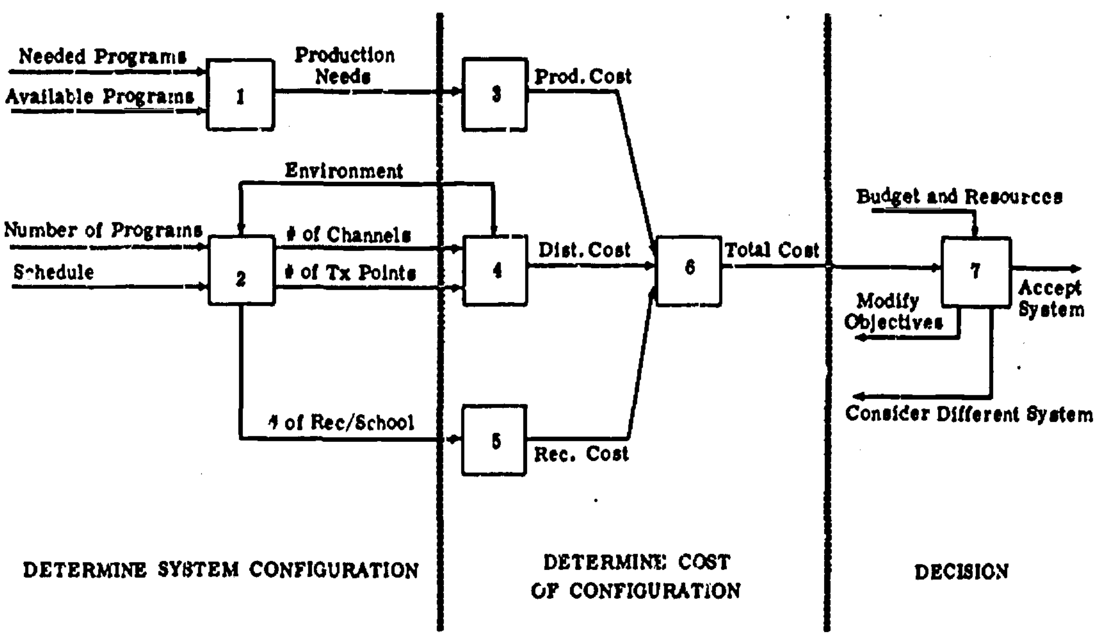


Figure 2 – Cost Determinations

Fig. 2 illustrates the sequence of general steps taken to determine the cost of a media system. Blocks 1 and 2 produce the media system characteristics which determine the system's configuration. Blocks 3, 4, and 5 develop the costs in each of the three divisions into which the system has been separated. Block 6 sums up all costs prior to the selection decision that is made in Block 7. Actually, decisions are made throughout the entire process and some systems may be rejected or modified well before Block 7 is reached.

II. METHODOLOGY

The method of the study involves the specification of a task and an environment. The task describes "what the system is doing" and the environment describes "over what area and for how many people it is doing it." A valid comparison of media systems can be made only when a single real environment and the actual educational task are specified in detail for each case under study. To attempt this type of approach would mean the illustration of hundreds of cases consisting of different systems and their variations applied to many educational tasks over many different environments. This monumental effort would still involve some generalizations and assumptions and would only produce a larger group of system costs which might result in more confusion than clarification.

Therefore, we have chosen a general expression for the task and a small number of generalized environments to construct a framework for media costs. Hopefully, this method may reduce the errors in system comparisons. It will not eliminate them. Where a media system does not fit a portion of the model at all, it will be so indicated. Where a media system does not fit a portion of the model as well as another system, it will be costed and explanatory notes appended (in the full original report) to describe the problem.

Environments defined

Each media system is costed with respect to a number of environments. The environments are to a great extent hypothetical. However, they are models which were created after examining actual data. In particular, city and metropolitan area descriptions closely resemble the city of Washington, D. C. and its environs. The geographical areas and population densities of the environments are similar to those found in section of the United States.

Local District Model: The smallest environment is the school district which may vary in size from a few hundred to over a million students. The size chosen for this study was 15,000 elementary and secondary students in an area of approximately 80 square miles. Although the majority of school districts in the United States are much smaller, those with 3,000 or 4,000 students will not have the distribution problems which become extremely important in larger systems. Also, some of the media systems are too expensive (even in their smallest configuration) to be supported by a small district. However, if these smaller administrative units join together in a cooperative effort of about 15,000 students, the costs can be apportioned on a per pupil rate for each unit.

The school district used as the model consists of 14 elementary schools and four secondary schools. The elementary schools are a combination of K-6 and K-8 configurations, and the secondary schools include junior, senior, and possibly a vocational high school. For the purpose of this study, an elementary school will have an average of about 600 students; a secondary school will have an average of about 1,400 students. (The student population in each environment (local, city, state, etc.) has been rounded off to form convenient numbers; as a result the number of students per school when multiplied by the number of schools will not produce the exact student population indicated.) The school district is irregular in shape, but all the schools are within a circle whose radius is six miles.

City Model: The city covers an area of 70 square miles and has a total population of about 800,000 with approximately 11,500 people per square mile. The shape of the city is roughly rectangular and the entire area can be encompassed by a six mile radius circle. There are 150,000 students in 136 elementary and 46 secondary schools. The city can consist of a single school district or a number of school districts which cooperate to gain efficiency and economy through the use of a common media system. The city is not the largest nor most densely populated in the United States. By way of comparison, New York City has approximately nine times the population, four times the area, and more than twice the population density of the city used in this study.

Metropolitan Area Model: The population of the metropolitan area is approximately two million. Its perimeter has an irregular shape and surrounds an area of approximately 1500 square miles. Because of its irregular shape, a circle with a 30 miles radius (2800 sq. mi.) is necessary to completely cover this area.

The metropolitan area, which contains a number of school districts, has 546 elementary and 183 secondary schools with a total of 600,000 students (K-12). It is assumed that these districts would cooperate with one another for some large media projects to achieve economy of operation.

State Model: The state has a population of about 4.5 million people. It does not contain a metropolitan area as large nor as populous as described above, though about 60 percent of the population is urban. It has an area of about 40,000 square miles and a population density of about 110 per square mile. Approximately one million students (K-12) are distributed among 920 elementary and 310 secondary schools.

Regional Model: The region is approximately a 10 to 1 extrapolation of the state, but a smaller population density is used to bring this figure closer to the national average. The region has an area of 550,000 square miles and a population of about 42 million. There are 10 million students in 9200 elementary and 3100 secondary schools. The region contains a few widely distributed metropolitan areas but no continuous corridor such as is found between Boston and Washington. (The corridor is considered separately in the full original report.)

Educational task defined

The task assumed in this report is: To provide each student with material via some medium during an average of 10% of his actual instructional time. In reality, no subject is taught entirely by the use of a media system at all. More than 10% of some subject may be presented by a media system. This task is general in nature so that it may be applied to any system. When a single system is considered for solving an actual problem, the task can be specified in terms of particular subject material and relative effectiveness of the media for the material.

A difficulty with respect to this study is not that the task is general in nature, but that it is not defined in units that have a relationship to system design. To bridge this gap, the following exercise is offered to illustrate the method used for this study to convert the general 10% task into an annual requirement for hours of unique program material for each of the defined environments. In a real situation, this exercise is unnecessary. The programs, lesson units, and other related factors would be determined from the educational objectives of the real situation.

Program requirements for a local environment

What follows is a description of the method used in this study to estimate the approximate number of unique programs which would have to be produced or acquired to perform a generalized educational assignment over a period of one year. The method is applied to grades 1 through 12 in two separate groups: grades 1-8 and grades 9-12. Only the calculation for grades 1-8 is shown in this abridgment.

For this illustration, it is assumed that general program material (enrichment, background material, general science, etc.) is acceptable for use over a four-grade span (average), e.g., 1-4, 3-6, 9-12. It is also assumed that specific subject-oriented material is acceptable for use in a single grade and only by a portion of the students within that grade; for example, Algebra I may only be applicable to algebra students in grade 8.

It is assumed that the students in grades 1-8 are all engaged in a single course of study, though this is not without exception. In some cases, course specialization may occur in grades 7 and 8; occasionally, elementary schools, especially private schools, may offer different courses. It is assumed that there are 900 hours in a school year.

180 days/year x 5 hours/day=900 hours/year

It is assumed that 70% of the student's total time in school is available to receive media presentations. (This excludes lunch, study periods, etc.)

900 hours x 0.7 = 630 hours available for media presentation.

It is assumed that media will be used an average of 10% of this time.

630 hours x 0.1 = 63 hours average media usage/student/year

It is assumed that 50% of the material presented applies to only a single grade.

63 hours/grade x 8 grades x 0.5 = 252 hours of material for single grade use

It is assumed that 50% of the material is applied to an average of four grades (some material may apply to eight grades).

63 hours/grade x $\frac{8}{4}$ x 0.5 = 63 hours of material for multigrade use

252 hours single grade materials
63 hours multigrade materials
315 hours of unique material for grades 1-8

Total unique programming
grades 1 - 8 = 315 hours
9 - 12 = 655 hours (Calculation of this is shown in the full report.)
= 970 hours of 1000 hours

It is assumed that each program is 20 minutes long.

1,000 hours x 3 program/hour = 3,000 unique programs to supply 10% average media coverage in a local district

Program requirements for city environment and above

If 1,000 unique program hours are sufficient to accomplish the task assigned to a single school district, will the same number of hours be sufficient for all the school districts in a state?

The concept of unique programming hours used in this study does not directly take into account the actual subject material involved. The method may be adequate to determine the average number of unique programming hours needed in a school or school district. However, an increase in overall program hours may be necessary when the task is applied to a larger environment such as a state or region. The 1,000 hours may be adequate to supply each student (on an average) in a school or district with 10% media usage or availability. Due to overall curriculum differences, such as a larger number of subject offerings and differences in teaching methods, the 1,000 hours of unique programming may be insufficient to provide 10% media coverage when applied to a large number of schools or school districts.

Taking this factor into account, the following number of hours of unique programming will be assigned to each area.

Local	1,000 hours
City	1,200 hours
Metropolitan area	1,300 hours
State	1,500 hours
Region	1,600 hours

Cost structure

The stated task, to provide each student with material via some medium during an average of 10% of his total instructional time, offers a common source of data for the design of each media system. The definition of environments provides a method of examining systems as they are affected by an alteration in the size of the environment.

Classification by Function -- Analysis for cost estimation can be further aided by classification of the elements of each media system as they relate to production, distribution, and reception.

Production: Production costs are those incurred in the inception, creation, development, and preparation of the instructional content. The acquisition of media programs and its related costs, such as selection and order handling, are also classified as production costs. For a media system, these costs must include the cost of curriculum design, the use and development of research and evaluation teams, media specialists, facilities, and all the myriad of inputs necessary to produce a successful learning experience for the student. Specific examples are script writing and recording of programs for radio and television.

Distribution: Distribution costs are those incurred in changing or copying the material from its original form, if necessary, and sending it to a point at which it will be reconverted to a usable form for the student. Usually, the transmitted material is not in a form which is immediately useful to the student. Examples are duplicating original tape and broadcasting for television, duplicating and mailing film from a processing center to a school, or duplicating and playing tape and transmitting to headphones in language laboratories.

Reception: Reception costs are those incurred in changing the form and presenting the distributed material so that it is useful to the student. Examples are antennas, TV sets, film projectors, screens, headphones, and carrels.

Classification as Capital or Operating Costs -- Production, distribution, and reception costs can be classified as either capital (initial) costs or operating (annual) costs. Costs classified as capital costs include all purchases of goods and services that have a useful value of longer than a year or that are not incurred every year. The following items are considered as capital costs.

1. Initial planning. A breakdown of the planning effort and some estimates of man hours, travel costs, fees, etc., must be made for each system. The planning effort includes these activities.

    Survey of educational needs
    Definition of the problem
    Examination of possible solutions
    Design of systems
    Technical assistance and consultation
    Determining cost of alternative proposals

2. Initial training. In order to start a media system with a reasonable level of efficiency, a formal training program should be in operation prior to and during the installation of the system. Traditionally, problems of attitude have developed with the ultimate users when they were not properly informed, motivated, and trained. Training can be subdivided into three areas:

   Training of teachers, producers, and others who will. actually produce the programs for the media

   Training of the technical operating and maintenance staff

   Training of classroom teachers to properly utilize the media

   The amount of training depends on the size of the system, intensity of usage, and the quality of performance which will be acceptable. Historically, it has depended upon the time and money that are available for this purpose.

3. Facilities. When an entire room, group of rooms, or separate building (such as a TV studio or film library) is required for a media function, it will be costed as new construction on a square foot basis and provision for future expansion is assumed. When a very small area of an existing facility (such as space taken by a TV set in classroom) is used, these costs will be ignored.

4. Initial equipment and programs. Included in this category are the costs of equipment (including test equipment) that must be purchased and program materials that must be produced or acquired to implement the system.

Costs classified as operating costs include all purchases of goods and services that have a useful value of less than a year or that are incurred every year. The following items are considered as operating costs.

1. Operation of equipment. Costs related to the operation of equipment are divided into these categories.

   Salaries of operating personnel (professional and/or technical)

   Annual cost of heating, air-conditioning, lighting, other utilities, etc.

   Consumable supplies

2. Maintenance of equipment and facilities. Most maintenance costs are calculated as a percentage of initial equipment cost. Equipment maintenance will usually average about 10% of purchase price and includes such items as replacement of spare parts, replacement of test equipment and tools, and some portion of building maintenance cost where applicable.

3. Training. A continuous training program is necessary due to

changes in personnel, methods, and equipment. Costs must be estimated for activities usually associated with continuing training programs.

4. Administration. Administrative costs vary with size and usage of the media system. Total costs of salaries increase at a somewhat linear rate as the system increases in size. Communication costs such as travel, telephone charges, and mail tend to expand rapidly as the size of the system, its complexities, and area of coverage increase.
5. Related materials. The operation of any media system requires the use of printed material to provide directions, schedules of events, guidelines, lesson plans, etc. The cost of this material is closely related to the number of hours of unique programming and the total number of users in the system (teachers and students). A cost for each unique hour of programming can be assigned and then extrapolated over a number of users as the system size increases from school district to state or region.
6. Current programming. This category covers the expenditures necessary to produce material other than those related to revision and modification of instructional programs. Included are announcements of school or community activities and materials for meeting, conferences, and special instructional projects.
7. Research, Testing and Evaluation, for Program Updating. A cost must be assigned to measuring and evaluating the operation of each media system. There must be an evaluative feedback within the system in order to properly operate and improve the system. Testing and restructuring the materials is one part of this process. This cost varies with student population, number of subjects offered, and intensity of media usage. Some of the costs will arise from the following activities:

   Test development and research
   Testing
   Evaluating
   Revision of materials

   The cost of actually remaking the program materials, as indicated by the research, is included in the programming cost, since this cost is incurred, on the average, every five years.

Equivalent Annual Cost: To simplify cost comparisons, the capital costs can be amortized over the life of the investment and added with interest to the average annual operating cost to form an equivalent annual cost. The result is a uniform yearly figure which includes amortization and interest. These costs can be examined for each environment to determine cost trends as they relate to student population, area serviced, etc. To calculate the equivalent annual cost, first a capital recovery factor (c. r. f.) is obtained from standard financial tables for a particular interest rate and life of the purchase. For example, the c. r. f. for five years and 1% interest is a little over 20%. The capital cost is multiplied by the c. r. f. and the product is added to the annual operating cost to obtain the equivalent annual cost.

Cost structure model

A cost structure can be established which encompasses the capital and operating costs for production, distribution, and reception for each system in each environment. This cost structure is illustrated in Fig. 3.

Cube "A" illustrates an area of costs which is associated with the operating expenses during the production (acquisition) of educational material to be used by a media system in a metropolitan school environment. Cube "B" is symbolic of operating costs for distributing instructional materials within a local school district.

Sources and use of cost data

The collection of cost data pertaining to an element of a media system usually resulted in a range of costs, not a precise value. The costs were collected from the following sources: equipment catalogs, reports (both objective and subjective), private conversations, and personal experiences.

The sources of cost data are indicated in most cases in the full original report, but there are some instances where the source is not

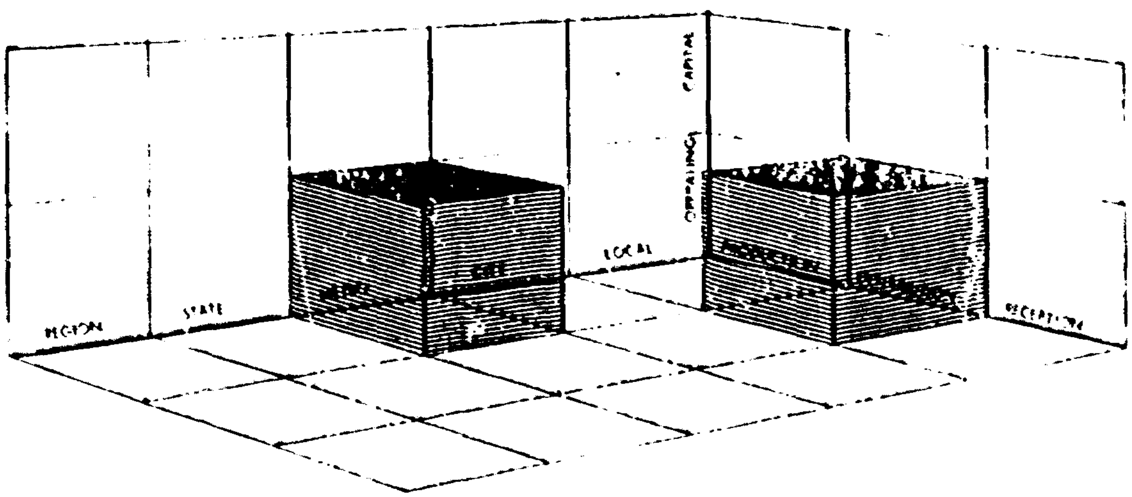


Figure 3 – Cost Structure Model

mentioned. These data costs are derived from the experience and personal investigation of the project participants. In those cases where the numbers presented need to be qualified, the type of interpretation which should be placed on their value is indicated.

To estimate total costs for the systems investigated, a single value for each item was selected from the range of costs collected. The choice was usually based on intuitive feeling of appropriateness for the environment. In most cases, the value selected might be the mode of the frequency distribution of selections by purchasing agents under the given conditions. The assumptions which were made to derive the estimated costs are included in the report as the need arises.

The actual dollar cost per system may not be directly applicable to a specific educator's unique problem, but it can indicate general cost trends. The value of this cost structure lies in the generality of its approach. The variables of a real situation can be applied to the structure to provide more realistic comparisons for an actual situation. The cost structure might be looked upon as a tool which can be applied along with measures of "media effectiveness" to solve "real world" problems.

III. COST ESTIMATES

Costs were estimated for each of the media systems investigated using the basic model discussed in the previous section. (The detailed cost data are presented in the original study, available from the ERIC Document Reproduction Service.)

Graphical illustrations have been prepared from the cost data. There are two major sets of graphs presented and discussed in the full report. Each graph in the first set presents the production, distribution, and reception costs for one instructional media system. A second set presents graphical comparisons of the costs of media systems. Production, distribution, reception, and total costs are shown individually. (In this abridgment, detailed estimates are provided only for television, but comparisons between the different media systems are included.)

The following graph presents the production, distribution, and reception equivalent annual cost per student, i.e., annual operating cost plus amortization with interest. The cost per student is shown over the range of environments. The environments are listed across the bottom of the graph. Each of the five environments has a given number of students and the costs have been estimated only at these five points.

Television production cost

Fig. 4 presents the equivalent annual production costs, operating plus amortization, used for each television system. The production of instructional television materials can be treated independently of distribution and reception, and it is, therefore, presented and discussed before the individual television systems are presented. Three different costs for production of materials are shown.

Minimum Production Cost: This is the minimum estimated cost of producing usable instructional television material. It is based on a $300 per hour basic production cost plus a fraction of a rental cost of $145 per hour plus associated costs of administration, related materials, and research and evaluation. (Complete figures and rationale are shown in the full original report.)

High Quality Production Cost: This is an estimate of the costs of advanced state-of-the-art production based on $5,000 per hour production cost and rental at $145 per hour plus associated costs of administration, related materials, and research and evaluation.

National Programming Source Costs: This cost assumes that a national center provided copies of materials at a figure approaching the duplication cost. No such source of instructional material now exists.

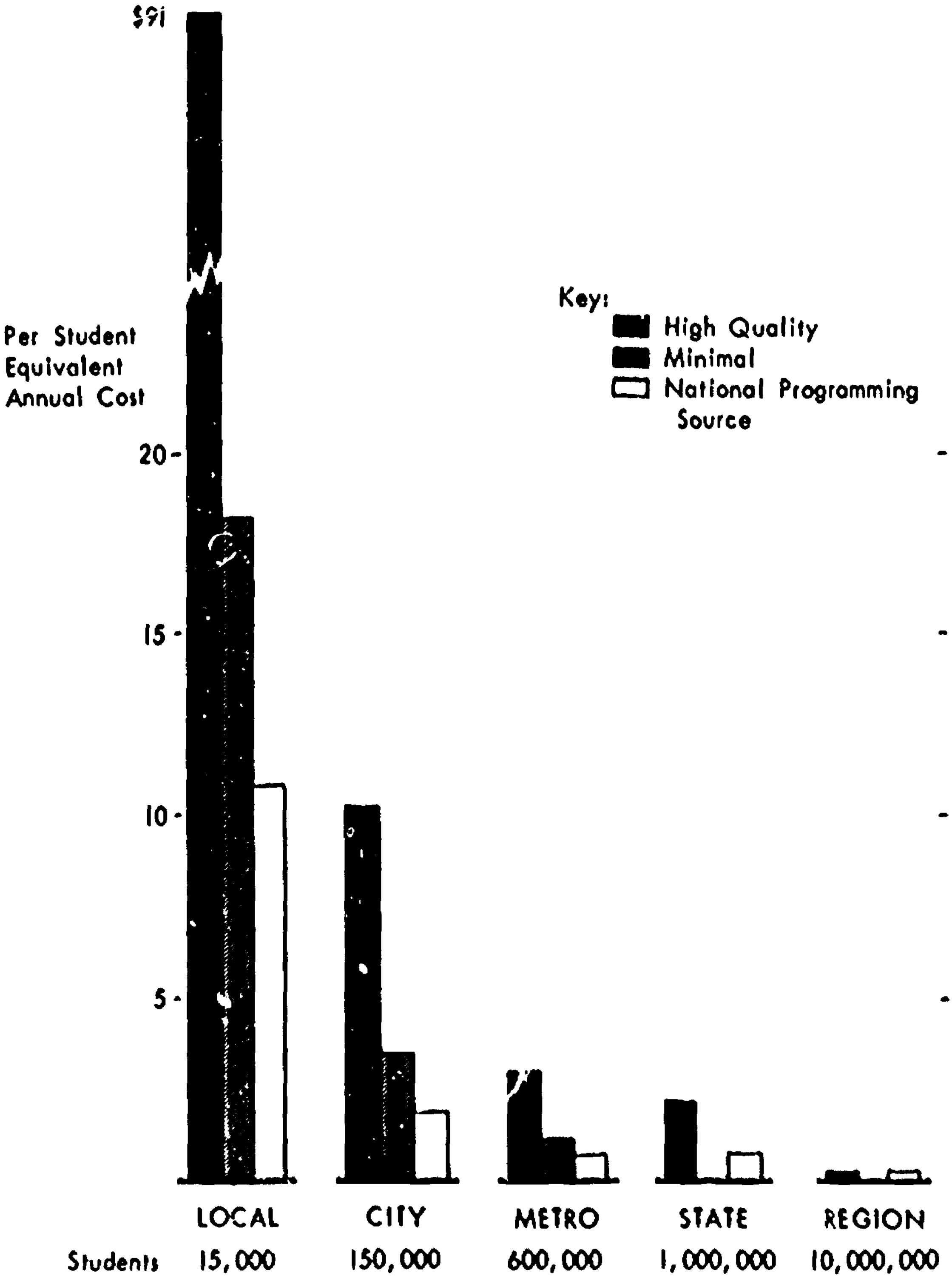


Figure 4 – TV Production Costs

The number of hours of programming in the model increases from 1,000 at the local level to 1,600 at the regional level.

The costs shown in Fig. 4 indicate that the cost of high quality production is $91 per student, which is certainly beyond the funding ability of a local school system of 15,000 students. The minimal programming cost for such a system is about $18 per student per year, which is still a large figure. Therefore, the minimum programming costs were used in the model for the local and city school systems. Although it would be desirable to offer the high quality materials in these schools, no school systems are presently able to do so. (If a different estimate of the cost is desired, the reader can substitute either the high quality or the national programming source costs shown in the tables in the full original report.)

The most important observation concerning production costs per student is that the cost decreases rapidly as the number of students increases. This behavior is typical of a fixed cost. The costs in the production category of the model are mostly those of producing the television programs. This programming cost has two variables, price and quantity. Quantity increases as larger areas are served. The increase in program hours is necessary because a wider range of students is encompassed by the larger system. An increase from 1,000 hours for the local environment to 1,600 hours for the regional environment was assumed in the model. Unfortunately, it is very difficult to estimate how large the increase should be. Even if it were 300%, the production cost for the largest system would be less than a dollar per student per year. The price of materials for the larger environments has not been increased directly, but the percentage of rented materials was decreased slightly. Fewer rentals means increased costs because rental is less expensive. In practice, the amount spent per program does seem to increase with the size of the area served, in contrast to the constant cost per hour assumed here. This is mostly a budgetary effect. Larger schools have more money, but since their programming is almost always below the "high quality" level, they spend more per program whenever funds are available. Since high quality production is provided in the model, no such increase is needed here.

Looking at the annual production costs per student, it is encouraging to find that high quality materials can be produced for under $11 per student for all areas of city size or greater. If minimum programming is acceptable, even school systems of 15,000 can produce materials for under $20 per student per year. There is at least one system in the U.S -- the Washington County, Maryland, system -- which is spending that much for programming. Finally, if a national center for copying a large supply of good materials were available, the programming cost would be about $10 per student for the local school and would decrease to only a few dollars for larger areas.

The production cost figure points to the need of school systems to cooperate in obtaining instructional television materials. It appears that any one school system will have great difficulty in financing its own production at any but a minimal level. Schools should join together in a cooperative production effort. It seems strange that no sizeable amount of cooperation in producing materials for physically separate distribution has taken place. The most obvious reason that cooperation has not been practiced is that each system has different problems and its materials reflect those problems. On the other hand, thousands of school systems use the same textbooks.

Equipment for television reception

The reception cost for each individual school must be computed before the actual reception equipment costs for a school district can be determined. The costs vary with the size of each school. An average cost per school could be obtained which would produce a fairly accurate cost extrapolation over areas larger than a single school district. This study will use two average costs, one for a small school (elementary) and one for a larger school (secondary). This method is used to illustrate that some costs vary with the number of television sets in use, and some costs are somewhat independent of this number.

The enrollment of the smaller school is 500 to 700 students. It contains 20 or more classrooms, and 20 rooms are wired for television reception. However, only 10 are supplied with television sets. This allows for future expansion or the use of portable sets which can be moved from room to room as needed. Ten television sets in this size school are adequate for the common task used throughout this study.

The larger school's enrollment is 1,000 to 1,500 students. It contains 40 or more classrooms. Thirty-five rooms are wired for television reception, and 20 rooms are supplied with television sets.

Television sets, stands, wiring of distribution coaxial cable, and a distribution amplifier are the basic reception equipment in all of the television systems. To the cost of the equipment is added the particular equipment costs which vary from system to system. Thus, the difference in reception equipment costs for each system consists mainly of the differences in antenna, preamplifier, tower, and converter costs for each system.

Standard 525 line 23-inch monochrome receivers are used throughout all of the systems. All of the system also use radio frequency distribution within the school building. No consideration is given in this study to special high resolution television systems using video monitors operating with rasters of more than 525 lines such as might be required in a medical school.

Included in the hardware costs are the costs of installation, sighting of antennas, and system checkout. For airborne and ITFS reception, the cost of an <u>average</u> tower has been included. Thus, some schools would actually have higher or lower reception costs. All reception costs are based on four-channel operation. Operation of fewer channels would not significantly reduce reception costs.

Brief descriptions of T.V. media distribution systems

Airborne T.V.--C-130 aircraft equipped with video tape recorders and transmitters would provide four channels of UHF television coverage over about a 200 mile radius for the state. Eight such systems would be required for the region.

ITFS--Four channels of standard Instructional Television Fixed Service equipment would provide service for the local and city environments. Five such stations would be connected by off-the-air pickup for the metropolitan system. The state and regional systems assume the use of a proposed higher-powered ITFS system with microwave relay between six stations for the state and 73 stations for the region.

UHF Broadcast Stations--Four channels of standard UHF broadcasting equipment would provide service for the local, city, and metropolitan environments. For the state and regional environments, microwave relay of the signal from a central point to each of 20 stations for the state and 154 stations for the region is assumed.

Closed Circuit T.V --Coaxial cable and microwave facilities would be used to connect each school with a central distribution center.

Satellite T.V.--A synchronous satellite equipped for four channel broadcast was derived from the computer model of G.E.'s Missile and Space Division. This model was based on 1973 projected technology.

VTR--This system assumes that each school is equipped with 4 helical-scan video tape recorders and a complete library of tapes.

Brief descriptions of other media systems

Film or Audio-Visual Media System--Equipping of each school with 16 mm. sound projectors and a minor amount of equipment for slides, filmstrips and transparencies is assumed. Film prints are purchased by a central facility and circulated to each school by truck.

Educational Radio--A four-channel FM multiplex system would broadcast from separate stations, each obtaining tapes from a national production facility. Each school room is equipped with a receiver.

Learning and Language Laboratories--For the local and city environments, a 30 station interactive audio facility for languages at each high school and a 30 station non-interactive audio facility at each elementary facility is assumed.

Dial Access--The dial access system would consist of a central bank of audio tapes prepared by the teacher which can be presented over a classroom speaker upon demand in any classroom.

Comparison of costs

The following graphs illustrate the equivalent annual cost per student of the production, distribution, reception, and total cost categories for all media for each environment. These graphs are used in discussing the cost comparisons of the media systems.

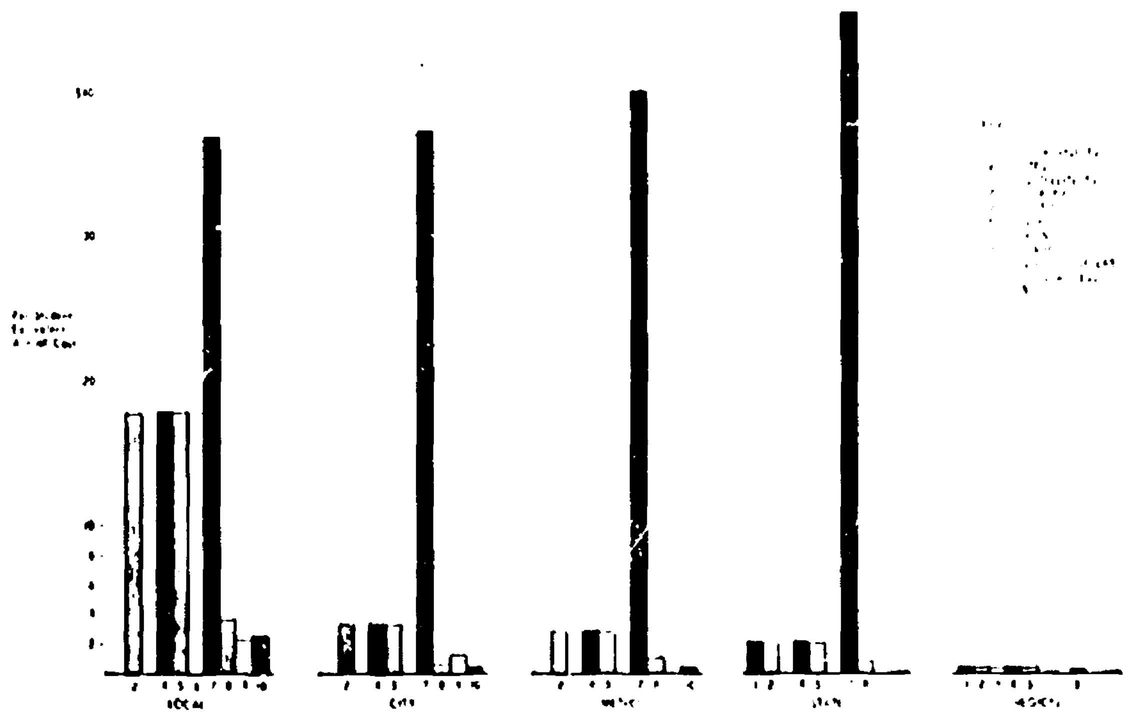


Figure 5 — Production Cost Comparison

Production costs

Fig. 5 shows annual equivalent production cost for each media. The cost for production of television and film per student per year is quite high, but the production cost for television decreases rapidly from \$18 to 25¢ as the number of students is increased. Recall that programming is the major portion of production cost. At the local and city levels, low-cost programming for television was chosen for the model while high quality programming was specified for the larger areas. In contrast, because of present film print pricing practices, the film cost for production does not decrease with higher numbers of students. It increases from \$37 to \$46 per student per year. The increase reflects the increase in the number of programming hours from 1,000 at the local level to 1,600 at the regional. The present pricing practices do not reflect the large increase in volume which is incorporated in the model, and might well change if an increased volume of prints were assured. Nor do the present pricing policies take into account the possibility of producing coordinated series of lessons with a simpler instructional television format. These would probably cost considerably less per lesson. On the other hand, to change these practices would lead to abandoning of one of the peculiar advantages of film, i.e., the ready availability of a wide range of materials of high technical quality.

The costs for radio production are somewhat high, about $4, at the local level, but decrease rapidly with larger numbers of students. The cost for the metropolitan and other areas is approximately $1 and less. The costs are based on rates higher than the present cost of obtaining duplicates for the Educational Audio Network. The increased rate provides funds for producing new series of instructional materials. The radio production costs also include costs for noninstructional broadcasting of about $1 per 100 persons in the broadcasting area. The radio production costs are much lower than the television production costs.

The production costs for language learning laboratories, around $2 per student per year, is not strictly comparable to the production cost for the other systems. The language laboratories can occupy 10% of the student's time without 1,000 hours of unique programming, which is the amount of programming assumed for other media at the local level. Nor is it at all obvious that the student should spend 10% of his time using a language laboratory. Therefore, a figure of 225 hours of unique programming has been used in the model. The elementary schools are assumed to use a passive or listening-only system. Only a small amount of money has been made available for programming for the elementary schools.

The production cost for the classroom dial access system is quite low, i.e., $2 at the local level and considerably less than 50¢ at the city and metropolitan levels. The production cost includes 1,000 hours of tapes of various readings, events, music, etc., which are presently available at a low cost of about $10 per hour. Because the system has 67 channels, and because of the general nature of the material, the instructional technique would largely consist of selecting short segments of the materials by the teacher. The teacher would assemble an instructional sequence for a particular class. This is quite different from the production of radio or television materials where the more limited number of channels assumed in the model means that most of the materials would be organized into complete instruction sequences by a central facility.

In summary, it can be said that production for visual materials can be accomplished at the reasonable cost of several dollars per student if the number of students in the system is in the hundreds of thousands. Moreover, the price structure for the materials must reflect the large volume. At present, television production cost is considerably less than the cost of producing films.

The production cost of audio materials for the 10% task is less than $1 per student when the number of students reaches the level of 100,000. If teachers produce their own tapes or if the somewhat limited number of tapes now available is used, the cost is only a few dollars per student even at the local level. Each of the audio methods is inexpensive to program at the city level.

Distribution costs

Fig. 6 presents the equivalent annual cost of distribution for each instructional media system. The costs of many of the systems which were examined across the entire range of environments show the same type of behavior, i. e., decreasing cost per student in the range from local to city and metropolitan area and then an increase from the metropolitan to the state and regional levels. The change in the number of students per basic transmitting unit of the distribution system causes this behavior. The city and metropolitan areas have densities on the order of 1,000 students per square mile, while the state and regional densities have less than 50. In general, the higher the cost of the basic unit, for example a radio transmitter, the higher the cost per student for the local area but the lower the cost for the larger areas. The local area does not utilize all of the larger systems' potential.

The television distribution systems are relatively expensive to use for the local school system, but become quite reasonable for the city and larger areas at about $2 or less per student per year.

The lowest-cost television distribution systems are the present ITFS for local, city and metropolitan area coverage and the new proposed higher-powered ITFS system for the state or regional areas. The UHF and closed-circuit systems are only $1 per student per year more than ITFS at the city level. It should be noted, however, that the costs for

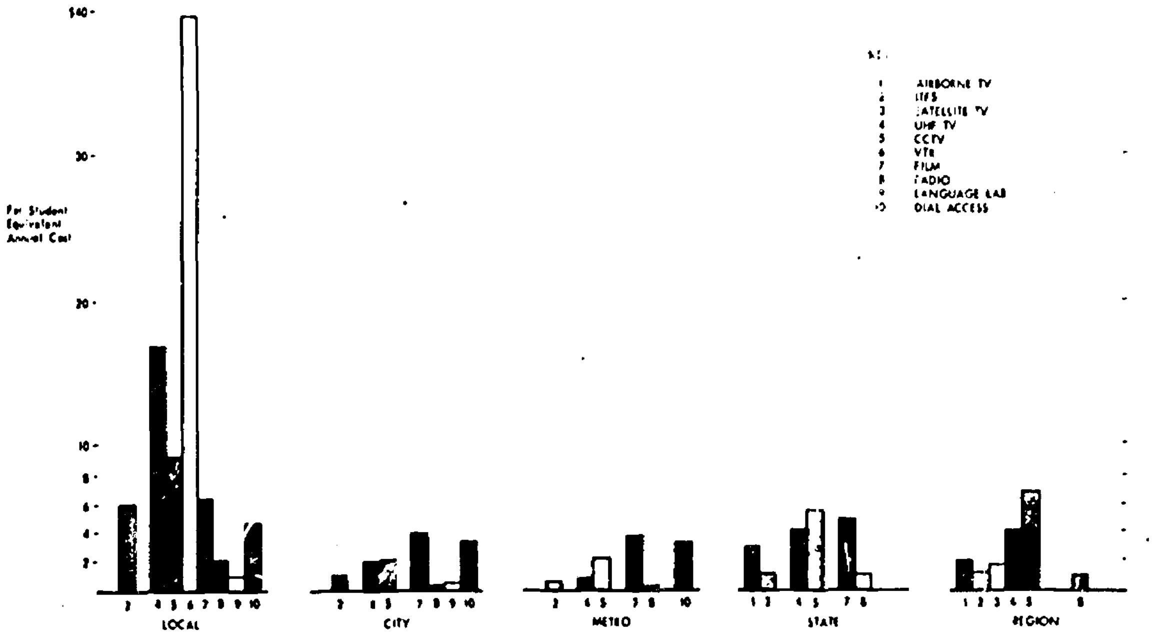


Figure 6 — Distribution Cost Comparison

this new type of ITFS equipment are conjectural, since none has been produced or operated. Also, almost all of the cost difference between UHF and the proposed higher-powered ITFS is due to higher power, more attention to providing a readily available signal, better control and monitoring, and higher operational reliability of the UHF system. The two systems are almost the same from a technical standpoint. It would be feasible to change either service to more closely resemble the other, although the FCC would have to approve such changes.

The projected 1973 satellite costs of a little under $2 per student per year and the airborne cost, which is slightly more, are roughly competitive with the higher-powered ITFS system for larger areas. The cost of the airborne system declines from state to region because the coverage patterns fit together better in a larger area.

The VTR system which places a video tape recorder and tape library in every school is quite expensive, about $36 per student per year. The cost would not decrease for larger areas since the basic cost is multiplied for each school.

The radio distribution system is even cheaper than television, particularly at the local level where it is only $2 per student per year.

The language laboratory distribution system costs about $1.50 per student per year for all of the environments for which it was costed.

The dial access distribution system is the most expensive audio system at $3 to $5 per student per year, ranging from the local to the metropolitan areas. The dial access system was not investigated for state or regional areas, but the costs would probably increase substantially because of increased transmission line charges.

The film distribution system costs about the same as dial access or closed-circuit television. The costs are in the $3 to $6 per student per year range.

In summary, television and radio are both available for the city and/or metropolitan areas at less than $1 per student for distribution. In the local school district, the distribution cost of the language laboratory and radio system is considerably less than any other system, about $2 per student per year. The radio system is a high-powered service which can serve homes as well as schools 18 hours per day. Film or classroom dial access distribution can be accomplished for $3 to $6 per student per year depending upon the size of the area. The VTR in the school is not an efficient method under the assumptions presented in the model. Among the television systems, for distribution cost alone, the ITFS system is cheapest for the local and city areas. For the larger areas, only a change in FCC rules to permit higher power will allow ITFS to be competitive with UHF or airborne for the state and region.

It should be noted that effectiveness has not been studied, and that some of the fairly small differences in distribution costs may be offset by educational advantages or disadvantages.

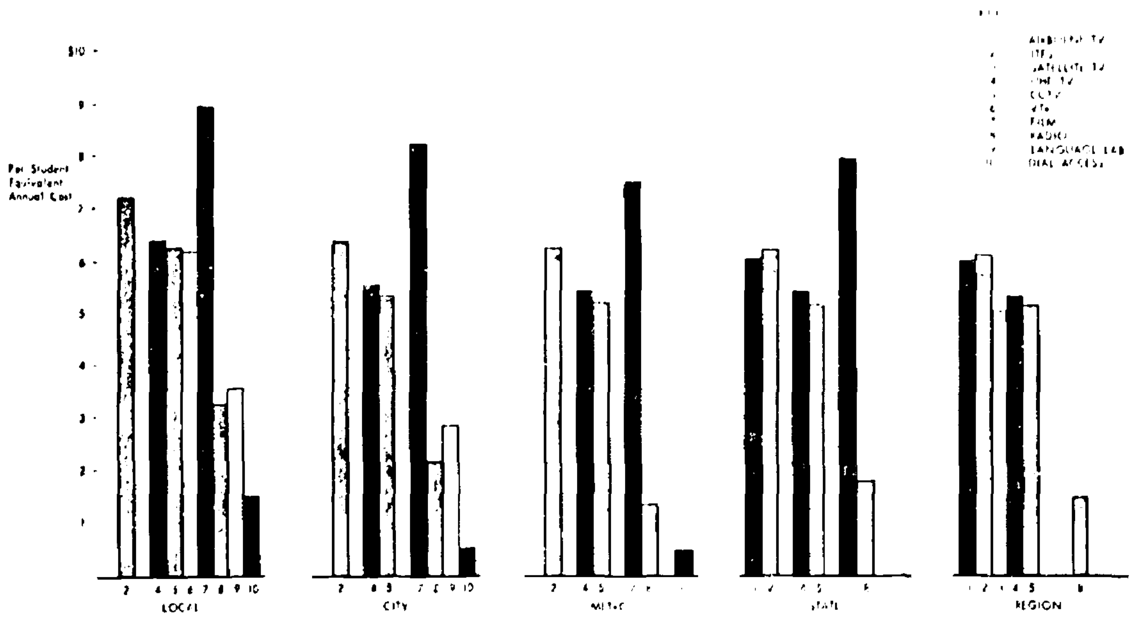


Figure 7 – Reception Cost Comparison

Reception costs

The equivalent annual costs per student for reception are presented in Fig. 7. The reception costs show a more constant behavior pattern as a function of area size than do the other costs.

The television costs fall in a band about $1 wide centering on $6.50 for the local system and decreasing to $5 per student per year for the regional system. Closed-circuit, VTR, and UHF broadcasts have the lowest costs. Airborne and ITFS have the highest costs because better antennas and towers are needed. The reception costs for the satellite system are projected at slightly less than the others because 1973 technology is assumed for this system. The present cost for this equipment would be considerably more. Approximately $2.50 of television reception cost per student is for teacher training and another $2 is for the television set.

The radio reception cost decreases from about $3 per student at the local level to about $1.50 per student per year at the regional level.

The film reception cost is about $9 for the local system but decreases to $8 per student per year for the metropolitan area. Film reception costs is the highest of all the media, but is only insignificantly higher than the television reception cost for the metropolitan area.

The language learning laboratories reception costs are slightly higher than radio reception costs because they include the carrel.

The reception cost for classroom dial access is the cheapest of the media -- less than $1 per student per year at the city and metropolitan level. The dial access reception equipment consists of one loudspeaker per room.

In summary, television reception cost -- including $2.50 for teacher training -- is about $6 per student per year. The reception cost for closed-circuit or VTR network is slightly more than for the other television systems. Film reception cost is somewhat more. The reception cost for radio the language laboratory is slightly more than for radio. The classroom dial access cost for reception is very low, about 50¢ for the city or the metropolitan area.

Total cost

The total equivalent annual cost per student is shown in Fig. 8, and is perhaps the most important cost of all.

The total costs fall into two broad bands with only a few exceptions. The television total costs (except for the VTR system) fall between $30 and $40 per student per year for the local area (5% to 10% of yearly expenditures). They converge on $10 for the city and roughly the same for the metropolitan area. They then spread to a range of $6 to $14 for the state and regional areas. The 1973 satellite has the lowest total cost but

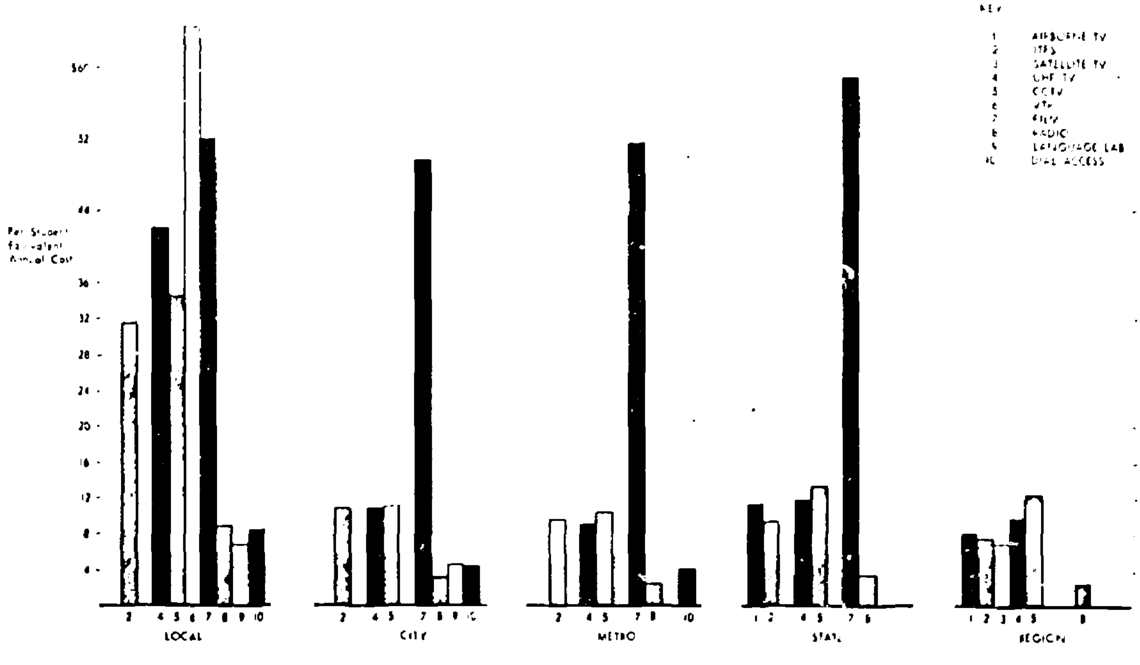


Figure 8 — Total Cost Comparison

only by an insignificant margin. The ITFS system is less in the local areas. For the city and metropolitan areas, costs are so close that technical questions of channel space would probably be more important and would no doubt favor the closed-circuit system. Much the same can be said for statewide multichannel systems unless FCC rules are changed.

The results for the audio systems, language learning laboratories, classroom dial access, and radio systems form the second band and all fall in the \$8 to \$10 range for the local area and in the \$3 to \$6 per student per year range for the city. The radio system is about \$2. 50 per student per year for the metropolitan area and \$3. 50 and \$2. 50 for the state and region, the lowest cost of any system.

The VTR system with video tape recorders in each school costs about \$65 at the local level, considerably more than any of the other systems. As cheaper and more reliable machines, high speed duplication, or the CBS Laboratories' EVR system become available, VTR should be given additional attention.

The total costs for film are about \$50 per student for the local, city, and metropolitan areas, but rise to about \$59 per student per year at the state and regional level.

In summary, audio instructional materials can be supplied by radio for low as \$2 to \$3 per student per year. Visual material costs are about \$10 per student per year when they are delivered by television in the city or metropolitan areas. Several new methods are available for coverage of wider areas at about the same or slightly lower cost. Smaller school districts must cooperate with one another or pay considerably more.

Effect of number of channels and task size on cost per student

The cost figures presented in the discussion of television and radio have been costs for a four-channel service. The four channels accommodate the defined task of 10% of student time with a considerable margin for repeated broadcasts and expansion. There is, of course, the possibility of changing the task and/or changing the number of channels. An estimate of the cost of doing this is shown in Fig. 9 and Fig. 10.

Fig. 9 presents the change in cost with a switch in the number of channels from four to two and one for selected television systems. The figures are obtained from those in the descriptions using the same production and reception costs per student and the distribution costs for one and two channels. It is assumed that a single six or eight-channel converter to UHF can be designed. The additional cost is quite small, little more than \$1 for six or eight channels. Regulatory limits on the number of channels might preclude such additions, however.

Fig. 10 considers the effect of a change in the level of the task accomplished by the instructional media system. The basic level of the model is 10% of student time. For a 20% task, the programming portion of production cost would almost double. Other costs would remain about the same. The result, roughly a 20% increase in total cost, is shown in

Figure 18 for the closed-circuit metropolitan system. Other television systems at the metropolitan level would change the same amount, given the above assumptions.

A combination of the two changes -- a 20% task and an eight channel system -- would result in an increased cost of only about 30%, but this is only a very crude estimate.

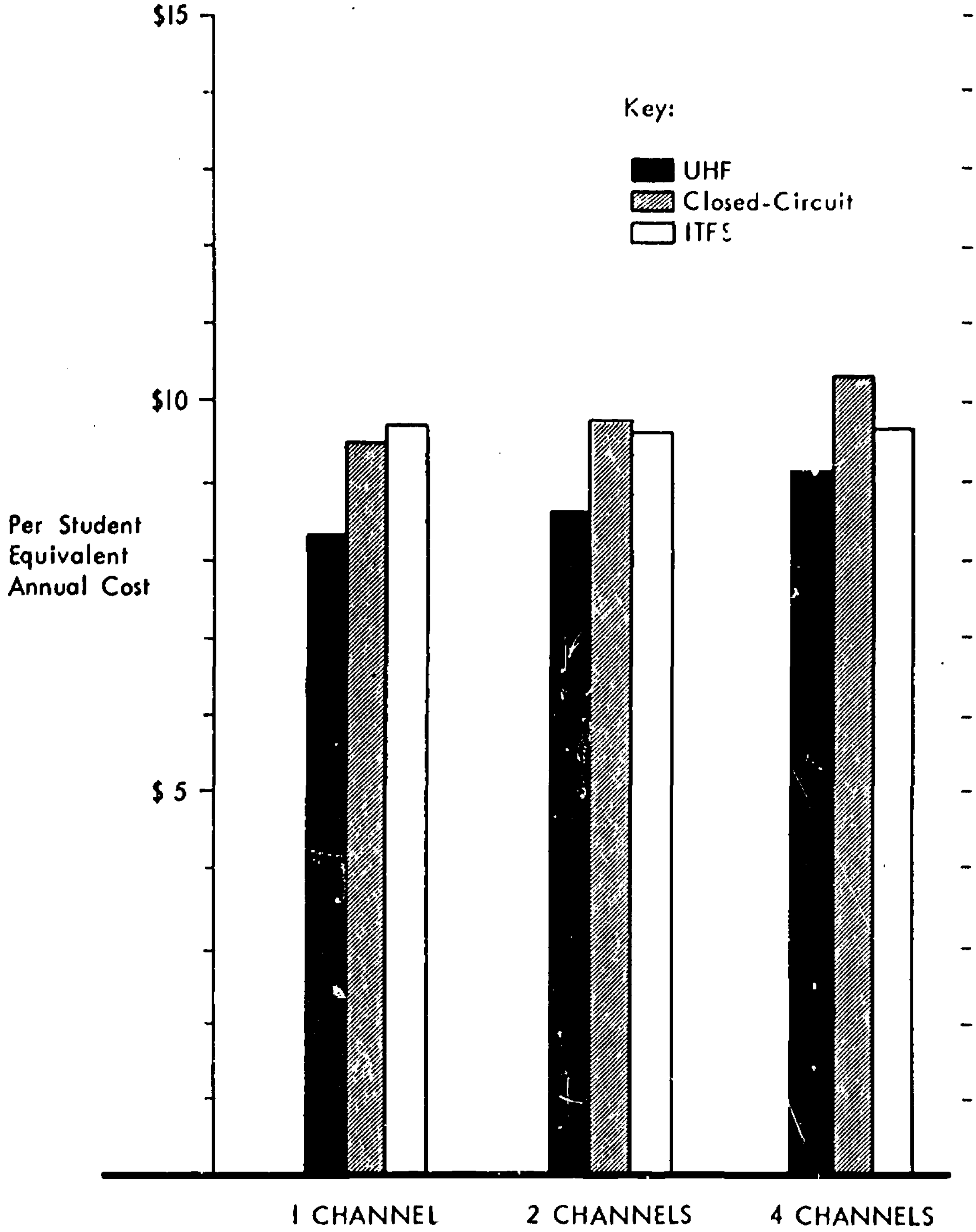


Figure 9 – Estimated Effect of Number of Channels on Cost – Metropolitan Area

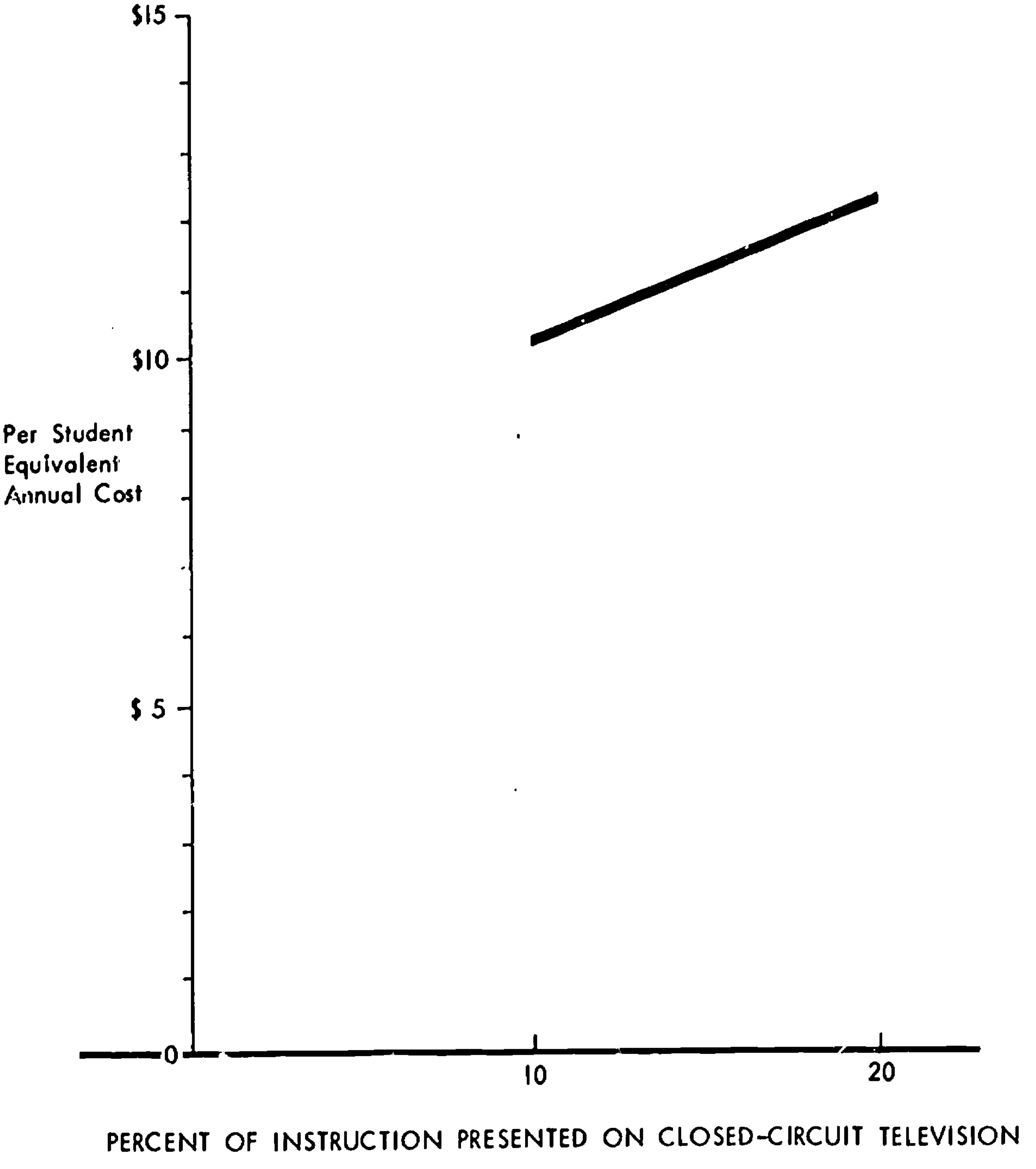


Figure 10 – Estimated Effect of Task Size on Cost – Metropolitan Area

IV. COST-SAVING CONSIDERATIONS

One objective of this study is to investigate ways in which costs in instructional media systems could be reduced. This section serves two purposes. The first is to present an overview of how cost savings may be achieved, the second to present suggestions which may lead to possible cost savings through organizational changes in the educational systems.

Three areas can be identified where changes are necessary if cost savings are to be achieved:

1. The utilization of media systems,
2. The technology of media systems, and
3. The organization of educational systems.

A discussion of each of these three areas is presented in this section.

Utilization of media systems

Wide-scale adoption and more intensive use of the media will result in cost reductions on a per student basis in the areas of production, distribution, and reception, as discussed below.

Production cost savings from increased utilization

Significant savings will result if a production effort can serve a larger number of students. However, if materials are to be accepted for widespread use, the quality of content and presentation must be improved by making more effective use of learning theory, techniques to motivate students, and studies of the curriculum needs of the schools. Preparation of materials in this manner would result in an increase in overall production cost but, through wider utilization, would alse result in a decrease in production cost per student.

Savings in quality production are predicated on the assumption that the need for materials is relatively uniform in widely scattered school districts and that reliable, convenient distribution and reception systems would be available to transmit these materials. The existing widespread adoption of the same textbook would seem to indicate that these assumptions are reasonable. However, some coordinating mechanism is needed to guide the production and distribution of materials for the newer media. The cooperation of school districts is an essential ingredient in the development of such a mechanism.

Fig. 4, earlier in this abridgment, illustrated the cost savings possible through wider utilization of the materials produced for television. The cost per student drops rapidly with the increase in the number of students served. This cost decrease occurs although there are two assumptions in the model which would tend to have the opposite effect: (1) the number of hours of material required increases 60% from the local to the regional environment, and (2) the quality of material changes from "minimum" at the city level to "high" at the metropolitan level.

Distribution cost savings from increased utilization

The distribution cost per student can be reduced if

1. More students can be served from a central facility, or
2. Mass reproduction methods can be found for making inexpensive copies of original materials.

The service of a media system can be increased through the use of network television techniques -- higher transmission antennae, increased transmission power, and an electronic relay of materials between school districts. Satellite and airborne television systems are also well suited to covering vast areas containing large numbers of students. More intensive use of such methods can reduce per student cost considerably, but only if materials and schedules are appropriately tailored to the educational needs of participating schools. To accomplish this, transmission centers must have multiple channels available, and schedules and materials must be coordinated with the schools.

Fig. 11 shows the behavior of distribution cost for broadcast television systems as a function of the number of students served. The cost per student decreases sharply over the range from the local to the metropolitan level. On the other hand, no decrease occurs from the state to the regional level because the population density does not increase; in other words, the utilization of any one station does not increase from the state to the regional level.

The critical factor in lowering the cost of reproducing original materials is the anticipated volume of distribution. Unless the volume is large enough, the development effort required to find inexpensive methods of duplicating films and video tapes would not be worthwhile. Present copying techniques are based on high quality broadcast standards and low volume. Although high speed reproduction of video tapes is potentially possible, the necessary techniques have not been developed. The price of a film print is many times the cost of making the print because of the low recovery rate of production and marketing costs. Assurance of a high-volume market for copies of video materials or federal financing of the needed research would encourage low cost reproduction methods of copying video educational materials.

Reception cost savings from increased utilization

Savings in reception costs can be effected through

1. Increased student utilization of some portions of the reception system, and
2. Lower costs of components through the adoption of mass production methods.

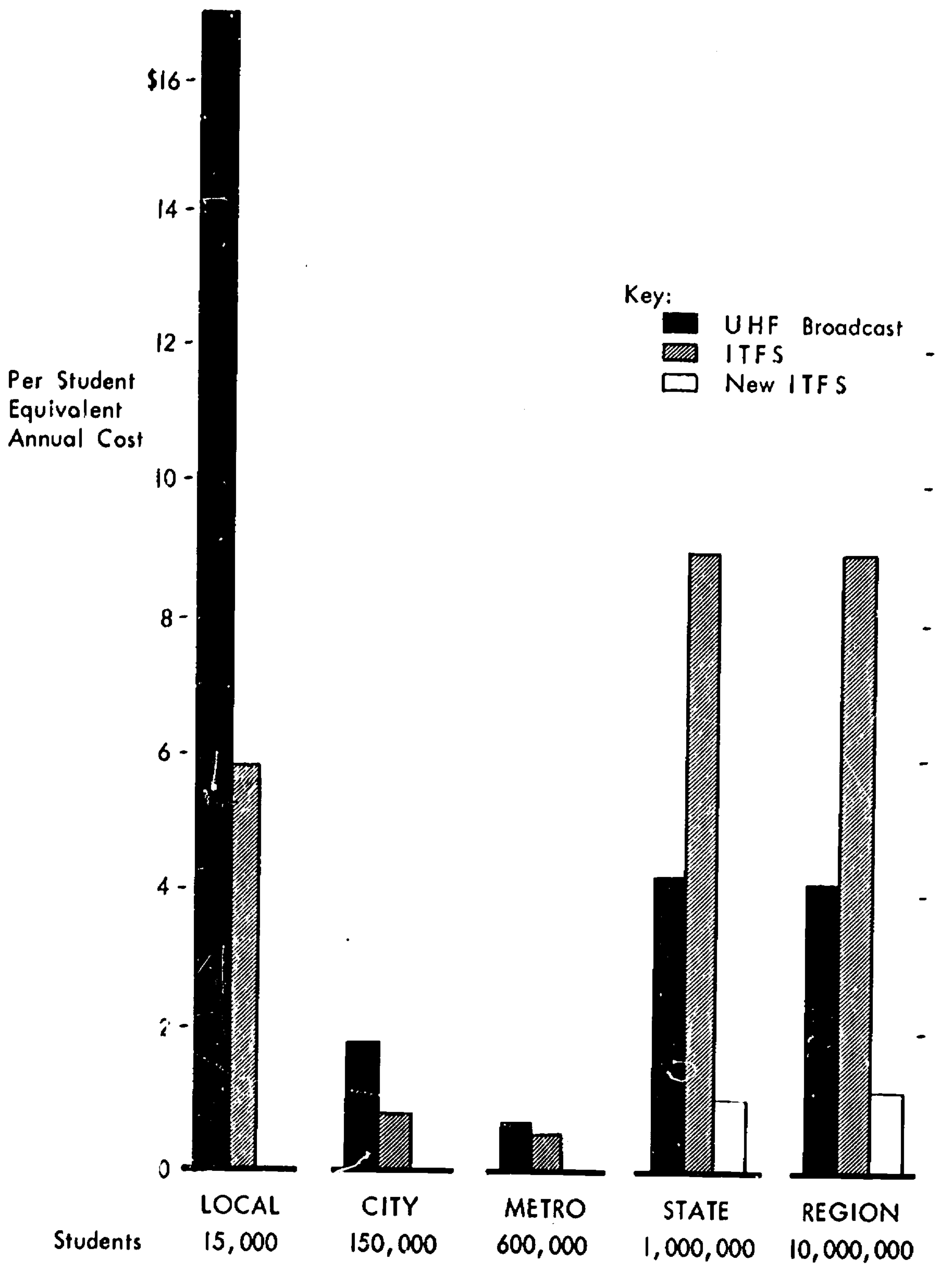


Figure 11 – TV Distribution Costs

Portions of the reception system would cost less per student if more student hours were devoted to the media. The central reception and distribution segments in the television reception systems are examples of areas where greater utilization would lower per student cost. However, since most of the reception cost is for the television set and teacher training, more students in the schools would not necessarily lower costs per student. The students would still need a television set and a trained teacher.

The discussion above shows that an increased number of students using a media system tends to lower per student costs. Also, there is another increase in the utilization of the media which would tend to affect cost favorably, i. e., the increased use of the system by the same students. Although the actual cost per student would rise as the system is expanded, the cost does not increase as rapidly as service is increased. Therefore, if total educational costs are considered, more intensive use of media systems may be desirable since the change in the cost of providing additional units of instruction is quite small.

Improved technology for instructional media

Improvements in the instructional media technology should lower the cost of the media. Several technological advances are suggested in this volume. For example, the satellite system is not now in existence; the higher-powered ITFS system is a new proposal. The suggested use of a four-channel television system would also be an innovation. Some aspects of the classroom dial access and language laboratories are new and the multiplex radio system is not now in educational use.

Organization of educational systems

The behavioral objectives and the types of learning associated with those objectives are key elements in the media selection process. The mode of presentation whether group or individual is also an important consideration in the selection procedure. If these elements play a part in the selection of a media system, it may be assumed that the need for both group and individually-oriented systems will be recognized. Would this change the traditional school organization? Yes, because there are few provisions for individualized instruction at the present time. Could these changes result in "cost saving" situations? Again the answer is "yes."

The cost savings which could result from changes in the organization of educational systems should probably be referred to as increases in "cost effectiveness." Most of the previous discussion has tended to equate cost savings with reduced costs. In this discussion cost savings will be equated with cost effectiveness.

The largest item in a school's operating budget is teachers' salaries. The implementation of media systems would not necessarily reduce the number of teachers. It would alter their role, however, so that they could devote a larger portion of their time to individual instruction and the guidance of learning experiences. This would be one step toward the achievement of optimum "cost effectiveness." The operation of the media, the monitoring of learning experiences, and other similar responsibilities could be assigned to paraprofessionals. This work, currently performed by the teacher, could be effectively accomplished by persons without the professional qualifications required of members of the teaching staff. Hence, a "cost saving" may result when a school system is organized along these lines.

The discussion of wider utilization of media systems indicated the cost savings are possible when the system is used by larger numbers of students. For example, a dramatic decrease in annual cost per student for the production of television material occurs as the number of students increases from 15 thousand to 10 million. The per pupil cost of the distribution portion of the media system is also favorably affected as the number of students increases in the area served by the system.

Wider utilization may reduce cost, but it may also present organizational problems. For example, if 11 states were to be served by the same instructional satellite system, the educational programs of those states would have to be coordinated.

If production costs are to be shared, the material must be acceptable to all of the participants. Therefore, the user schools must be involved in the design, development, testing and evaluation, and revision of materials. The financial arrangements to support the production of materials must be agreed upon. All of the above considerations would affect the present organization of the user schools.

A distribution system which serves more than one school or district also presents problems. The scheduling of "what and when" can be a horrendous task. Again, the organization of the schools using the system is affected by the scheduling, so these schools must cooperate to determine the policies of a central distribution facility.

The media cannot be effective unless the teacher is trained to make use of the capabilities which the media system provides. Therefore, teacher training is of prime importance, and the educational system must provide adequate training. Teacher training may tend to increase per student cost, but lack of training in the use of the tools provided by media can affect cost effectiveness immeasurably.

The scope of this report does not include the investigation of designs for the effective organization of educational systems, but this discussion has been included to point to some of the ways in which media system cost reductions and cost effectiveness are related to the organization of the educational system.

V. REGULATORY IMPLICATIONS

Electronic systems

Some of the multichannel instructional television systems proposed in this study are not explicitly covered by the present regulations or policies of the FCC. Specifically, the higher-powered ITFS specified for the state and region, the four-channel UHF system, the UHF airborne system, and the use of satellites for direct transmission on the 2500 MHz frequencies are all somewhat outside established practice. These departures were made for two reasons, cost and regulatory tardiness.

The production costs for instructional media for the local school system of 15,000 students were found to be $60 per student per year for high quality programming, $15 per student for minimal quality programming, and $6.67 for copies of materials produced by national sources. The distribution cost was almost $6 per student, even for ITFS, which has the lowest cost. These high costs decrease as more students are served and should encourage schools to share production and/or distribution efforts by joining an area-wide system such as a metropolitan, state, or regional system.

The possibility of a wide area multichannel instructional television system is limited under present FCC regulations and policies. An examination of the policies regarding multichannel wide area systems shows that these limitations make it impractical to implement a large scale instructional television system outside of a metropolitan area. Existing regulations are examined below.

The UHF frequencies are designated as broadcast frequencies. The Communications Act of 1934 defines broadcasting as "the dissemination of radio communication intended to be received by the public." The FCC regards this definition as separating instructional television from broadcasting since ITV is not intended for the entire "public." FCC policy is that instructional service, if designed for instruction alone, should not be placed in the UHF band. Multiple channels would be particularly hard to obtain for educational purposes. Recent FCC actions which give evidence of this viewpoint are the denial of the NAEB request for multiple-channel educational reservations in the latest UHF allocation table, the denial of the Georgia State Board of Education petition for a block of 30 UHF channels, and the refusal by the FCC to allow the airborne television project to continue using the UHF channels assigned to it.

The FCC has specifically allowed educators to use the 2500 MHz band on a shared basis with other users for a three year period ending in 1966. As of 1968, no final action has been taken. This service, the Instructional Television Fixed Service or ITFS, was set up at the urging of an electronics firm which desired an additional market for its low power microwave relay transmitters. The service is low power, localized for individual school systems. Use of low transmitting heights and directional transmitting antennas is recommended. Paragraph 26 of the Report and Order on Docket No. 14744 of the FCC specifically bans use of ITFS "to distribute material over an entire state or a large portion thereof." Even when used within a metropolitan area, the FCC concept of shared use of ITFS channels has required the concurrence of all school districts in the area before service can be instituted. Such service is not economical for wide area coverage, as is shown in the standard ITFS cost figure for state coverage in the full original report.

The airborne system was given until 1969 to relinquish its UHF channels and went off the air in June 1968. Meanwhile the FCC designated six ITFS channels in the midwest for its use. Airborne broadcast on even four ITFS channels in any area except that covered by the midwest airborne project would have to obtain the explicit permission of all school districts within its area, according to the present FCC policy. This would be difficult.

The use of a satellite for direct telecasting is not covered by FCC regulations. There are strong political and economic forces that must be overcome before such an operation would be approved.

The only alternatives to the telecasting methods discussed above are closed-circuit systems and the portable video tape recorder, neither of which uses the airways. These are by far the most costly systems, as was shown earlier in Fig. 8. Neither of these systems is within the province of the FCC unless microwave is used or state lines are crossed.

In summary, the use of the airwaves for multichannel instructional television for a wide area has been almost precluded by present FCC regulation and policy. Since such a system has considerable cost advantages, several instructional media systems which would be difficult to establish under present FCC policies and regulations were included in this report. The systems which are specified can be justified in terms of channel allocation and the economics of providing the service if a priority were assigned for instructional service. A brief justification for each of the systems follows.

The four-channel UHF instructional system could be accommodated if the FCC would recognize the difference between instructional service and other broadcasting. The taboos -- limitations on close spacing of channels -- could be changed. The taboos were eliminated for ITFS in recognition of this fact. Reservation of a block of channels for instructional systems was thoroughly studied for the Georgia State Board of Education proposal and found to be practical. A block of 20 channels would be sufficient for a four-channel state or regional service. In the UHF channels 52-72 or 63-83, there are only the merest handful of broadcast stations operating. They could be moved down into the region below 52 or 63 if some of the allocations to small communities were deleted from the allocation table or if a more "saturated" allocation table were prepared. It has been shown that the great majority of the UHF station allocations will not be used in the foreseeable future because they are not economically feasible. It has been said that the FCC is thinking of transferring a portion of the UHF broadcast channels to the land mobile service for this very reason.

The four-channel airborne system was generally assumed to be operating in the UHF in this study. However, it was noted that the transmitting equipment could be produced for about the same price at the ITFS frequency. Thus, the airborne system could operate at either frequency except for regulatory considerations. Extensive analysis of the allocations in the midwest in 1964 showed that there were adequate channels available for both a six-channel airborne instructional system and all the commercial stations which would be economically feasible in the foreseeable future. The same is probably true for all regions except the eastern megalopolis, which has been treated in a separate statement in the full original report.

The low power of the present ITFS system does not make it economically feasible for use in a large area. For this reason, a higher-powered, wide-area ITFS service is proposed in this study. The reason for examining the state and regional areas is because the local school system cannot afford programming for the multichannel systems. A state or regional system is the only way to serve the small school districts if they are outside of a metropolitan area. While the local school system may find scheduling advantages in the use of ITFS, there are serious problems of financing the production of materials for telecasting. The FCC's recent pamphlet on ITFS points to the desirability of renting materials rather than producing them in each school system. Unfortunately, there are not adequate rentals available and even rental is expensive for the small school system. Many schools are proceeding with live production without adequate resources, personnel, planning or experience. Many thousands of schools will soon undergo the frustrating programming experience which ETV stations have experienced during the last 15 years.

The proposed higher-powered ITFS system would include a 20 channel block for the state or regional system, leaving four to six blocks of two or three channels per block within the present ITFS allocation for purely local use or for local retransmission to avoid scheduling problems.

The satellite system in this study is on the same frequency as ITFS. It is assumed that provision could also be made for a few channels of local ITFS service, as would be done with the higher-powered ITFS.

The problem of frequency allocation is currently under inspection by several groups on a national and international level. This is a particularly opportune time to make adequate provision for instructional television.

In summary, without a national program source, only a state or regional system can economically provide multichannel instructional television for the local school. The FCC does not provide for such a system. Therefore the assumption has been made that the regulations can be changed. It is suggested that economical and efficient four-channel systems can be instituted at either UHF or ITFS, leaving sufficient channels still available for local commercial and educational interests.

Film systems

Some cost efficiencies in a 16mm media system could be realized with a favorable outcome of the current copyright legislation. Unfortunately, Congress is trying to develop a piece of universal legislation that will satisfy both the author and the publisher of all art forms for all communication media, both commercial and educational. A proposed draft of suggested copyright changes was authored by members of National Association of Educational Broadcasters for the Department of Audiovisual Instruction of the National Education Association. The bulk of this draft was adopted as the official position of the NEA, which then recommended the changes to Congress. These recommendations have provoked considerable discussion during the past two years.

The fair use doctrine was expanded to permit a school to make one copy of a film without obtaining permission from the copyright holder, use it once, and then destroy the copy. Certainly this clause can only tempt honest individuals to break the law. On the other hand, modern photocopying equipment allows individuals to infringe upon the existing law every day. The textbook publishing industry has helped to create this problem by refusing to allow teachers to duplicate passages from books for testing purposes. Schools are permitted to make a duplicate video tape copy of an existing film program, but it is doubtful that they will destroy the copy once made. Accordingly, most producers and distributors charge exorbitant prices for schools for the right to copy. They feel that permitting video tape copies of films will decrease their sales to a school system because the schools will use the multiple transmission capabilities of television rather than buy enough films for the classrooms. No research has been done to prove or disprove this argument.

Another area of infringement, according to legislation now in effect, is excerpting short segments of footage from longer films. This can be resolved easily by establishing a national facility which would catalog existing film footage, source, and price. Footage cataloging is virtually nonexistent today and would require computer cataloging procedures to describe sequences.

A difficult area, avoided by the proposed copyright bill, concerns films that were produced by federal government grants. A few years ago marketing or distribution right for films, texts, and other materials were given to corporations which then priced these items at commercial rates. Competitive companies complained about the exclusive distribution rights, educators complained about the commercial prices, and the

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*This section is by Joseph E. Lynch

federal government was in the middle. No group of commercial companies would cooperate and market the programs on a nonexclusive basis. Also, they would not allow the program development agency to market their programs because they feared government competition.

As curriculum development programs continue to be funded by various agencies of the federal government, some nonexclusive distribution contracts have been negotiated. However, a new problem has developed. Publishers, distributors, etc. refuse to accept a program the way it is designed, but rather wish to change content and/or form to be consistent with their own programs or manufacturing capabilities. For example, if a program consists of 10 odd sized booklets each having 10 pages, a publisher would package it in one volume of 100 standard textbook size pages. One solution to this problem is to fund the curriculum groups and allow them to develop their own distribution capability. Another alternative is to help individuals from the educational and commercial communities to establish new companies for this purpose by funding the initial capital requirements of these groups. Currently the Small Business Administration is slow to loan money for the formulation of this new type of company.

In summary, if a national program source is not available, 16mm film programs could still become less expensive if the following steps were taken:

1. Redraft the current copyright bill to better serve the needs of educators and commercial producers.
2. Create a national cataloging service so that schools can locate short film segments that best fit their needs.
3. Permit films that were produced with federal funds to be sold at less than commercial prices.
4. Permit curriculum groups to market or distribute newly developed materials.