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ABSTRACT

A two-day conference was held in 1969 with industrial representatives and COSINE members to examine the impact that computer technology has had upon the practice of engineering in industry and to assess the meaning of these changes upon the structure of electrical engineering education. The major conclusions and recommendations of the meeting may be summarized as follows: (1) Every electrical engineer should understand the capabilities and limitations of computers. He should know how to use computers as an aid in solving complex technical problems; (2) Digital and analog circuits are of major importance in the design of modern systems. Students should have equal familiarity with both classes of circuits; (3) Students should have more design experience. This experience can be obtained by introducing more project-oriented course and laboratory work into the undergraduate program; (4) Students should obtain more experience with simulation techniques and model making. They should also learn the factors that limit the usefulness of these techniques; and (5) The undergraduate program of a student should provide considerable flexibility and a minimum of required courses. The actual program of study, selected by a student with the help of a faculty advisor, should help provide the background for a lifetime of self-motivated and self-directed study. (Author/TS)

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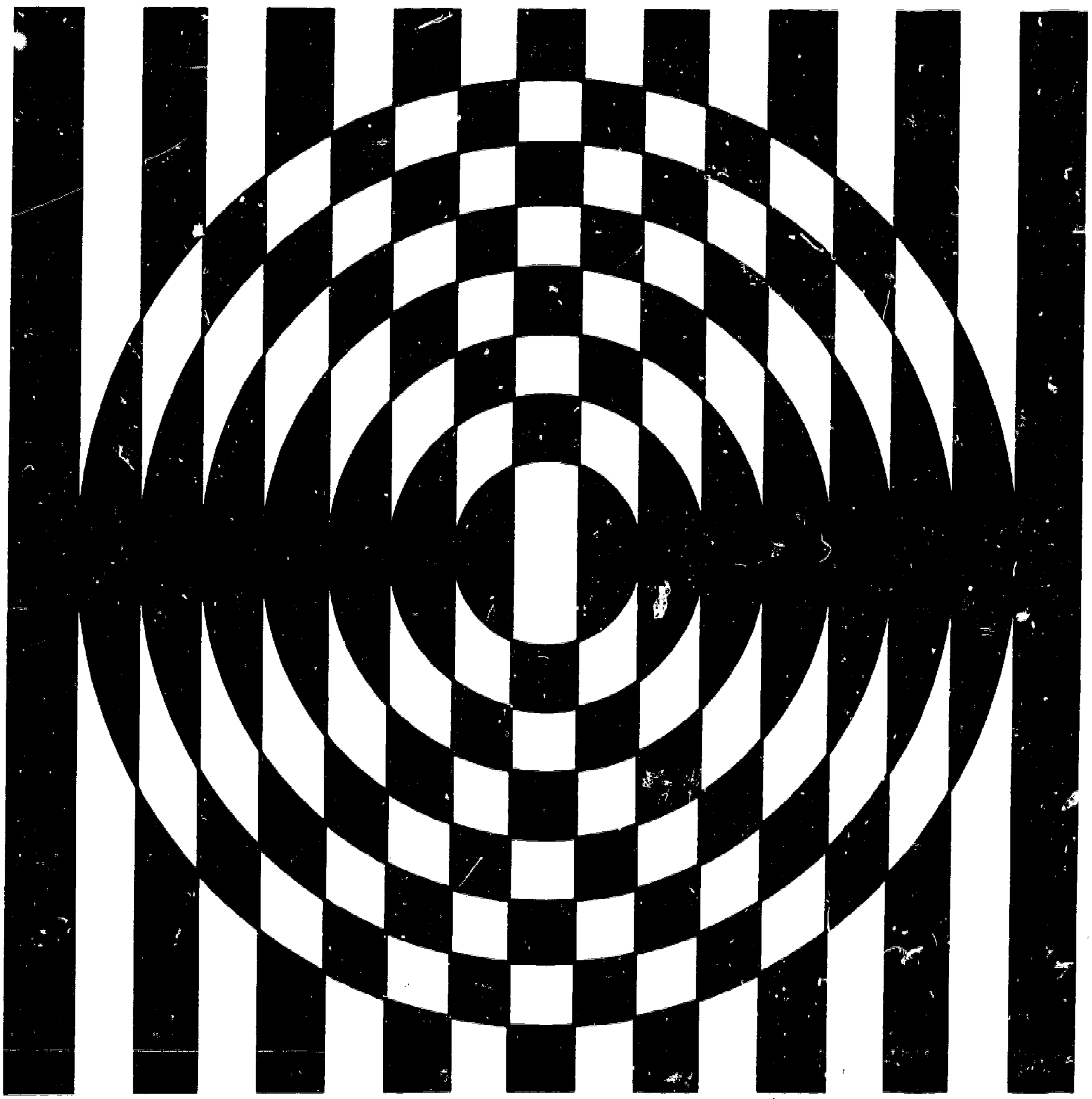
Cosine Committee

Commission on Education



IMPACT OF COMPUTERS ON ELECTRICAL ENGINEERING EDUCATION — A VIEW FROM INDUSTRY

An Interim Report of the

COSINE COMMITTEE

of the

COMMISSION ON EDUCATION

of

THE NATIONAL ACADEMY OF ENGINEERING
2101 Constitution Avenue
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September 1969

TASK FORCE ON INDUSTRIAL LIAISON (TASK FORCE V)

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Summary

On June 12 and 13 five industrial representatives and five COSINE members met to examine the impact that computer technology has had upon the practice of engineering in industry and to assess the meaning of these changes upon the structure of electrical engineering educatior This report presents the major conclusions and recommendations of the meeting.

Five major topic areas were considered in detail and extensive recommendations were made concerning each area. These conclusions can be briefly summarized as follows:

1. Every electrical engineer should understand the capabilities and limitations of computers. He should know how to use computers as an aid in solving complex technical problems.

2. Digital and analog circuits are of major importance in the design of modern systems. Students should have equal familiarity with both classes of circuits.

3. Students should have more design experience. This experience can be obtained by introducing morr projectoriented course and laboratory work into the ι ergraduate program.

4. Students should obtain more experience with simulation techniques and model making. They should also learn the factors that limit the usefulness of these techniques.

5. The undergraduate program of a student should provide considerable flexibility and a minimum of required courses. The actual program of study, selected by a student with the help of a faculty advisor, should help provide the background for a lifetime of self-motivated and self-directed study.

Throughout the meeting it was obvious that industry is applying computers and digital system concepts to a much greater degree than is represented in most undergraduate curricula. It appears that the electrical engineering departments are not updating their curricula in this area as fast as the practice of engineering would warrent.

I. INTRODUCTION

One of the primary goals of the COSINE committee is to keep abreast of trends and developments in the area of computer engineering and computer science and bring this information to the attention of electrical engineering educators. As part of this program COSINE has maintained a close working relationship with industry. One of the first formal activities of the COSINE committee was a meeting on December 12, 1966 with representatives of industry to determine the impact that computer technology was having upon industry. Since that time there has been very close cooperation between COSINE and industry.

During the spring of 1969 COSINE concluded that computer technology had led industry to make a major change in the way it handled its engineering problems. Consequently, a task force on Industrial Liaison, consisting of five industrial representatives and five members of COSINE, was established to obtain information about how the current trends in computer and digital systems technology are affecting the practice of engineering and how these trends bear on the educational objectives of a modern electrical engineering program.

This group met at the University of Connecticut on June 12 and 13. Initially it had been assumed that the discussion would be mainly involved with identifying the ways that computer and digital systems concepts are being applied in various industrial situations. However, this topic was soon seen to be representative of only a part of the changes that were taking place in the way that engineering is being practiced in industry. The task force also explored the implication of these changes upon the educational program needed to prepare a student for the engineering profession.

This report summarizes the recommendations and conclusions reached by this task force. No attempt is made to recommend specific curriculum changes or specific courses that should be included in every curriculum since these are the concerns of other task forces. Instead, the emphasis is upon describing typical problems that are of current technological importance and the implications that these problems have upon the type of background needed by students entering industry. This information will hopefully provide useful background material when changes in curriculum are discussed by individual departments.

II. ORGANIZATION OF THE TASK FORCE

During the initial planning of this project the following general criteria were established for selecting the industrial representatives who would serve on the task force:

1. The man must be an experienced engineer.
2. He must be involved with the hiring and technical supervision of recent graduates from engineering and other technical programs.
3. He must have such a position in his company that he is aware of the technological trends the company is following and how new technological developments influence the practice of engineering.
4. Each representative should be selected from a different industrial group or technical area.
5. An additional, but not essential, requirement was that he be familiar with the educational processes that go into the development of the engineering curriculum.

Using these criteria as a guide, a list of possible participants was formulated. As each man on the list was contacted, it became evident that there was a great desire on the part of industry to make known its views on the education process. Clearly all these people had the background and experience that would provide an excellent insight into the types of problems faced by engineers and the tools that were used to solve these problems.

Five people accepted the invitation to join the task force and meet at the University of Connecticut on June 12 and 13. Table I lists the industrial members of the task force and indicates the industry and areas of interest represented at the meeting.

TABLE I

MEMBERS OF TASK FORCE ON INDUSTRIAL LIAISON

INDUSTRIAL MEMBERS

Richard A. Abate	- Chief Information Processing Section, General Dynamics/ Electric Boat Responsible for the development of advance antisubmarine sonar detection systems. Directs studies of sonar signal processing techniques and methods of using digital computers to reduce experimental data.
Leonard Atran	- Manager, Weapons System Analysis, Westinghouse Electric Corporation/Aerospace Division Responsible for the establishment and evaluation of future aerospace weapon systems. Directs analytical and simulation studies of these systems to evaluate their cost-effectiveness.
Albert S. Hoagland	- Director of Technical Planning, IBM, Research Division Responsible for overall planning and research relationships with the operating divisions. The research Headquarters staff reports to his office.
Charles E. Reichard	- Computer Applications Engineer, Northeast Utilities Service Company Responsible for applying computer technology to the solution of problems involved in the generation, distribution and utilization of electrical power. Develops specifications and evaluates bids for on-line and control computers. Development of the software necessary to support the various installed computer systems.
Joe M. Watson	- Computational Systems Engineer, Research and Development Center, General Electric Company Responsible for the design, development and dissemination of methods, techniques, processes, information and general purpose software for the solution of engineering and scientific problems. Leader of Computations Technology Workshops which interchange and disseminate information within GE in areas such as control systems, heat transfer, mathematical simulation and design automation.

In addition to these industrial representatives the task force also included the five following members of COSINE.

T. L. Booth - University of Connecticut
C. L. Coates- University of Texas
J. F. Kaiser - Bell Telephone Laboratories
S. Seely - University of Massachusetts
L. A. Zadeh - University of California at Berkeley

In addition to expressing their own viewpoints these members were given the responsibility of appraising the comments of the industrial members and discussing their implications in terms of their impact upon the contents of undergraduate curricula.

The first day of the task force meeting was of an exploratory nature. The industrial representatives discussed the impact that cpmputer and digital system technology was having upon industry and they also indicated how technological changes were influencing the methods that they used to solve their engineering problems. Similarly, the COSINE representatives described the various trends in the undergraduate engineering curriculum. This discussion served to identify the major topic areas that were examined during the rest of the meeting.

The topics considered by the task force were roughly divided into two areas. The first concerned the place of computer and digital systems technology in modern engineering and the second concerned the general type of education that would best prepare the student to enter the engineering profession. In the following sections the discussion relating to each topic is summarized and the implications relative to the educational process are presented.

III. THE COMPUTER AS A COMPUTING DEVICE

Historically the computer has been considered of value mainly for its ability to carry out massive and repetitive computations. However, the increasing availability of time-sharing computer facilities has altered this viewpoint. The members of the task force felt that within a few years almost every engineer will have on-line access to facilities to help him in carrying out his assignments.

Two general modes are used to carry out general computing tasks, batch and time-sharing. A great deal of the work makes use of standard packaged programs, such as

SCEPTRE, that have been designed as an aid for the solution of specific classes of problems. For other calculations engineers use a scientific programming language, such as FORTRAN or PL/i, to create their own special purpose programs to handle specific assignments. For less extensive tasks conversational languages such as BASIC or CPS are used in time-sharing.

In the future the batch and time-sharing modes will be blended; the engineer will use on-line capability for input/output and short processing tasks, and off-line resources for more extensive processing, all on the same computer system.

Current experience points out the fact that the inexperienced computer user tends to misuse the computation capabilities presented by modern computer systems. Some of the particular problems mentioned were as follows:

a. The "Reinvention of the Wheel:" A large number of standard programs are available to every computer user. Many times a user will fail to investigate the programs that are available to him and develop a completely new program to carry out computations that could have been done using a program that was already contained in the software library associated with the computer.

b. Poor Program Implementation and/or Documentation: The development of a complete computer program often involves a considerable expense in manpower and computer time. In many cases the person who developed the program does not take the time to work out the best techniques and/or adequately document the program. Poor implementation will result in expensive processing, and failure to document may result in loss of the capability.

c. Overpowering of a Problem: Many users try to substitute computer programming for thinking. Some problems are easier and more economically done using paper and pencils and a slide rule. Oftentimes the tendency is to rush to the computer to carry out these computations without giving enough thought to the actual scope of the problem.

d. Unorganized Approach to Problem Solution: Some users attempt to use a computer to obtain a solution to a problem before they adequately understand the complete problem. They write an extensive computer program and collect a massive amount of data with the hope that the data will indicate the proper direction to take to arrive at a solution. This problem generally results from a misunderstanding of the heuristic method of problem solution which is of significant value when properly applied.

The task force felt that these problems could be minimized if the following ideas were introduced into the undergraduate program.

1. Introductory Computing Course

Every engineering student should take an introductory computing course early in his program. This course should be more than a course in "How to Program ——— Using ——— Language." Although one of the standard programming languages and language structure must be thoroughly taught, the main emphasis of the course should be upon using the computer to solve problems effectively.

This course would teach the student how to use an algorithmic approach to describe and solve problems. He would be introduced to the standard programming and numerical analysis techniques for different types of computation and would thus learn how different types of assumptions and approximations influence his results. Above all he would write and debug a sufficient number of programs to insure that he fully understands these concepts as well as the mechanical process of using a computer system.

The methods of documenting a program so that it will be useful both to himself and others at a later date should also be emphasized.

Finally the course should introduce the theory of computer operation and organization so that the student would be able to understand the limitations as well as the capabilities of computers.

2. Integration of Computer Usage Into Other Courses

A student quickly loses his ability to work with a computer if he does not apply this skill throughout his undergraduate program. Each engineering course should therefore include one or more problems or assignments that require the student to use a computer. The emphasis should be upon solving a problem, possibly by using a packaged program such as SCEPTRE, rather than upon the actual writing of a complex program. This suggests the desirability of an increased effort in the development of problem oriented computer programs that would be generally available to our engineering colleges as part of their educational software library resources. During the course the student should be given several opportunities where he has an option of whether or not to use a computer to carry out an assignment. These problems should be selected so that in some cases he will find that using the computer is required to solve the problem, while in other cases it should be easier to do the problem by other means. After each problem of this type the instructor should spend some time in class discussing the relative merits of each approach. This should include a discussion, when appropriate, of how the computer program could best be organized to take maximum advantage of the computer.

3. Economics of Computer Operation

Students must also be introduced to the economics of computer operation. In industry an engineer will often be required to select the best computing means to use in solving a given problem. He must thus be familiar with the relative computation capabilities, cost and limitation of digital (batch and time-sharing), analog and hybrid computers systems. With this background he should be able to select the computing device, or combination, that will give him his desired results at the minimal cost and expenditure of time and effort.

4. Advanced Computing Techniques

For those students planning on entering areas that make extensive use of computers, an opportunity should be provided for work in the area of program design, structure, efficient programming techniques, and problem organization. Detailed study of non-numeric information processing techniques and examples of problem-oriented languages would be useful.

Advanced work in numerical analysis such as matrix manipulation, solution of ordinary and partial differential equations, error analysis and simulation techniques should be introduced to the students. This material might be included as an advanced course that the student would normally take or separate elective courses might be established to cover this material.

IV. CIRCUIT AND SYSTEM DESIGN

The introduction of digital integrated circuits has had a very pronounced influence upon system design. Digital, rather than continuous, techniques are used in many situations where it is necessary to process information on a real time basis or to reduce the effect of noise. One of the main reasons for this is that digital networks built from integrated circuits have been found to be easier to design and are more reliable than the conventional continuous circuits previously used. An engineer must be aware of the advantages and disadvantages of using both digital and continuous techniques in designing circuits and systems. This in turn means that an engineer must be equally familiar with conventional circuit design and with the design of systems utilizing logic circuits.

Integrated circuits have also had a major impact upon the way an engineer goes about designing a system. In the digital area all new system designs employ integrated circuit logic modules as the basic functional elements. This trend is also becoming commonplace in the design of continuous systems. As a consequence, an engineer can easily carry out the design of complex systems without having to devote a considerable amount of time to designing each of the individual amplifiers, etc., that make up the system.

Small digital computers which can be built right into a system are also becoming available. To use these computers effectively an engineer must be able to understand how a computer stores and processes data, the factors that limit the information processing capabilities of a computer and the techniques for designing a system which includes a computer as one of its major components.

These considerations lead to the following recommendations:

1. Every undergraduate electrical engineering student should be introduced to the concept of digital network and system design. This should include a discussion of how information can be represented in digital form, a basic treatment of switching theory, a discussion of the properties and design of elementary sequential networks, and a discussion of some of the standard methods used to store and process information in a digital computer or other information processing systems.

2. The electronic circuit design courses should spend less time on the design of discrete component circuits and spend more time on the use of integrated functional building blocks to realize systems that carry out a complete task. For example, the design of a complete telemetry system might be used to show when integrated circuits should be used and when it is best to use discrete component networks.

3. The student should be required to carry out a series of system design projects as part of his laboratory work. In each project he should be required to define the desired specifications of the system under investigation and decide upon the best method to meet these specifications. Finally, he should be required to build a prototype of the system, making use of integrated circuits or other system modules when possible, to prove that his design satisfies the stated design goal. Projects that integrate digital and continuous systems concepts are extremely valuable.

4. The increasing use of digital computers as an integral part of complex control systems dictates that systems courses should include a discussion of discrete system as well as continuous system theory. In particular the problem of interfacing computers with the real world, which involves the relationship between sample rate, quantization levels, and speed of the digital process to overall system performance, should be treated in detail.

V. SYSTEM SIMULATION

An electrical engineer is often called upon to solve problems involving the design of large systems. When this happens the engineer usually cannot build a breadboard prototype of the system and get rid of the major bugs before the system is actually built in its final form. A common solution to this problem is to use simulation techniques to study system behavior and evaluate the suitability and cost of different designs. Modern computers provide an excellent method of carrying out these simulation studies.

Simulation studies are usually carried out on either an analog, digital or a hybrid computer. Each type of computer has its own advantages and disadvantages as far as simulation is concerned. Consequently a person who fully appreciates the problems of simulation and the characteristics of each class of computer can often minimize the cost, time and effort to carry out a simulation study by selecting both the proper simulation techniques and the most appropriate type of computer on which to perform the simulation.

Besides being aware of the methods of simulation, an engineer must understand how the model used in simulation is developed. He must also understand how well his model actually represents the system over the range of parameters for which it remains valid. In many cases the inexperienced engineer will rush into a simulation study without sufficient analysis of his problem and of the relevance of the models he is using. To overcome this tendency the following ideas should be included as part of every undergraduate program:

1. Model Making

The idea of developing and using a mathematical model to represent an actual device or system is an important concept and should be presented as such to students. Although models are extensively used in current courses, often there is never any formal discussion that explains to the student the reasons for making the model, the general techniques that can be used, and the size vs. cost trade-off. The concept of modeling should be taken up as a concept by itself, and should not be hidden in the discussion of other material. The discussion should include models with nonlinear elements since these models much more nearly represent real-world devices than do simple linear models.

2. Simulation Experience

The idea of using simulation techniques to solve large scale engineering problems should be introduced to the student in one or more undergraduate courses. When these ideas are discussed, particular emphasis should be placed upon the relationship between simulation, system analysis, and the performance of the actual system.

3. Use of Simulation

Engineering courses could profitably employ simulation as a teaching aid. Besides requiring a student to carry out a complete simulation problem an instructor could have a system already programmed on a computer and the student could carry out studies involving the behavior of the system. This approach is also useful in the laboratory. A student can be asked to develop a device or a subsystem that has to meet certain specifications. He can then test his device by using an analog or digital computer to simulate those parts of the system he did not work with or which are not available in the laboratory.

VI. INDUSTRIAL TRENDS AND ENGINEERING CURRICULA

The young engineer entering the engineering profession today faces a technological environment that is quite different from that of ten or more years ago. For the present environment, the educational process must be aimed at more than developing student proficiency in solving problems related to course work alone. Thus it is necessary to effect a better balance between the acquisition of new knowledge and the ability to solve new and original problems that might extend beyond his formal course studies.

It is an unfortunate fact that few recent graduates have had an opportunity in their undergraduate studies to carry out a comprehensive design or development problem from initial conception to final solution. If properly employed, the use of a computer in a laboratory experience can go far in providing the student with an opportunity to acquire such an experience.

To provide the student with an opportunity for the broad training here discussed, it is most desirable that:

1. An undergraduate student should have considerable flexibility in planning, in conjunction with a faculty advisor, his course of study. The number of required courses should be held to a minimum. Instead, the student should be encouraged to undertake a coherent sequence of courses that relate to his area of professional interest and overall ability.

2. The student should be required to take at least one project oriented course that allows him to carry out a complete project in an area of particular interest. The project and its execution should be the responsibility of the student from initial concept to the preparation of a clear and comprehensive final report. Experimental as well as analytical methods should be employed. The student should be required to present periodic oral progress reports to his class; the ability to express and communicate his ideas should be rated as critically as his technical capacities.

3. The undergraduate mathematics courses taken by a student should include work in the areas of probability and statistics, numerical analysis, and for students interested in computer engineering or computer science, there should be studies in logic, linear algebra and modern algebra.

4. The faculty should seriously consider developing socio-technological courses, possibly in conjunction with other departments, that stress the relationship between technology and the problems facing society. Many students are seriously concerned with the "relevance" of their studies, and with the moral and social consequences of their training. A significant educational experience is possible even in relatively technological areas, as, for example: The Computer and Privacy; Mass Transportation; Pollution; Science and a Science Policy.

VII. GRADUATE STUDIES AND CONTINUING EDUCATION

A feature of the engineering world is that the level of competence required of an engineer is continually increasing. Most of the routine, handbook and repetitive type engineering jobs have been eliminated through automation or computer techniques, or they have been transferred to non-professional or semi-professional personnel. Consequently, the engineering graduate will be faced with technical demands that may be outside his formal areas of study. Despite this, he will be expected to perform competently in his work. It is extremely important, therefore, that the young engineer be instilled with the habit and discipline of self-directed learning. This capacity is essential not only for progress in his work and his place in the company, but it can also be a very important factor in his ultimate job security. In view of this, the following recommendations are made:

1. Graduate study is of increasing importance. Qualified students should be encouraged to complete graduate studies before entering industry. Comparatively, a year of graduate study will increase a person's technical knowledge to a higher degree than will a year of experience in industry. This is particularly true if the student can immerse himself in the learning process under the guidance of a faculty member who is himself actively engaged in meaningful research.

2. Part-time graduate programs are generally not as desirable as full-time programs since conflicts often arise between the students' job responsibilities and the demands of his academic program. Part-time programs extend over a number of years. Consequently a student will often take an advanced course and find that the material presented in a prerequisite course taken three or four years earlier will not be the same as the material currently being offered in that prerequisite course. This places the student at a distinct disadvantage. This is particularly true in the computer and digital-systems area. Further, part-time programs may be taught by part-time instructors from industry, and will probably lack the overview of new areas that a professor who is conducting research in the area will have, although they might, conversely, reflect a current state-of-the-art approach that has immediate value.

3. The undergraduate program should be designed in such a manner that it psychologically conditions the student for a professional lifetime of independent study. This requires a conscious effort in program design that leads from directed study, to semi-directed study, to independent study. Project courses and laboratories that require and reward individual incentive and ability are of extreme value in this respect.

VIII. CONCLUSIONS

Probably the most general conclusion reached by the task force was that industry depends upon engineers who are able to carry out, with a minimum of supervision, either alone or as a member of a small team, a complete engineering assignment from initial problem specification to final solution. To do this an engineer must be able to solve problems from a variety of areas, some of which probably involve technical concepts that he has rarely or never encountered before. In fact, this is the main distinction that makes an engineering education particularly valuable.

To be prepared to handle these problems a student must be given an opportunity to work on complete problems that develop both his theoretical knowledge and also his ability to apply this knowledge to practical problems. This is essential no matter in which technical area the student happens to be interested.

The second major conclusion is that industry is employing and applying computers and digital system concepts to a much greater degree than is represented in most undergraduate curricula today. It appears that the electrical engineering departments are not updating their curricula in this area as fast as the present and future practice of engineering would warrant.