THE IMPACT OF COMPUTERS ON TEACHING AND RESEARCH IN MATHEMATICS AND RELATED SUBJECTS

Technion — Israel Institute of Technology
THE SAMUEL NEAMAN INSTITUTE FOR
ADVANCED STUDIES IN SCIENCE AND TECHNOLOGY

הטכניון - מכון טכנולוגי לישראל
TECHNION- ISRAEL INSTITUTE OF TECHNOLOGY

THE S. NEAMAN INSTITUTE
FOR ADVANCED STUDIES IN SCIENCE & TECHNOLOGY

מוסד שמואל נאמן
למחקר מתקדם במדע ובטכנולוגיה

THE IMPACT OF COMPUTERS ON TEACHING AND RESEARCH IN MATHEMATICS AND RELATED SUBJECTS

Final Report of the
Neaman Institute-Technion Committee
for Mathematics and Computers in the Teaching Schedule

N. Liron, Professor of Mathematics
L. Pismen, Professor of Chemical Engineering
M. Wolfshtein, Professor of Aeronautics, Chairman
Z. Ziegler, Professor of Mathematics

October, 1990

Technion City, Haifa 32000, Israel, Tel. 237145 / 292329.קרית הטכניון, חיפה 32000,טל
Telex 471170 SNI IL FAX 4231889

הטכניון - מכון טכנולוגי לישראל
TECHNION - ISRAEL INSTITUTE OF TECHNOLOGY

THE S. NEAMAN INSTITUTE
FOR ADVANCED STUDIES IN SCIENCE & TECHNOLOGY

מוסד שמואל נאמן
למחקר מתקדם במדע ובטכנולוגיה

THE IMPACT OF COMPUTERS ON TEACHING AND RESEARCH IN MATHEMATICS AND RELATED SUBJECTS

Final Report of the
Neaman Institute-Technion Committee
for Mathematics and Computers in the Teaching Schedule

N. Liron, Professor of Mathematics
L. Pismen, Professor of Chemical Engineering
M. Wolfshtein, Professor of Aeronautics, Chairman
Z. Ziegler, Professor of Mathematics

October, 1990

Table of Contents

1. EXECUTIVE SUMMARY

The Neaman Institute/Technion Committee for Mathematics and Computers in the Teaching Schedule was appointed by Prof. B. Silver and Prof Z. Tadmor on 26 January 1989. The objectives of the committee as defined in the appointment letter were:

a. To study in depth the scope and contents of the expected and desired mathematical foundations in engineering education, in view of the significant influence of computer technology on mathematical tools in science, engineering and teaching methods.

b. To examine the needs of the Technion in software and computations from both research and teaching point of view.

The members of the committee are:
N. Liron, L. Pismen, M. Wolfshtein and Z. Ziegler.

The activities of the committee included examination of papers on the subject; discussions with E. Dubinsky; a search for educational software; and preparation of this report.

The committee met during the period January to June 1989, and from September 1989 to June 1990 and discussed the subject. One of the major issues examined by the committee was to check whether the Technion is taking all the necessary steps to ensure that it can face the challenges of the rapidly evolving computer technology. The committee had to examine various options available to the Technion and to make some recommendations for action. In particular, the committee wanted to find out whether curricular modifications of a general nature are called for in view of the widespread availability of computers, and whether some special other steps are required to support computer utilization in both research and teaching in either mathematics or mathematically related subjects in science and engineering in the Technion.

The committee started its work by examining the curricula and syllabi of various courses with mathematical contents taught at the Technion. This was followed by long discussions, a trial and error process, a study of the available literature, and consultations with E. Dubinsky of Purdue University, who is one of the leading experts in the area of utilization of computers for the teaching of mathematics. In particular Professor Ed Dubinsky gave the committee his perspective of the subject and introduced some of the educational software developed and used in Purdue for the teaching of undergraduate mathematics.

This report summarizes the perspectives opened to the committee and outlines its suggestions for future action by the Technion.

The major conclusions are:

1. The time for a general curricular revision has not yet come, and the current state of the art does not warrant major changes at the present moment. Instead, the "computerization" of the curricula and class work would be best achieved by individual faculties. The committee noted with satisfaction that some progress along these lines had already been made and that several faculty members are experimenting with computerization of courses. Such efforts should be encouraged in the future by technical and financial support.

2. The research capabilities of the Technion should be enhanced by institutionalizing the handling of scientific software packages. It is necessary to devise mechanisms for collection and sorting of information, and for advise, tutoring and scientific support to potential users.

3. The committee recommends that a scientific and educational software Center be established. Such a center will serve as a catalyst for future developments, and will provide the infrastructure necessary for the incorporation and integration of computers in teaching and research in mathematics and mathematically oriented subjects.

2. REVIEW OF CONTEMPORARY COMPUTING

The computer arena is varying in a very quick pace. Therefore any description is valid only for a limited time, and the present one is no exception. We shall try to give some account of the situation in 1990, with the full understanding that major changes are likely to occur in the very near future.

When considering hardware, we classify machines to supercomputers, mainframes (and super minis), work stations, and personal computers. Terminals are described together with mainframes although they may be used with work stations too. Classification of software is to operating systems and programming tools, compilers and interpreters (or programming languages), scientific applications (like mathematical packages), and non scientific applications (like word processors, spread sheets and data bases, as well as graphics). Such classifications are somewhat artificial, but they are still useful to allow an orderly description of the field.

2.1 Current potential of computer utilization in science and engineering

Recent years have seen a great change in the computer industry. The small machines of today are bigger than the large machines of yesterday. Moreover, the computer market has been characterized by a continuous decrease in the price of the machines, which is often not fully appreciated due to the tremendous increase in computer power without any rise in prices. On top of this phenomenon, contemporary computers can perform operations and tasks which were not dreamt of some years ago. Solutions of very complex systems of differential equations, graphical capabilities and computer aided design, symbolic algebra and expert systems are but a few of the examples which abound not only in science and technology, but also in social science and even in the arts.

Naturally, such an intense development opened new possibilities and capabilities in all walks of life. In the scientific and technological areas computers are used for a large variety of applications, like:

- Numerical analysis
- Analysis and maintenance of numerical and non numerical data
- Data acquisition from experiments
- Symbolic algebra
- Graphic processing
- Computer Aided Design
- Computer Aided Manufacturing
- Computer Aided Engineering
- Computer Aided Instruction
- Communications
- Word processing

All these possibilities open new horizons, but also new challenges to academic institutions. On one hand, the modern student needs to know more about the utilization of computers, so as to make him a better researcher or engineer. On the other hand, successful contemporary research often depends on the availability of first class computing capabilities. Moreover, the advent of computational educational technology opens the prospect of increased efficiency of the educational process, by implementation of computers and computational technology in the teaching process itself. On the other hand, universities are required to examine the syllabus and find out topics which can be removed from the curriculum in view of the changed requirements and capabilities.

2.2 Hardware for scientific computing

2.2.1 Supercomputers

In a somewhat vague definition, supercomputers are defined as the largest machines available at a given time. These are the large working horses in the computer field. Today their power is achieved through the application of parallel processing technology. This technology has two different varieties:

a. **Vector processors.** Vector processors are machines in which some non-similar units arranged in a pipe-line, one after the other, operate on an array of inputs. Typical such machines are the CRAY computers (when utilizing only a single processor per job). The success of the vector processing idea was so significant that today vector processing is migrating to smaller machines (below the supercomputer class) as well.

b. **Parallel computers.** Parallel computers are machines in which parallelism is obtained by performing the computation on similar units, which can (but do not have to) perform the same type of computations. In this case the computations are performed simultaneously on all processors. Such machines can achieve a tremendous number of operations per second (up to 10^{10} floating point operations per second).

It should be noted that vector processing technology is well developed, and slowly finds its way into general purpose computers and even into smaller machines. Thus it may be expected that even work stations will use vector processors in the near future. On the other hand the parallel processing technology is not sufficiently developed, (especially the software) and these machines can not be considered as general purpose machines at present. Indeed there are serious doubts whether they will become general purpose machines in the near future.

The vector computers available in the computer center today are the Convex C220 computer and the DIGITAL VAX 9210. Parallel computers are just beginning to appear in the Technion now (end of 1990).

2.2.2 Mainframe computers

Smaller than supercomputers are the general purpose machines usually referred to as mainframes and super-minis. These are still using the conventional scalar computing technology (in contradiction to the vector or parallel computing technology). Such machines are still very common, but in recent years they are losing ground when large problems are transferred to supercomputers, while other problems migrate to work stations. The future of such machines in science and technology is not certain, but it appears that in the near future these machines will still be quite widespread. Some role for these machines in the more distant future may be as hosts to big data bases, or as servers for certain programming tools. The Technion mainframes are 2 IBM 3081D computers.

The communication to supercomputers and mainframes is usually made through terminals. These may be text terminals or graphic terminals. Modern terminals may be quite powerful, often with intensive graphic capabilities. The newest variety of terminals is the X-windows terminal which can work simultaneously with a few computers of various makes, and display all sessions on the same screen. These terminals offer a standard graphic interface, as well as a powerful user interface, with menues and mouse utilization.

2.2.3 Work stations

Work stations are computers used by a single worker, often with large graphic screens. Contemporary work stations often have very powerful processors which are often as powerful as (or even stronger than) those of mainframe computers. They also utilize significant memory, although not as large as that of mainframe computers. It may be expected that in the future large work stations will utilize vector processors, thus making them extremely fast. Yet the price of a work station is only a small fraction of that of a mainframe computer, thus making them very widespread. The total installed work station processor power in the Technion is already quite significant, and probably bigger than the total installed mainframe and super-mini processor power. Work stations used in the Technion today are mainly from SUN, Silicon Graphics, DIGITAL and Hewlet Packard/Appolo. It is very likely that the new generation of IBM work stations (RS6000) will gain a significant place in the Technion as well.

2.2.4 Personal computers

The smallest computers used today are the personal computers. Traditionally these were small and cheap machines with very small computing power. Yet these machines have become stronger in recent years, and the largest personal computers are not smaller than small work stations, although they still lack their graphic capabilities. Two major classes of personal computers are used in the Technion. The Machintosh computers, and IBM PC compatibles.

2.3 Software

The kinds of software used in scientific environment nowadays are very diverse and varied. Therefore it is possible to discuss here only very basic facts about software, and to consider only software which is (or may be) used in the Technion.

2.3.1 Operating systems

a. **IBM.** The two major IBM operating systems currently used in the Technion are the batch oriented MVS and the interactive VM/CMS. MVS is mainly used for large batch jobs, while the interactive VM/CMS is probably the most widely used operating system in the campus. As most educational software is likely to run in interactive mode, the VM/CMS is the more likely venue for such activities. The IBM compatible graphic terminals available in the campus are relatively weak, and they limit the quality of graphic display. A recent development is the AIX operating system which is a UNIX system to be discussed below. IBM recent announcements stress the central role of this operating system in future IBM marketing policy.

b. **DIGITAL.** The major DIGITAL operating system is VMS. This is a very good interactive and user friendly system, with very good graphic capabilities, and with a large body of software available for it. Thus it appears very attractive for interactive and/or educational software. The main deficiency of VMS is that it is almost completely limited to DIGITAL machines.

DIGITAL is marketing also a UNIX operating systems, under the name of ULTRIX. This operating system is becoming more central to DIGITAL's marketing policy in recent years.

c. **UNIX.** UNIX operating systems are widely used in work stations but they are spreading into other slices of the markets fairly rapidly. UNIX was designed as an operating system for single user interactive applications. Its use as a multi user system is relatively new. The main advantages of UNIX are its very wide distribution over the industry, as well as its vendor independence. A commercial version is distributed by AT&T, while a non commercial version is available in the form of the BERKELEY UNIX (BSD). Nearly all computer vendors offer a proprietary version of UNIX today. SUN, Silicon Graphics and Convex have always offered versions of UNIX as their operating system. The IBM AIX and DIGITAL ULTRIX versions of UNIX have been mentioned above. Other versions are available for all other work stations in the market, for most supercomputers, and for large micro computers. Although all of these systems are UNIX systems, the variation between different vendors is not negligible, especially in the security and multi user parts of the system. An emerging standard for UNIX is the POSIX system.

Software for UNIX systems is usually readily available. The graphic capabilities used to be machine dependent. This is changing now with the introduction of the X11 windowing system into most UNIX operating systems. We should also mention here the TCP/IP software which has been the standard communication software for UNIX systems for a long time. Recently it has become an unofficial communication standard for practically all operating systems. File sharing between different computers is achieved by NFS software.

d. **Microcomputers operating systems.** The most widely used PC operating system is MS-DOS. This is a cheap system, and relatively weak. Yet the availability of software for it is tremendous, and at very attractive prices. Another popular operating system is that of the Macintosh computers. It is characterized by very good human interface, but it is not as widely spread, and the availability of scientific software is therefore not as good as that of the MS-DOS software. The major difference between the MS-DOS and Macintosh systems used to be the utilization of the "mouse" hardware and the application of interactive menus through windowing software. These features are gaining wide popularity between all vendors of computer equipment and are expected to become a standard part of any operating system in the future. In particular X11 amd MOTIF standards (for larger computers) and MS-WINDOWS (for PCs) are edvancing these machines up to Macintosh standards.

2.3.2 Programming tools

a. **Communication systems.** A major feature of modern computers is the communication system which allows the user to perform a large spectrum of operations, from remote login and file transfer, up to the utilization of remote servers for CPU, file or other services. The standard communication software for UNIX systems is TCP/IP, with its NFS file transfer protocol which allows easy access of remote files. The DIGITAL DECNET is popular with users of VMS but not with other operating systems. Both are available at the Technion.

b. **Compilers and interpreters.** One of the most important tools for the utilization of computers are programming languages. These may be divided into low and high level languages. We shall discuss here only the latter, which are usually written in a form similar to that used when writing mathematical formulae or even plain English. The most common language for scientific computation is FORTRAN. Its major advantage is its flexibility and its immense popularity. Another very popular language is BASIC, which is similar to FORTRAN in its philosophy although simpler (and less powerful). Basic is primarily used in PCs. Another group of languages is that of the structured languages like PASCAL or C. These languages allow more consistent and allow logical programming methods. Thus they are very popular among computer scientists. Other special purpose languages are available as well (e.g. LISP or PROLOG for artificial intelligence, etc.).

c. **Program development tools.** Modern software engineering offers various tools to aid the programmer. In particular, debuggers are used to allow interactive tracing of program performance and changes of variables. Analysers present a breakdown of CPU time required by each part of the program and are very important for program optimization.

2.3.3 Scientific applications

It is impossible to imagine modern scientific computing without software packages which perform a large number of important and complicated applications. The most widely used are mathematical packages, like the general purpose IMSL mathematical library, the LINPAK linear algebra package, and the ELLPAK or FISHPAK partial differential equation solvers. The CSMP simulation package is also popular.

Another group of general purpose scientific software includes packages for symbolic algebra like MACSYMA, REDUCE, and MATHEMATICA that combines powerful symbolic, numerical and graphic capabilities.

Other packages are dedicated to specific engineering or scientific applications, like the NASTRAN finite element code for solution of problems in elasticity, or the CFD packages like FIDAP, PISCES, PHOENICS, FLOWxx, etc.

2.3.4 Non-scientific applications

Last but not least are general applications which are often used for non-scientific applications and do not require any scientific or mathematical background. The most well known of these are word processors, but spreadsheets and data bases have gained wide popularity as well. Another important such field is graphics. Typical graphic packages used in the Technion are SAS, DISSPLA, GKS and PHIGS. Even more sophisticated are CAD/CAM packages like KATIA, MEDUSA or ICEM. Graphic post processors are very important too.

2.4 The software packages revolution

2.4.1 Software houses

The very fast growth of computer power, as well as the increased awareness to the potential of computers in all walks of life have brought about a rapid growth of a new software industry. This industry is composed of a large number of companies of a very wide range of sizes and specialization. Some companies are small one man operations, while others are huge international companies employing thousands of employees. Some specialize in special applications like graphics or CFD, while others are general purpose establishments working in various fields. However, the important point here is that the total amount of man-years invested in the development of commercial software is immense. It is therefore very disadvantageous to refrain from using commercial software packages, and users who do so put themselves in a large disadvantage relative to other users.

In the following subsections we discuss some classes of commercially available software packages.

2.4.2 General scientific packages

These are mainly mathematical packages. They offer prepared routines for mathematical problems in linear algebra, ordinary or partial differential equations, statistics, etc. Some of these packages are very sophisticated packages, including very efficient solvers, of a very wide applicability.

2.4.3 Technological packages

This category includes various software packages suitable for the solution of engineering problems. Typical examples are finite element programs for the solution of problems in structures, others are programs in computational aerodynamics, used for aerodynamic design of aeroplanes. Packages for CAD/CAM are also very popular.

2.4.4 Preprocessors

Many scientific and technological programs require special preparation of data for the actual run. While such data may be somehow prepared by the user, it often requires a lot of work, and is best done by a special computer program, referred to as preprocessors. Typically these programs are used for a wide variety of tasks. For instance, to prepare discrete meshes covering complicated fields, or to check large set of input data for internal consistency.

2.4.5 Postprocessors

Modern programs often produce huge amounts of data, which may include millions of data points. It is therefore necessary to use special techniques to analyze the data. These techniques often call for advanced graphic capabilities and very user friendly user interfaces. The immensity of such tasks makes computerized postprocessing indispensable.

2.5 Relation between price of hardware and software packages

It is sometimes assumed that the major part of investment in a computing facility is the hardware. This is a wrong assumption in many cases. It is true that many software applications are cheaper than the hardware required to run them. Yet, there are certain packages which cost more than the computer on which they run. Moreover, most computer installations require many software packages, and the total price of all packages may be quite significant. When the best software is not available, computing time may rise, and the computer can handle less work. It is therefore necessary to consider both software and hardware together, and seek the best price performance of the combined investment. It is often possible to avoid a massive investment in hardware by a smaller (yet significant) investment in software.

3. COMPUTERS IN SCIENTIFIC RESEARCH AND EDUCATION

3.1 General perspective.

The advent of digital computers opened new possibilities for the application of mathematics to scientific and engineering problems. New methods were developed for the efficient solution of various mathematical problems, thus allowing solutions of problems for which no solution was known in the past. These new methods often require such mathematical techniques and understanding which were not very practical in the past and therefore were not well known to scientific practitioners of mathematics. Consequently, the curricular requirements of scientists and engineers are undergoing profound changes, both in the relative importance of whole subjects and in their contents. Specifically, the computer opens new possibilities for the calculation, understanding and teaching of topics having a quantitative, logical or graphical character.

Some examples of this process are:

1. The substitution of arithmetic skills by pocket computers.

2. The disappearance of logarithmic and trigonometric tables and the removal of subjects related to the use of such tables from the curriculum.

3. The reduction of the need for algebraic manipulation by symbolic algebra.

4. The utilization of computer experimentation (using both fast computations and computer graphics) as a tool for parametric investigations and for the study of functions.

This partial list suffices to demonstrate the potential of the computer to enhance and improve our skills and understanding. In general, it is now possible to solve "unclean" problems which are so typical of real life situations. This has wide consequences in scientific research, in engineering and in education, but it also puts some new demands on the curriculum in mathematics and related subjects. It is reasonable to assume that this trend will continue also in the future. Thus, we can expect that:

1. Existing analytical and experimental methods will be supplemented and even replaced by numerical ones.

2. New skills will be required as subjects like image processing, artificial intelligence, computer graphics, parallel processing, etc. are becoming more popular.

It is important to note here that understanding of mathematics will remain at least as important in the future as now. However, the methods and the relative importance of topics may change significantly. It is therefore to be expected that the changes will be more significant in the applications of mathematics rather than in basic mathematics. Yet, it appears very likely that even the education and research in pure mathematics will undergo some serious changes (e.g. subjects like fractals and chaos could not have been developed without the computer). Altogether engineers and scientists will have to master new skills, but will also need less of the old skills. Thus, we may expect changes in the contents of the curriculum in mathematics and in science and engineering courses.

3.2 Educational computing

The rapid development of computational technology had a marked influence on education as well. We shall discuss here three aspects of the subject, namely changes in curricula, new tools for the organization of education, and the utilization of computers as an educational tool.

3.2.1 Curricular changes

The development of computers and numerical mathematics makes it necessary to include new material in the curriculum. This material may be of two kinds. The first kind includes new mathematical methods which were not very practical before the computers became so abundant but are very useful and necessary now. Typical such subjects are related to linear algebra, numerical geometry, tensor analysis, and differential equations. The second kind of curricular additions is related to various computational subjects, like computational physics, computational chemistry, computational fluid dynamics, or computer graphics, as well as special computational techniques like spectral methods, finite elements methods, finite difference methods, etc. Unfortunately the inclusion of such new material in the curriculum is possible only if some material is removed. While some material may be removed without large damage to the quality of the graduates, it is difficult to make room for all the new material required without seriously decreasing the amount of existing but necessary material.

A possible solution is the utilization of computers to improve teaching techniques, and thus make room for new curricular material. However, this proposition (which is discussed below) requires new computerized teaching techniques and software. Moreover, it is difficult to estimate how more efficient can teaching become by utilization of computers. Another approach may be by training of a new breed of mathematically oriented engineers. However, such a rift between computational, experimental and design engineers is not usually considered advantageous neither by most engineering educators nor by industry. Thus, the problem of curricular changes requires more attention in the future.

3.2.2 Educational administrative tools

One field in which computers have created new possibilities in education is in the administration of teaching. Needless to say that universities use computers to manage all the students marks and follow their educational achievements. However, computers can serve also as tools for the individual teacher, for collating of marks, statistical processing, and general determination of the advancement of students.

Special software packages are available for such applications. They enable individual follow-up of the achievements of students, allocation of special home work exercises, and interaction of the student with the computer so as to encourage and indeed enable individual learning. However, full advantage of these techniques may be taken only when special learning software is available, as discussed in the next section.

3.2.3 Educational software

The most difficult task is that of preparing special educational software. There are some levels of computer utilization in the learning process:

1. Preparation of multitude of examples with different numerical values and known solutions as home work exercises .

2. Utilization of software packages for solution of complicated problems, thus introducing the student to problems of much more difficult nature than those which may be solved by hand only.

3. Preparation of interactive computer software for the teaching of class material in an individual session.

The amount of resources required to prepare educational software is very large. Even the preparation of numerical examples consumes many hours for each example. When considering software substitutes for class room teaching, a massive investment of manpower is required. Ratios of 40 hours (and more) per a single class room hour are often quoted for high level advanced learning software.

The current situation is in a state of rapid flux. Every year new educational software of various levels of complexity is being generated by universities as well as commercial software houses. Some very large projects have been carried out (e.g. the MIT ATHENA project) and software clearing houses have been established. International organizations (like EDUCOM or CACHE) are actively supporting and enhancing the development of educational software. A partial list of such software is given in the Appendix. Yet, major difficulties are slowing down the the development of educational software. This applies to the Technion as well and will require very careful consideration. The sophistication of the software as well as the subjects to be covered should be thoughtfully planned, so as to maximize the results.

3.3 Challenges to academic institutions

The infiltration of computational methods into science and technology pose difficult questions and major challenges to institutions of higher education. The new computational capabilities (such as numerical computation, artificial intelligence and graphic tools) are expected to expand the arsenal of tools available to scientists and engineers to such an extent that it will be impossible to conduct research, development, design, production and management without them. Thus the impact on academic and vocational education is going to be felt in two ways: not only will academic researchers need the new tools for their work, but curricular changes will be needed in both alteration of existing syllabi and addition of new subjects, so that graduates are fit to the new evolving techniques. Moreover, educational technology itself may soon see new techniques based on Computer Aided Instruction, which may change many features of higher education in a very significant way.

This process is already starting. Educational institutions in general and universities in particular are faced with the problem of how to implement the necessary curricular changes. The traditional mechanism for curricular changes in the academic world is the action of departmental curricular committees, motivated by the views and interests of the faculty. While this mechanism is very likely to remain the dominant one also in the future, one has to seriously check whether the slow diffusion of these ideas into all walks of the academic community is fast enough a process to allow the necessary changes in the right time. One way to make the process somewhat faster is to encourage the necessary curricular changes by some policy priorities determined centrally, and the recognition of the field of computer applications in research and education as a "schwer punkt".

3.4 The national significance of the software development

Software development is a very colorful and varied activity. On the side of very large software houses, which employ thousands of programmers, and dominate certain parts of the market, we find small ventures, sometimes numbering only a few workers. This is a quickly developing field, requiring a lot of initiative and creative thinking, but it is also a high risk area. On the Israeli national arena there are two questions to be considered:

1. What are the software technologies which are critical to the Israeli community, and which steps are required to make them available here. Considering the academic part of the community, it becomes clear that the teaching and training in the utilization of modern software should become an important part of both the regular curriculum and the non-degree courses offered by academic institutions.

2. Augmentation of the educational side of software technology alone is not sufficient, and academic institutions must also engage themselves in Research and Development activities in the field of software development and utilization. This side of the activity is important not only in order to provide "warehouses" of software knowhow and expertise, but also in order to encourage larger involvement in the process of the generation of software, for local and international use. Such activity is necessary not only as a potentially successful economic activity, but also as a tool to ensure availability of the required software technology to the Israeli community, which may, otherwise, be deprived of necessary software tools due to economical, political, or other reasons.

3.5 The role of the Technion

The thesis offered here is that the Technion, as the central and major institution for engineering education in Israel, should initiate and encourage innovative activities in this field. This is necessary in order to ensure the academic excellence of the Technion, and the quality and level of capabilities injected into the Israeli industry through Technion graduates. Still, the existing constraints on resources in general and on human resources in particular, as well as the risks involved in the penetration into such a new unfamiliar and conceptually different field call for a careful approach and allocation of resources.

The following questions should be considered:

1. What are the predicted curricular changes, either by introduction of new material or by reduction and even removal of existing parts of the syllabi?

2. Is it possible to make the educational process in the Technion more efficient by the introduction of computers? (this is a possible way to create free credit points for some of the curricular changes suggested above).

3. Is it possible to identify new directions in research which will become necessary in view of the expansion of computer resources?

4. Is it necessary and possible to enhance the utilization of computers in the Technion, and is it advantageous to create special organizational structures for this purpose?

The complexity and novelty of the subject call for careful examination of possible steps towards the changes outlined above. Identification and definition of the required activities must be supplemented by identification of faculty members who are interested in the subject and willing to participate in the activities and contribute towards the goals. Moreover, it will be advisable to generate favorable atmosphere by increasing the awareness of the faculty and by allowing as many of them as possible to participate in the preparatory stages. We do not make specific recommendations of such activities here, but suggest that positive action in this direction is initiated by the Technion.

4. RECOMMENDATIONS

4.1 General policy issues

4.1.1 Field experiments in computerized teaching

In view of the situation outlined above, universities and, in particular institutes of science and technology are faced with a difficult decision. Can they predict the future trends and try to get ready for them by initialization of structural and substantial changes? Or should they wait for further development of the subject and to more universal awareness of the new demands? The safe way appears to be the introduction of curricular, methodical and administrative changes only when they are called upon by internal pressures or existence of proven needs. However, such a policy may result in the transfer of academic leadership from institutions which will not venture sufficiently early into this field to such institutions who are ready to face this challenge. On the national scale, such a policy may lead to slow advances and loss of expertise and leadership in both science and engineering. Such loses are dangerous to national competitive capabilities. Thus the quality of scientific research is bound to deteriorate, and the economical potential and capabilities are bound to decrease.

The long range activities required include both professional and organizational steps. The definition of steps required for policy decisions has to do with the following questions:

1. What will be the influence of the computer on science and technology in general?

2. Which curricular changes in universities are called upon?

3. Is it possible to forecast such changes and to start preparing for them before individual faculty members are ready?

4. Is it possible to use the computer to improve or speed up the academic educational process?

4.1.2 Recommended Technion policy

The conclusion reached by the present committee is that it is not wise to try and predict the whole spectrum of future changes in a rapidly developing field of scientific and educational uses of computers and of related changes in curricula and educational methodics. Rather than that, one should aim at creating the efficient and flexible infrastructure that would be most suitable to be a vehicle of future changes, and serve to concentrate intellectual and material resources at the most promising directions, and at most important problems that may arise in the future.

Most attention should be paid to the enhancement of the research and educational facilities at the Technion by improving the handling of scientific software packages, and devising mechanisms for better collection and sorting of information, and for advise, tutoring and scientific support to potential users on such packages.

The computerization of the curricula and class work would be best achieved by individual faculties. Some progress along these lines had already been made and several faculty members are experimenting with computerization of courses. Such efforts should be encouraged in the future by technical and financial support.

The committee recommends that a Center for scientific and educational software structured along the lines drawn in the following section, be established. Such a center will serve as a catalyst for future developments, and will provide the infrastructure necessary for the incorporation and integration of computers in teaching and research in mathematics and mathematically oriented subjects.

4.1.3 Specific activities

4.1.3.1 Field experiments in computerized teaching

The performance of controlled field experiments in computer aided instruction in the Technion is desirable, and should be encouraged and regulated. The relevant problems in this respect are :

1. If and how to encourage the activity (by allocation of equipment, purchase of software and development of software by allocation of budget and academic and non academic workers).

2. Definition of priorities for eligible subjects.

3. Definition of mechanism for project selection: Should projects be selected by central initialization or by inviting faculty to submit proposals? Should a central unit (e.g. the center for computer applications to be discussed below) be involved in the process, and how?

4. Definition of requirements for eligible projects.

5. Definition of methods of control of such projects and requirements from final reports on selected projects.

4.1.3.2 Computational laboratories

The utilization of computer laboratories for experiments in mathematics and mathematically related subjects is one of the most significant ways for the effective advancement of the subject. Such laboratories allow faculty to tackle more complicated problems, and allow students to practice with more realistic problems and situations.

In the Technion there are already some examples of such laboratories. More are required. Yet such laboratories should be left to local initiative of faculty members. The role of the Technion here is mainly to support and encourage attempts to generate such laboratories.

4.1.3.3 Centers for computer applications

The establishment of centers or institutions for computer applications in various disciplines is yet another possibility. This is not an easy problem, bringing to mind not only the large resources required, but also the risks involved in the separation between analyses, experiments and numerics. Yet we believe that such centers are important and they should be established wherever possible.

Typical examples for disciplines in which such centers are possible are Computational Mechanics, Expert Systems, Computer Vision and Image Processing, Parallel Computing, Computer Aided Instruction, etc. Needless to say that such activities may require cooperation between faculties. Such units should be concerned with enhancement of research in their field, in advise on special applications, in the utilization of software packages, etc.

The establishment of such centers is a major undertaking which requires initiative on faculty level, and attraction of special funds from external sources. Yet the very existence of such centers is going to be most effective in the advancement of the subject.

4.2 Center for scientific and educational software

The committee is of the opinion that the advancement of the subject as discussed above will be greatly enhanced by the formation of a special center for scientific and educational software. In the following sections we outline a proposal for such a center.

4.2.1 Aims

The mission of the center is to support activities related to application software in mathematics and fields which are methodically related to mathematics.

The Center that will coordinate the development and application of scientific and educational software at the Technion, and serve as a forum for the Technion faculty concerned with the scientific, engineering and educational uses of computers.

4.2.2 **Functions**

It is envisaged that activities of the Center will be concentrated in the following fields:

a. **Scientific software.** Activity in this field is expected to facilitate the advanced research at the Technion and to enhance the interdisciplinary cooperation. The functions of the Center will include:

1. Collecting, studying and cataloguing the available software according to the fields, subjects and tasks.

2. Adaptation of the software for the Technion use, and ensuring the compatibility and standardization of general use software systems.

3. Professional advice on the availability and usage of software and distributing the information on the campus.

4. Development of new software.

b. **Educational software.** It is envisaged that after a certain period of time most courses with substantial mathematical and computational content will become computer-aided. The Center will endeavor to enhance and facilitate this process by the following means:

1. Providing the Technion faculty with suitable environment and technical help for the development of computer-aided courses.

2. Maintaining a computer laboratory for classroom use.

3. Providing information on the available educational software and maintaining the connection with the worldwide effort for the development of computer-aided advanced courses on the undergraduate and graduate level.

c. **Teaching the use of software.** The Center will offer regular courses on the application of general use software for the staff of the Technion and graduate students, as well as for the outside audience in the framework of continuing education programs.

4.2.3 Framework

The overall structure of the Center should be designed with a particular attention to its connection with other Technion units: Science and Engineering departments, Computer Center and External Studies, in order to ensure minimal overlapping of functions and easy cooperation. The possible options include setting the Center as an academic, service or research unit, or as a combination of the above.

The disadvantage of the first option is it would contradict the purpose of the Center to serve the entire Technion. The structure of an academic unit is also too rigid for the Center that has to quickly adjust to new problems of the development of this rapidly changing field. The overlapping of functions and conflict of interests with some other department would be also difficult to avoid in this case.

The second option is also undesirable, since it would then just imitate the existing structure of the Computer Center. It would be also difficult to draw to a service unit academic and research staff possessing necessary qualifications.

A research center appears to be the most suitable model, though with modifications grafting some structural elements of a service unit, and at the same time ensuring permanent connection with the educational process.

4.2.4 Staff

The academic activity of the center will be based on Technion academic staff (on the basis of secondary affiliation), a small core of support personnel, academic visitors and research assistants. The detailed administrative structure is described in the following section.

4.2.5 Facilities

The proposed functions require a certain amount of resources, on both permanent and annual basis. These will cover installation of equipment, purchase of software, and all the other amenities required for the operation of the center. An outline of the necessary items is given in the next section.

4.3 The administrative structure of the Center.

4.3.1 Steering Committee

The center will be overseen by an Steering Committee. The Steering Committee directs the center activities, and approves yearly working plans, long-term plans and yearly reports. The Steering Committee consists of seven members: the Vice President for academic Affairs, the Vice President for Research, the head of the center, two representatives of current members of the center and two senate representatives. The Steering Committee is appointed by the Technion Steering Committee. Members will be nominated for a two year period, renewable.

All activities of academic significance will be approved by the Steering Committee, and discussed with the Vice President for Academic affairs and the Vice President for Research. Final approval is by the Technion, according to the usual Technion procedures.

4.3.2 Connection to academic units

An academic unit may become a Member Unit by submitting a written request to the Technion Steering Committee. The request should describe the background for the application, the benefits to the unit and the Technion, and the list of members of the applying faculty who are the potential candidates for membership in the center. The Vice President for Research will consult with the Steering Committee and bring the application for final approval to the Technion Steering Committee.

4.3.3 Head of the Center

The center is headed by a head. The Head bears general responsibility for the activities and the running of the center. The head is assisted by a Steering Committee including senior Faculty affiliated with the Center. In particular the head is responsible for the following tasks:

1. Preparation of an annual work plan to be proposed to the Steering Committee including all activities, as well as budget estimates, staff, affiliated members, etc.

2. Preparation of the annual budget to be approved by the Technion management.

3. Preparation of the annual report to be submitted to the senate after approval by the Steering Committee.

The head will be nominated by the Technion Steering Committee from within the members of the senate, according to the proposal of the Vice President for Research.

The Vice President for Research will consult the deans of all Member Faculties and the members of the center Steering Committee. The head is appointed by the Technion Steering Committee for a three year term. A two year extension period is possible. Subsequent reappointments are possible only after a break of at least two years.

4.3.4 Academic staff

The academic staff will consist of affiliated Faculty members interested in advancing the aims of the Center. A faculty member interested in an affiliation with the center will submit a proposal and an obligation to engage during the affiliation period in activities which contribute to the charter of the center. Typical examples are the preparation of a certain computer-aided course, the writing or modification of a general use software package, or the development of a new numerical technique or algorithm to solve a problem which is defined as critical by the center.

Faculty members who are willing to contribute to the activities of the centers in other ways are eligible for membership as well (subject to the approval of the Steering Committee).

The proposal should specify the requested resources, including the proposer time, technical staff time and computer resources. The proposal should be approved by the head of the proposer's department and go under peer review. The final decision on the acceptance of the proposal lies with the Steering Committee of the center. The appointment will be coordinated with the relevant dean and the vice president for academic affairs.

The affiliation has a character of a contract for a fixed period imposing certain obligations on the Center, the Faculty member in question, his home Department and the Technion management. The Center would take an obligation to provide necessary equipment and technical help.

The faculty member will continue as a full fledged member of his home faculty for all purposes. Wherever necessary and possible the home Department would grant a full or partial release from teaching duties for the period in question, and, in turn, would be compensated by the Technion that will provide funds necessary to hire an adjunct replacement.

Affiliation of academic staff will be for the duration of the project in which they are active.

4.3.5 Graduate assistants

Graduate assistants will be assigned to the center to support the teaching, service and research activities of the center. In particular they will assist the senior staff in activities such as preparing computer-aided courses, the teaching of the use of packages, or any other activities falling within the charter of the center.

Assignment of graduate students will be in a similar manner to that of academic departments. The degree research will be done under the home department of the supervisor, but it should be relevant to the activities of the center and approved by the Steering Committee. Such projects should be proposed to the center by prospective supervisors. If the project is approved the supervisor becomes a member of the center for the period of the study of the graduate student or the duration of the project, whichever is longer.

4.3.6 Academic visitors

Academic visitors will be nominated according to the rules of academic visitors, after consulting the appropriate VP. This, in conjunction with a specific project, and for a period of up to one year. Extensions for a second year are possible.

4.3.7 Research associates

Research associates, adjuncts and freelancers will be appointed on a temporary basis only , with the help of funds assigned to a specific project .

4.3.8 Support staff

The permanent technical support staff will be held to a minimum including hardware and software engineers, a librarian (in charge of both conventional and software libraries), and a secretary. Additional funds should be available to hire qualified outside help for specific projects on a temporary basis.

4.3.9 Equipment

The center should be well equipped with computer hardware and software to fulfil its tasks. In particular the following is required:

1. A computer laboratory with network connection serving the staff working on the software development.

2. A computer classroom suitable for interactive teaching.

3. A software library and a conventional library including program listings and literature on of scientific and educational computer applications.

4.3.10 Budget

The center will be an independent budgetary unit, according to the rules and regulations of the Technion.

APPENDIX

List of available educational software
(Based on information obtained at EDUCOM 90, Atlanta, 14-17 Oct 1990)

Vendor	O/S	S/W	Discipine	Description
MIT (Athena)	UNIX+X	QP	EE	Quantitative Physiology
MIT (Athena)	UNIX+X	QP	BP	Quantitative Physiology
MIT (Athena)	UNIX+X	Todor	AE	Aerodynamics
MIT (Athena)	UNIX+X	Growltiger	CE	Interactive structural
				analysis and technology
MIT (Athena)	UNIX+X	Cardiovascular simulation		
			HST	Understanding the
				cardiovascular systems
MIT (Athena	)UNIX+X	Xmap	USP	Graphical representation of
				large data sets
MIT (Athena)	UNIX+X	GMATS	PS	Graphics make argument
				theory simple
MIT (Athena)	UNIX+X	Multimedia Applications		
				Examples in foreign
				languages, Engineering,
				Biology, etc.
MIT (Athena)	UNIX+X	EOS		System for electronic
				submission, annotating and
				grading of assignments
MIT (Athena)	UNIX+X	CDS		Authoring tool for creating
				electronic "books" using
				MOTIF interface
MIT (Athena)	UNIX+X	OLTA		Adaptation of On Line
				Consulting system for use by
				teaching assistants on a
				course by course basis
Wisc-Ware	DOS	26 titles		Arts and Humanities
Wisc-Ware	DOS	17 titles		Business/Economics
Wisc-Ware	DOS	4 titles		Education
Wisc-Ware	DOS	39 titles		Engineering/Computer
				Science
Wisc-Ware	DOS	15 titles		Graphics/Image processing
Wisc-Ware	DOS	17 titles		Health Sciences

Wisc-Ware	DOS	18 titles		Life Sciences
Wisc-Ware	DOS	35 titles		Mathematics/Statistics
Wisc-Ware	DOS	3 titles		Networking
Wisc-Ware	DOS	4 titles		Philosophy
Wisc-Ware	DOS	58 titles		Physical Sciences
Wisc-Ware	DOS	11 titles		Programming Tools
Wisc-Ware	DOS	10 titles		Psychology
Wisc-Ware	DOS	28 titles		Social Sciences
Wisc-Ware	DOS	1 title		Text Processing
Wisc-Ware	DOS	11 titles		Utilities
Wisc-Ware	DOS	6 titles		Miscellaneous
ABACUS Educational Systems				
	CMI/4.0			Instructional management
				system
College Board		ACCUPLACER		Computerized Placement
				Tests
Softwards	SUN	MicroNATAL		CAI course preparation
Catalytics Corp	SUN	C Trainer	C Trainer	
CourseWare technologies Inc				
	SUN	CTI UNIX		
CourseWare				
Technologies Inc.	Training Manager			Tool for CTI UNIX
Software Fair 90		10 titles		Natural Sciences
Software Fair 90		15 titles		Humanities
Software Fair 90		4 titles		Mathematics
Software Fair 90		13 titles		Engineering
Software Fair 90		3 titles		Social Sciences and
				Accounting
Software Fair 90	NCSC	9 titles		various subjects
Software Fair	VMS	CFAS		Titles in biology, chemistry,
				agriculture, engineering etc
Software Fair 90		TASL		16 titles in various subjects
Conduit	DOS			First Year Algebra
Conduit	Apple			Graphics Calculator
Conduit	DOS			Discovery Learning in
				trigonometry
Conduit	Apple			Discovery Learning in
				trigonometry
Conduit	MAC	Theorist		Investigate mathematical
				relationship
Conduit	DOS	DERIVE		Mathematical assistant

Conduit	Apple			Graphing Equations
Conduit	Apple			Interpreting Graphs
Conduit	Apple	ARBPLOT		plotting curves
Conduit	DOS			Matrix calculator
Conduit	Apple			Geometry & Micros
				Transformational Geometry
Conduit	Apple			ODE's
Conduit	Apple			Surfaces for Multivariable
				Calculus
Conduit	Apple	SURFACE		Creating 3D surfaces
Uni of ILL DOS				General Chemistry for 1st
				year
Intellimation	Apple	15 titles		Humanities and language
Intellimation	Apple	4 titles		Literacy
Intellimation	Apple	9 titles		Social Sciences
Intellimation	Apple	15 titles		Computer Science and
				Engineering
Intellimation	Apple	14 titles		Mathematics, Statistics and
				Logic
Intellimation	Apple	20 titles		Life Sciences
Intellimation	Apple	23 titles		Physics, Chemistry, Earth
				Science
Intellimation	Apple	22 titles		Tools and Utilities
TASL	DOS	1 title		Engineering
TASL	DOS	1 title		Languages
TASL	DOS	3 titles		Linguistics
TASL	DOS	7 titles		Physics
TASL	DOS	6 titles		Political Science
Uni of Maryland	MS-Win	EUCLID		A geometry Workbench
Uni of Maryland	MS-Win			Astro Labs 2.1
The Clearinghouse				Introduction to statistics

Note: Some of the above programs may be general tools useful for students, but are NOT CAI tools!

Electrical Engineering			EE	
Bio Physics			BP	
Aeronautical Engineering			AE	
Civil Engineering			CE	
Health Science and Technology			HST	
Urban Studies and Planning			USP	
Political Science			PS	