U2698

OCTOBER, 1957

STUDY AND EVALUATION OF THE STATUS OF UNIVERSITY PROGRAMS IN THE UNITED STATES IN COMPUTERS, DATA-PROCESSING AND RELATED FIELDS INCLUDING RECOMMENDATIONS TO STANFORD UNIVERSITY ON THEIR POTENTIAL ROLE IN THESE FIELDS.

By: LOUIS FEIN
PALO ALTO, CALIFORNIA

L. Fein

Prepared for: STANFORD UNIVERSITY
PALO ALTO, CALIFORNIA

COPY NUMBER
27

TABLE OF CONTENTS

Section I

PREFACE

This study was undertaken at the request of Dr. Albert H. Bowker, Assistant Provost and Head of the Statistics Department of Stanford University. The work extended over a 12-month period from October 1956 to October 1957. Its purpose was:

1. To study and evaluate the organization, curriculum, research program, computing equipment, financing and facilities of universities in the United States having computer and/or data processing and/or related programs.

2. To identify those fields of study (those already formally identified as disciplines as well as those not yet so designated) that are unambiguously part of the computer and data-processing fields and those closely related fields that might legitimately be part of a university program.

3. To recommend to Stanford University what it might do to build a distinguished program in these fields.

To obtain information, interviews were held with university administrators, directors of computing centers, faculty members, students, industrial representatives and others interested. Places of interview were universities, scientific meetings, social gatherings, industrial plants and research institutes. Important information was obtained from a few publications.[2,3,7]

In the course of the study, general pertinent questions arose that had to be considered in a program for a university. Such questions included "What is the function of the university?" and "What fields of study legitimately constitute disciplines?" These questions were considered as by-products of the main study.

The three objectives are considered to have been essentially achieved. A summary of the significant facts, conclusions and recommendations is included in the body of the report.

The scope of the survey did not allow for any more than a fortuitous gathering of information by the investigator who made many of his contacts during visits in cities of his clients. A questionnaire intended for mailing was considered and dropped because it became clear very early that only personal interviews could bring out the important facts and opinions. Besides, results from other similar questionnaires became available. Hence, the conclusions and recommendations are not always derived from a mass of accumulated data - they do reflect the writer's own experience in the computer and data processing field, information about what other universities are doing and especially what they are not doing, and the influence of those individuals interviewed who have experienced and reflected on the same problems as those considered in this report.

Section II

SUMMARY AND CONCLUSIONS

The present and future need in the United States for qualified professional and nonprofessional personnel in the computer, data-processing and related fields has been well established.[2,3,6,17] Government, industry and the student body at large are seeking but not getting nearly enough in the curriculum of American universities to satisfy these needs. They will continue to seek this curriculum for at least the next ten years.

Many activities in fields like econometrics, information theory, management science, operations research, computers, data-processing, decision theory, model theory, etc., are related somehow - but the fields are so new that even an adequate terminology has not yet been developed within most of them. Consequently, individuals working in these respective fields cannot adequately communicate with each other - let alone with individuals in another related field. There is much work to be done in integrating these fields into a unified discipline and identifying those areas that are disciplines on their own so that they can be developed independently.

There is the opportunity and obligation now for Stanford University not only to help satisfy the needs of the community for trained professionals in the computer, data-processing and related fields - but also to become distinguished academic leaders in these fields - by accumulating a competent faculty to instruct and to conduct a research program that will develop the "computer" discipline/s as well as to create and develop techniques and theories of applications of these computer disciplines as tools for use by other disciplines, established and otherwise.

It is recommended that plans be made for the creation of a new Graduate School at Stanford University in September 1958, to be called the Graduate School of Computer Sciences. This school would grant degrees in a variety of topics covered by the departments within the school. The avowed purpose of the school would be (1) to train professionals in the fields of interest and competence in the school, (2) to train scholars in these fields, (3) to do exploratory research in these fields, and (4) to develop the new disciplines.

These departments should now include a Computer Department (that has cognizance over the computing equipment), Information and Communication Department, Systems Department, and Operations Research Department. Consideration should be given to including the present Statistics Laboratory in the school.

This recommendation does not exclude other Schools and Departments in the University from adding faculty to their staff competent in these fields. As a matter of fact, this should be expressly encouraged in those departments and schools devoted to subjects whose research and instruction could profit from utilizing models from the fields of interest to the new Graduate School of Computer Science. However, other Schools or Departments should not be depended upon to devote instruction and research in these fields.

One of the important reasons for recommending a School rather than a Department or an Interdepartmental Committee as the organizational entity is the conviction that fields of study that do not have a key organizational entity of a university associated with it, will not become associated in the interested public's mind with that university.

If Stanford University creates the Graduate School of Computer Science, there is little doubt that other universities would soon follow with similar organizations and programs.

One word of caution may be in order: It is appreciated that the recommended action is a major undertaking and that the University officials may want to act more slowly than is recommended here. There can be no objection to slow, deliberate action provided it is a planned, scheduled and deliberated movement toward specifically well defined goals - rather than an opportunistic delaying action that seems to characterize several of the current university programs in the United States.

Section III

GENERAL OBSERVATIONS

The milieu of our society is characterized by a demand that more phases* of our traditional culture be subjected to a critique guided by rationalistic and scientific rules of evidence.[14] Thus:

INFORMATION-DATA	gathering, reception, accumulation, storage, searching, classification, cataloguing, retrieval, handling, processing, encoding, decoding, interpretation, sampling, filtering, analyzing, checking,
MODELS	mathematical, Boolean algebraic, Post algebraic, logical, stochastic, computational, statistical,

SIMULATORS, ISOMORPHISMS, HOMEOMORPHISMS, COMPUTERS, LANGUAGE TRANSLATION, SWITCHING THEORY, INFORMATION THEORY, CODING THEORY, CYBERNETICS, STATISTICS, DECISION THEORY, SYMBOLIC LOGIC, AUTOMATA THEORY, ARTIFICIAL INTELLIGENCE, NEURAL PHYSIOLOGY, OPERATIONS RESEARCH, ECONOMETRICS, MANAGEMENT SCIENCE, PSYCHOMETRICS, CRYPTOGRAPHY, PROBABILITY, LEARNING, GENERAL SYSTEMS THEORY, LINEAR PROGRAMMING, GAME THEORY, AUTOMATION, DYNAMIC PROGRAMMING, NUMERICAL ANALYSIS are examples of topics, some old - some new, that are having a terrific impact on and general acceptance by the industrial, business, government, and intellectual community.

This acceptance is due in no small measure to the spectacular successes enjoyed by some of these fields when applied to the solutions of problems in many of the crash programs that characterize the present generation. That, in some cases, the use of the new knowledge has pointed up the ridiculousness of some of these crash programs has not dulled the luster of the new look.

Behind this new look is a substantial and basic change - in the scope of problems that can be attacked - in philosophy and method of approach - in the norms, standards, criteria, and set of values, indeed of the aims and ideals of society.

The following excerpt characterizes a phase of the milieu:

"The field of sales management viewed in its broadest terms - including the direction of personal sales activity and the integration of auditing with other sales functions - presents a third major opportunity for management science. Primarily, what are needed are methods for grappling with multi-variable situations as they occur in the world

---

*Including the running of a university, as well as the preparation of a report such as this.

rather than the single-variable methods of classic laboratory science. Hopefully, it should be possible to start with qualitative or rough quantitative approaches and gradually develop tools of greater precision. This suggests the use of mathematical models in both their qualitative and quantitative aspects. Techniques grounded in mathematics, notably including linear programming, search theory, and game theory (particularly nonzero sum multi-person games) have outstanding potential contributions. Marketing budgets involve commitments on too large a scale to permit executives to continue to accept historical patterns in a management world in which rational explanations of alternative strategies and planned optimizing are becoming standard operating procedures."*

Industry, business and government have varied requirements for trained people to do the work requiring talents in these fields. Need for investigating these fields from the scholar's viewpoint has also been recognized although support for this endeavor lags. The problems of solving practical problems in and with these fields, training professionals, training scholars, and doing research, have been handled in a variety of ways by industry, business, government and the university when indeed they have tried to handle the problems at all. On the whole, each of these four important segments of the community has been unprepared by virtue of its traditional organization, philosophy, responsibilities and procedures to incorporate and cope with a phenomenon whose fundamental implications usually requires a modification of these organizations, philosophies, responsibilities, and procedures.

Thus, the government has set up Rand Corporation(s) for research and project work - they have set up and supported institutes at universities for research and project work - they have indirectly supported development, if not exploratory work, in these fields as by-products of government project contracts to industry.

Industry and business have set up separate departments charged with over-all responsibility of applying these techniques to company operation, management, design, manufacturing, sales, etc. Graduate level schools for instruction of professionals in these fields are being run by industry itself.

Universities have sometimes introduced courses in existing departments, sometimes a new department has been set up - sometimes an interdepartmental committee, sometimes an institute or a laboratory - for instruction of professionals and to do thesis research.

One is impressed by the ambiguous and yet apparently overlapping characteristics of some of these fields. Organizations have been formed and magazines are being published by devotees of this or that field. Yet in many cases, the nature and function of the field is vague in the minds

---

*Melvin Anshen, p. 231, "Management Science in Marketing," Management Science, Vol. 2, No. 3, April 1956.

of these people. One of them, writing in the Transactions of the Institute for Management Sciences, stated: "The writer has a strong feeling that these who worked so hard and successfully to organize TIMS were on the right track. However, it appears that they were led more by broad feelings than by logical reasoning. They knew (in the sense of having faith) that there was a need for something not yet in existence but they failed to develop a clear and distinct picture of what they intended to accomplish."

And further, the following statement of editorial policy in the new journal, "Information and Control":

" Statement of Editorial Policy"

"The theories of communication, computers, and automatic control were initially of interest primarily to mathematicians and engineers. The papers relating to these fields have therefore appeared in a wide variety of engineering and mathematical journals. Some of the results of this work have been applied by scholars in such areas as linguistics, psychology, statistics, physics, genetics, neurophysiology, and even philosophy. Such applications have lead to results which are of interest in their own areas, but which in some instances have also suggested models and raised questions of fundamental interest to the theories being applied. Unfortunately they appear in many entirely different sets of professional publications, which few readers of engineering and mathematical journals see.

"It is the purpose of this new journal, 'Information and Control,' to publish papers which make significant contributions to the theories of communication, computers, and automatic control, and also papers which present experimental evidence or theoretical results bearing on the use of ideas from such theories in any field to which the ideas are relevant. Papers will be published, for example, on such topics as:

- Theory of communication
- Theory of automata
- Theory of Automatic control systems
- Description and analysis of language and other natural information sources
- Communications and control systems which may include links within or between organisms
- Informational aspects of physics and of the theory of observation and measurement
- Organization, processing and retrieval of data

"Since people in a number of disciplines will be communicating through this journal, it will from time to time publish editorials, or papers of an editorial nature, discussing views of the relationships between fields. The paper 'Mathematics, Physics and Information' in the current issue falls in this category. Since people in many countries have contributed to this field, the editorial board is international in character.

"Any statement of policy for a new enterprise is, at best, an educated guess, and this one is no exception. It is, of course, subject to gradual change without formal notice, as the Journal takes shape under the diverse pressures of authors, editorial board, editors, and readers."

So it will probably be with the course content and research topics in the universities. Doubtless, some of the topics of present interest will develop into disciplines of their own, while others will flower and die. Not knowing which topics are destined for what fate, the university scholar is presently interested in all of them.

Ancient Controversies

These doubts and fumblings about how to incorporate new topics into the university structure, what is the function of a university and, indeed, what is an intellectual discipline worthy of scholarly inquiry, are subjects of ancient controversies.

The following excerpt is from an article by A. N. Whitehead, concerning the function of a university, especially in connection with the opening of the new Business School at Harvard University in 1927.

"This article will only deal with the most general principles, though the special problems of the various departments in any university are, of course, innumerable. But generalities require illustration, and for this purpose I choose the business school of a university. This choice is dictated by the fact that business schools represent one of the newer developments of university activity. They are also more particularly relevant to the dominant social activities of modern nations, and for that reason are good examples of the way in which the national life should be affected by the activities of its universities. Also at Harvard, where I have the honour to hold office, the new foundation of a business school on a scale amounting to magnificence has just reached its completion.

"There is a certain novelty in the provision of such a school of training, on this scale of magnitude, in one of the few leading universities of the world. It marks the culmination of a movement which for many years past has introduced analogous departments throughout American universities. This is a new fact in the university world; and it alone would justify some general reflections upon the purpose of a university education, and upon the proved importance of that purpose for the welfare of the social organism.

"The novelty of business schools must not be exaggerated. At no time have universities been restricted to pure abstract learning. The University of Salerno in Italy, the earliest of European universities, was devoted to medicine. In England, at Cambridge, in the year 1316, a college was founded for the special purpose of providing 'clerks for the King's service.' Universities have trained clergy, medical men, lawyers, engineers. Business is now a highly intellectualized vocation, so it well fits into the series. There is, however, this novelty: the curriculum suitable for a business school, and the various modes of activity of such a school, are still in the experimental stage. Hence the peculiar importance of recurrence to general principles in connection with the moulding of these schools. It would, however, be an act of presumption on my part if I were to enter upon any consideration of details, or even upon types of policy affecting the balance of the whole training. Upon such questions I have no special knowledge, and therefore have no word of advice.

"The universities are schools of education, and schools of research. But the primary reason for their existence is not to be found either in the mere knowledge conveyed to the students or in the mere opportunities for research afforded to the members of the faculty.

"Both these functions could be performed at a cheaper rate, apart from these very expensive institutions. Books are cheap, and the system of apprenticeship is well understood. So far as the mere imparting of information is concerned, no university has had any justification for existence since the popularization of printing in the fifteenth century. Yet the chief impetus to the foundation of universities came after that date, and in more recent times has even increased.

"The justification for a university is that it preserves the connection between knowledge and the zest of life, by uniting the young and the old in the imaginative consideration of learning. The university imparts information, but it imparts it imaginatively. At least, this is the function which it should perform for society. A university which fails in this respect has no reason for existence. This atmosphere of excitement, arising from imaginative consideration, transforms knowledge. A fact is no longer a bare fact: it is invested with all its possibilities. It is no longer a burden on the memory: it is energizing as the poet of our dreams, and as the architect of our purposes.

"Imagination is not to be divorced from the facts: it is a way of illuminating the facts. It works by eliciting the general principles which apply to the facts, as they exist, and then by an intellectual survey of alternative possibilities which are consistent with those principles. It enables men to construct an intellectual vision of a new world, and it preserves the zest of life by the suggestion of satisfying purposes.

"Youth is imaginative, and if the imagination be strengthened by discipline this energy of imagination can in great measure be preserved through life. The tragedy of the world is that those who are imaginative have but slight experience, and those who are experienced have feeble imaginations. Fools act on imagination without knowledge; pedants act on knowledge without imagination. The task of a university is to weld together imagination and experience.

"The initial discipline of imagination in its period of youthful vigor requires that there be no responsibility for immediate action. The habit of unbiased thought, whereby the ideal variety of exemplifications is discerned in its derivation from general principles, cannot be acquired when there is the daily task of preserving a concrete organization. You must be free to think rightly and wrongly, and free to appreciate the variousness of the universe undisturbed by its perils.

"These reflections upon the general functions of a university can be at once translated in terms of the particular functions of a business school. We need not flinch from the assertion that the main function of such a school is to produce men with a greater zest for business. It is a libel upon human nature to conceive that zest for life is the product of pedestrian purposes directed toward the narrow routine of material comforts. Mankind by its pioneering instinct, and in a hundred other ways, proclaims falsehood of that lie.

"In the modern complex social organism, the adventure of life cannot be disjoined from intellectual adventure. Amid simpler circumstances, the pioneer can follow the urge of his instinct, directed toward the scene of his vision from the mountain top. But in the complex organizations of modern business the intellectual adventure of analysis, and of imaginative reconstruction, must precede any successful reorganization. In a simpler world, business relations were simpler, being based on the immediate contact of man with man and on immediate confrontation with all relevant material circumstances. Today business organization requires an imaginative grasp of the psychologies of populations engaged in differing modes of occupation; of populations scattered through cities, through mountains, through plains; of populations on the ocean, and of populations in mines, and of populations in forests. It requires an imaginative grasp of conditions in the tropics, and of conditions in temperate zones. It requires an imaginative grasp of the interlocking interests of great organizations, and of the reactions of the whole complex to any change in one of its elements. It requires an imaginative understanding of laws of political economy, not merely in the abstract, but also with the power to construe them in terms of the particular circumstances of a concrete business. It requires some knowledge of the habits of government, and of the variations of those habits under diverse conditions. It requires an imaginative vision of the binding forces of any human organization, a sympathetic vision of the limits of human nature and of the conditions which evoke loyalty of service. It requires some knowledge of the laws of health, and of the laws of fatigue, and of the conditions for sustained reliability. It requires an imaginative understanding of the social effects of the conditions of factories. It requires a sufficient conception of the role of applied science in modern society. It requires that discipline of character which can say 'yes' and 'no' to other men, not by reason of blind obstinacy, but with firmness derived from a conscious evaluation of relevant alternatives.

"The universities have trained the intellectual pioneers of our civilization - the priests, the lawyers, the statesmen, the doctors, the men of science, and the men of letters. They have been the home of those ideals which lead men to confront the confusion of their present times. The Pilgrim Fathers left England to found a state of society according to the ideals of their religious faith; and one of their earlier acts was the foundation of Harvard University in Cambridge, named after that ancient mother of ideals in England, to which so many of them owed their training. The conduct of business now requires intellectual imagination of the same type as that which in former times has mainly passed into those other occupations; and the universities are the organizations which have supplied this type of mentality for the service of the progress of the European races."

It is difficult now and seems to have always been difficult to get agreement on what the functions and product of a university should be - or what it should not be, for that matter. Gray areas seem always to turn up that cannot be unambiguously adjudicated. One can find proponents of the policy that "education" is the realm of the university, while "training" is not. Others will insist that the university is concerned with all aspects of the mental, intellectual, abstract disciplines and nothing else, etc. The creating of medical, law, business and engineering schools as part of the university systems came only after much disagreement. It is not at all clear to many university people today what aspects, if any, of computers, data-processing, and related fields are the proper province for a university.

Characteristics of Disciplines

This leads us to the question, "What constitutes a discipline?"

Although a set of agreed-to criteria do not exist by which one can determine whether or not a field rates as a discipline, there are several characteristics of accepted established "disciplines" that may be referred to when one has the problem, as we do, of deciding whether or not a given field is potentially a discipline.

Established disciplines, like mathematics, e.g., have the following characteristics:

1. the terminology has been established; a glossary of terms exists;
2. workers in the field do non-routine intellectual work;
3. the field has sometimes been axiomatized;
4. the field is open, i.e., problems are self-regenerating;
5. there is an established body of literature, textbooks exist, sometimes treatises - even handbooks; also professional journals;
6. university courses, sometimes departments and indeed schools are devoted to the field.

Most aspects of computers, data processing and the related fields discussed in this study now meet these specifications or may be meeting them in the next ten years. It is clearly the job of university people to help create the axiomatization, theory, terminology, curriculum, etc.

Policy

In talking to university administrators and faculty, sympathetic or otherwise, about the problems of incorporating computer or data processing or related fields into their university programs, I was impressed with the fact that many of them spent most of our discussion time relating difficulties in generalities and illustrating these difficulties with practical, though trivial, examples. Thus, one man described the difficulties he had in getting a course in matrix methods approved by the faculty committee for inclusion in the curriculum. Another man concluded that an important prerequisite for adding a faculty member for instruction and research in computers was that the new man be under thirty years old. It was carefully explained that the quota for the other age groups in the department was already filled. In discussing the possibility that faculty would have to be recruited from industry in some cases to fill university positions in these fields, one man took the trouble to make it abundantly clear that such recruits would most certainly have to be willing to share the department secretary.

It was difficult to find people who had before been involved in incorporating new programs into a university or who would release themselves from their immediate constraints to discuss the essentials of the present situation.

There have been several reports written by university committees chartered to recommend a course of action for their respective universities. Some people offered these reports for reference, but as it turned out none were actually ever made available to me. I suspect that an element of embarrassment was involved.

This behavior betrays a general lack of confidence, policy and philosophy at universities regarding their role and function in these fields. My conclusion was that for many university members - his status is at least as much a vehicle for personal security and the maintenance of vested interests, as it is an opportunity to teach and inquire.

The scramble to get in on a "free" 650 computer from IBM is a disgrace in some cases. Course titles and contents have been created on the spur of the moment to fit the IBM requirements. Faculty have been assigned on the basis of their not having a full load. More evidence of what one does when one does not have a clear, well defined policy and program.

Section IV

SOME OBSERVATIONS ON THE PRESENT SITUATION

POLICY

Probably 200 universities and colleges are engaged in some kind of activity in the fields of our concern. The purpose of the schools that first got involved was "to get their feet wet" in fields that seemed to have appeal. Usually, one man who had a strong interest in this or that field would give a course in whatever department he happened to be in. Several institutions embarked on a program of building large-scale digital computers. Few were successful. Later, as the pressures for information in these fields grew, courses were added, some equipment was obtained, centers and institutes were established. Only a few universities made a determined effort to select a field of interest, set up a policy and goal and implement it. Most were feeling their way.

Most are now feeling their way.

The most important impact on university programs in these areas has been the educational program of IBM. IBM has a manpower problem now - they know it will be severe in ten years. Their problem is two-fold. They need professionally trained people to help sell their product. They want their customers to have professionally trained people to use their product properly. IBM has "presented" 650's to over a hundred universities by now under the condition (among others) that a couple of courses in data processing and numerical analysis be given. A 705 has been "given" to UCLA for "emphasis on the study of business management problems." MIT has been "given" a 704 for "research and education of students in computing techniques." The University of California has a re-tread 701. (Harvard and University of Pennsylvania have been "given" Univacs; one or two universities "have" Datatrons.) It is fair to say that in most cases, to the extent that a university activity has a purpose at all, it has been made for them by IBM. It is true that for many universities, this is good. Otherwise, they may never have gotten around to a program at all. Nevertheless, there are no distinguished centers of computers, data processing, etc. and I believe that this is so because not enough attention has yet been given by anyone to the development of an integrated program and policy in response to the needs and conditions of the whole community rather than to the specific needs of computer manufacturers and their customers.

ORGANIZATION

The university entity most popular as the center of activity for computer, data processing, operations research, industrial engineering, mathematics, business, etc. is the computing service center. Sometimes an interdepartmental committee is in charge of the service and of a few courses. Sometimes, all courses are given in one department without any necessary relation between course content and department. For example, Course 634, "Applications of large-scale digital computers to business and industrial systems" is given in the Moorse School of Electrical Engineering at the University of Pennsylvania. Some schools run one-week seminars. Others run symposia. In many cases, institutes, not altogether part of the university structure, are involved.

RESEARCH - SUBJECT MATTER

The range and variety of potential research activity in the design, programming and utilization of computers and closely related fields is enormous.

Theses and research papers have been written[18] on topics in computer logic, automatic coding, switching theory, coding theory, neurophysiology, inventory control, production control, office automation, machine translation, organization, classification and retrieval of knowledge, and solutions of problems having computational models in almost every quantitative discipline.

Here, as in the curriculum, the fields of computer theory, application theory, model theory do not yet appear to have been attacked.

The following comments concern the structure of a digital computer and problems of research concerning its use as both a manual and a mental aid. Data Processing and its relation to other fields is also discussed.

THE MODERN HIGH-SPEED DIGITAL COMPUTER SYSTEM

The modern high-speed digital computing systems consist of a combination of devices whose ultimate use may be characterized as being a manual and/or a mental aid, indeed an extension or part of the user. The system's internal structure and organization is sometimes used as a model of certain theories as well as of human structures - the brain and nervous system in particular.

In considering exactly how a computing machine may operate as indicated, let us identify the significant components and characteristics of a typical one.

Bulk Storage (Input-Output)

A system usually has a medium (paper tape, punched cards, magnetic tape, photographic film) for storage of initial information, intermediate results, instructions or permanent storage. Access to and reading this information on this medium is fast (compared to a human being doing an equivalent search job on a paper file). Information density on these media is high and thus much information may be stored in a small volume. Information may be written onto these media from a keyboard or from the computer. When under control of the machine, the medium may be searched automatically at high speed. When the medium is "on line," it can be read by the machine. When "off line," it may be read and converted to information on another medium, such as a printed page. The printed page is sometimes used as "on line" input as well as output from the computer.

Internal High-Speed Storage

These devices (magnetic drum, mercury delay lines, electrostatic storage tubes, magnetic cores, etc.) store instructions, original data, intermediate and final results. They are written onto (fed by) the bulk storage memory and the arithmetic unit (results of computation). They are read by the bulk storage, the arithmetic unit and the instruction unit. They operate (access) at high speeds, but their information density is usually low.

Arithmetic Unit

This unit performs the arithmetic operations of addition, subtraction, multiplication and division on data it already has in its registers or has received from the internal high-speed storage unit. It also performs the logical and "bookkeeping" operations.

Central Control

This unit contains the instruction and control registers that the other units respond to. Instructions are read from the internal high-speed storage. Address portions are sent to address selection equipment - arithmetic and terminal equipment operation codes are also distributed from the instruction register.

Stored program digital computers are capable of automatically executing a series of instructions that are created by the system and/or initially entered into the system. The speed with which the system solves a problem or performs a task depends on the capacity and access time of the storage devices, the speed of performing arithmetic operations and the efficiency of the program. Preparation for using the system involves restating a problem or task in machine language and preparing an input medium with data and instructions for entry into the system.

Manual Aids

Manual aids, such as desk computers, computresses, bookkeeping machines, punched card machines and the like, have been extremely valuable to university scholars and students in the physical sciences, humanities, social sciences, mathematical sciences, business sciences, library science, etc. The ability of modern high-speed equipment to do a superior job in storage, retrieval, and calculations means that the quality and quantity of university output should be improved to the extent that this kind of manual aid is made available and used efficiently.

It may here be noted that the quantity of the output should increase not only because of the high speed and versatility of the electronic aid, but also because more of the problems, tasks and the models created in the various disciplines become tractable with the use of the new aid. The quality should improve for a similar reason. There exist models of various phenomenon in almost all disciplines whose problems have not been soluble with present techniques. In many cases "simplifying assumptions" are made and the model revamped in order tomake the problems soluble. In these cases, the wrong problems have been solved quite accurately. Present high-speed equipment makes possible the accurate solution of more of the right problems.

The availability of high-speed computing systems and efficient operating crews has a much greater impact on the university output than, say, the availability of batteries of desk calculators and operators. The curriculum, research program and even faculty education is affected. Scholars and students will have to learn enough about the available devices to use them well with their present models. This knowledge should serve to motivate them to the creation of new machine soluble models. In fact, a general theory of the construction of techniques of machine soluble model construction for any discipline seems clearly to be a job for the university scholar.

This is an unexpected but inescapable development growing out of the computer as a manual tool!

In addition, those techniques peculiar to the design and programming of high-speed equipment should be developed if they can serve to make it a more efficient aid for manual routine work, and especially if it results in an aid that could help handle more models. As a basis for this endeavor, there will undoubtedly be required at least a COMPETENT THEORY OF COMPUTING MACHINES, A COMPETENT THEORY OF MODELS AND A COMPETENT THEORY RELATING THE TWO.

Mental Aids

Equipment for aid in routine mental tasks has fewer precedents than equipment as an aid for routine manual tasks. Computers are now being used to check results of some mental efforts. For example, they are being used to check the logical design of other computers. The ability to use equipment as an aid to do routine mental work and thus make it literally an adjunct of one's self in creating new disciplines or developing existing ones may turn out to be a discipline in itself. To be sure, this is rather vague, but this in no way weakens the conviction that it is a legitimate interest of the university. The university scholar must also be interested in the peculiar programming and design techniques of an equipment that will make it (the equipment) most useful as an aid to routine mental work.

Data Processing and Related Fields

Computers are related to other fields in one or more of four ways:

1. Workers in these fields use the computer as a mechanical or a mental aid,

2. These fields provide models useful in the design, programming and applications of computers,

3. Analogies exist in the internal structure and organization of a computer with structures and organizations in other fields,

4. The methods, tactics, philosophy, modus operandi are similar.

Many fields of applied mathematics* are now providing models for many other disciplines. Thus, work under the province of operation research, or game theory or decision theory or management science, or linear programming, or econometrics or statistics is being applied to business problems like market analysis, inventory control, long-range planning, etc. In many instances, a computer is used to process data, solve equations, do analyses - even make decisions based on criteria it has been given.

Switching theory, coding theory, information theory, Boolean algebra provide models not only for design and programming and applications of computers but also of analogous fields like neurophysiology.

The computer thus provides a significant link among various established disciplines as well as those fields of endeavor of intense present interest, some of which will develop into disciplines on their own, while others will no doubt flower for a while and die. Since there is no way of knowing which ones are destined for what fate, the university scholar is presently interested in all of them.

Curriculum

A few selected examples of topics covered in the present curriculum of universities are the following:

use of electronic data processing
logical design of computers
computer electronics
electronic digital computers - digital computer circuitry
theory of and operation of computing machines
statistics in business forecasting
dynamic programming
numerical mathematical analysis
numerical mathematical analysis laboratory
matrix analysis
matrix analysis laboratory
numerical solution of differential equation
numerical solution of differential equation laboratory
principles of digital computers
programming for digital computers
business and industrial analysis
statistical methods - regression
probability models
linear programming
game theory
Monte Carlo techniques

---

* a controversial characterization

data processing
- record keeping
- sorting
- searching
- collating
- file maintenance

automation
- systems analysis
- information theory

switching and computing circuits
theory of coding
information storage and retrieval
documentation and classification

Such topics are covered not only in normal courses, but in special courses, seminars, symposia, and lectures.

It may be seen that even this incomplete list covers aspects in the design and design models for computers, programming and applications of interest to people in the business schools, engineering, the physical and biological sciences, applied mathematics, statistics, industrial engineering, logic, etc. These courses reflect an appreciation of the computer as an aid for routine manual work in many applications. They reflect an appreciation of the ability of a computer to handle new computational models. They reflect an appreciation of the theoretical techniques of computer design.

What is impressive is the lack of courses reflecting appreication of the computer as an AID TO ROUTINE MENTAL EFFORT, A THEORY OF COMPUTERS, A THEORY OF PROGRAMMING, A THEORY OF APPLICATIONS. This in turn is probably a reflection of the youth of the fields. Such theories have not yet been born. When they are created and developed, courses will doubtless follow.

Few, if any, of the university curricula are integrated. Even those that do have an aspect of integration, as the one at the Engineering School at the University of Pennsylvania, for example, or the contemplated one at the Business School at UCLA, concentrate on the interests of people in particular disciplines interested in computers or data processing as tools for their own use exclusively. This is not to say that this is bad. But it is narrower than a university program ought to be.

COMPUTATIONAL MODELS FOR VARIOUS FIELDS

The following list of typical engineering applications of computers will serve to illustrate the wide variety of disciplines that can find appropriate models in the fields we are discussing. These may, of course, motivate the creation of courses and research in these techniques in various departments and schools of the university.

Aeronautical Engineering
- Aeroelastic flutter and vibration analysis
- Armament systems evaluation
- Bombing systems evaluation

Body and duct design, lofting
Compressible flow studies
Data reduction-telemetered, theodolite, wind tunnel
Engine cooling
Fire control pursuit course calculations
Flight trajectory calculations
Fuel cell pressure analysis
Guidance problems
Guided missile optimization studies
Heating studies
High-speed instrumentation
Landing gear design
Load, sheer and moment calculations
Nozzle design
Optical system design
Power plant performance calculations
Radar equipment design
Radar detection probabilities
Radar echo studies
Radio interference
Radome studies
Servomechanism calculations
Sound pressure analysis
Standard performance calculations
Wind tunnel balance computing

Chemical Engineering

Absorption analysis
Crude oil evaluation
Flash vaporization
Gas vapor cycle performance coefficient
Liquid-vapor equilibrium calculations
Mass spectrometer analysis
Multi-source planer diffusion
Pilot diffusion cascade data analysis
Pipeline design, stress analysis
Refinery simulation, production analysis
Tankage studies

Mathematics

Algebraic equations - real and complex
Applied probability functions
Complex polynomials
Eigenvalues
Fourier analyses
Generation, tables of special functions
Linear programming
Matrix calculations
Minimize functions of two variables
Ordinary differential equations
Random number generation
Random walks
Simultaneous linear and non-linear equations
Simultaneous linear and non-linear differential equations
Transportation problems

Electrical Engineering
- Circuit design and minimization
- Circuit breaker design
- Motor and generator core losses
- Motor and generator - critical shaft speeds
- Power system - economic operations
- Power system - loading and losses
- Power sub-station studies
- Stability and transient studies
- Transformer de 'ign

Physics
- Atomic power studies
- Gamma ray attenuation
- Neutron absorption breakdown
- Nuclear calculations
- Upper atmosphere research
- X-ray crystal structure analysis

Statistics
- Analysis of variance
- Auto-correlation and power spectra
- Climatological statistical analysis
- Least squares curve fitting
- Multiple correlation and regression
- Multiple bivariate frequency distribution tables of weather elements
- Quality control
- Standard deviations and means

Miscellaneous
- Bridge and truss design
- Traffic control
- Cut and fill - road-building

Faculty

The range and variety of faculty participating in university computer and data-processing programs compares favorably to the range and variety of the programs themselves. Everyone from the novice to people with ten years of experience is participating, with the former predominating. Part-time instructors from industry and government have been used. Interest without regard to experience and competence seems the main requisite of the teacher in many instances. With the exception of some instruction in programming, courses designed for faculty training hardly exist.

There are several reasons for this unfortunate situation. First, the fields are so new and the need so great, that not enough experienced and competent people have developed to handle this need. Secondly, many people who could usually most adequately fill the need are being more highly paid for their services by industry or by the government. Thirdly, competent researchers ordinarily have better facilities and equipment for work, which, in many industries and government, is identical to what he would be doing at a university.

Equipment Facilities

Most of the equipment now present in computing centers in universities in the United States has been selected on the basis of a single criterion - the cutrate price - in spite of the fact that the selection committee would sometimes have preferred other equipments on the basis of technical and operational criteria. The effect of this on the quantity and quality of the research output cannot be measured. However, it is clear that the basis for selection of equipment ought to be the maximum benefit to the university community. It is difficult to see how any of the universities, now selling computing time to sponsored contracts (in order to pay the bill, to be sure) and having little time (usually the second shift) for legitimate academic research and instructional pursuits, will gain an outstanding reputation for solving university research problems with computational models. They will become known for providing bargains for service to sponsored (usually government) research. The main objection to this sort of thing is that the benefit to the university research staff derived from the activity is fortuitous and incidental rather than the planned, aggressive activity it ought to be and must be for maximum benefit to the proper university function.

Some universities, like Chicago and Michigan State, plan to build their own computing equipment. There seems to be little reason to attempt this now, even at the present prices of commercially available computers.

Section V

SUMMARY OF OBSERVATIONS AFFECTING A UNIVERSITY PROGRAM

The following is a set of random observations and a few predictions that have a bearing on the structure and aims of a university program covering topics of interest among the "new" fields. These considerations have been taken into account in developing the ideal programs in the next section and the recommended program for Stanford University in the last section.

1. The milieu of our generation requiring quantitative models for social, physical, business, and other phenomena will also characterize the last half of the twentieth century. The number and kinds of techniques for implementing these requirements will increase. Student and community demand for knowledge in these fields will increase.

2. Some of these fields will turn out to be disciplines in themselves. All of them will be useful tools providing techniques for solutions of new models in many fields of interest. Some of these will be transient - they will be replaced by more efficient or more exhaustive tools.

3. Like a library, or mathematics, where library science or mathematics are disciplines in themselves as well as providing service tools to other disciplines, future university courses of instruction and research will be provided in the unit devoted to the disciplines of interest and in units using these disciplines as tools.

4. The basic structure of the university entity selected to cover topics in computers, data processing, etc., will not be affected by the availability, price, size or whatever of digital computers.

5. Whereas, in the past, the university was looked to almost exclusively for the training of professional artists, scientists, and scholars and for basic exploratory research in almost all fields, especially in the fields of interest under discussion here - government, industry and business - will be engaged in these activities on an academic level matching the universities. Thus, the university is now and will be in competition with government, industry and business not only for faculty - but also for students and exploratory research itself.

6. A university will not be a distinguished center of computing or data-processing or whatever merely by having excellent equipment without having the university community use the equipment properly and efficiently as mechanical aids and mental aids.

7. Probably the most significant requirement in the administration of a program that must cope with this dynamic situation is a continual budgeted and scheduled creation and review of plans, policies, aims and ideals of the university entity devoted to these fields.

Section VI

AN IDEAL PROGRAM

One would like to have a standard against which to measure the extent to which an adopted program is successful. The following is a description of a hypothetical program without details. The success of a real program may thus be measured by how well this description of the hypothetical program applies as a description of the real program.

Policy

The organizational entity of the university dedicated to certain fields will always be operated under a clear, unambiguous, well-defined policy on such matters as the function of this entity, its relation to other entities within the university, the nature of the topics it will cover, academic objectives and the like. These policies will be subjected to periodic review and modification when deemed necessary. Practices and procedures will at all times reflect the current announced policies. All members of the organizational unit will consider it important that policies be announced and implemented.

Among other things, the policy will reflect an appreciation of the important fact that today, unlike the past, the university is no longer depended on exclusively for education and research, certainly not in the fields under consideration here. (Business, industry and the government are supporting their own programs of education and research.)

Organization

The organizational entity selected as the one best fitted for the university to cover the selected topics will be of a graduate level. It will be flexible to the extent that it can handle the changing role of the university and the changing nature of the subject matter and equipment. To the extent that some topics that it is covering are of interest to other organizational entities within the university or vice versa, a mechanism will be available to evaluate the advisability of replacing, exchanging or even duplicating fields of inquiry among organizational units. The mechanism for implementing such changes will also exist.

The administration of this entity will report as high as possible in the university structure - preferably to the president. The responsible administrators will be scholars first and foremost. Their professional field of interest will be in the fields of interest of the organizational entity. They will have an appreciation and respect for the problems, philosophy, ideals and scholars in fields other than those of their own interest. They will be enthusiastic, competent and experienced.

They will not be "promoters." The problems of budget, financing, equipment support and public relations, normally requiring the talents and time of a promoter type will indeed be assigned to professionals in this field. This activity will report to the administration, and will be observers in policy meetings. This will be a service activity - not an academic one.

None of the academic administrators will be required to show a profit on his activity. All activities with an objective of making money will be organized under the service activities associated with, but not an essential part of, the academic unit. (This is especially true for the computer service center.)

Facilities, equipment, and personnel associated with the organizational unit will be adequate for the needs of the unit in implementing the policies and objectives of the administration.

Curriculum

The curriculum will contain courses, seminars, lectures, etc., that constitute an integrated program for students pursuing an advanced degree. (What constitutes an integrated program will be determined as part of policy.) Special courses, or seminars, or symposia may be given as the need arises. Content of the curriculum will be expanded, deleted, modified in accordance with periodic, scheduled evaluations of curriculum content by appropriate personnel. An activity devoted exclusively to what other universities and industry and government are doing will make appropriate information available to the curriculum evaluators.

The curriculum will also reflect the needs of other departments and schools within the university.

Each course, lecture, symposium will be conducted by faculty that is competent to teach the course, give the lecture or conduct the symposium. They (the faculty) will be interested, enthusiastic and competent, and preferably experienced. They will be paid a salary commensurate with their experience and ability on a scale more in keeping with present industrial scales than the present university scales.

A faculty member will not be assigned to instruct because his teaching schedule isn't full or because he is a competent researcher and "ought" to teach, or because he is enthusiastic though inexperienced in the field or for other similarly artificial reasons.

Students will come from government, industry, and undergraduate schools. These people will be interested in later applying knowledge gained to industrial or business pursuits; others will wish to be trained as a basis for becoming researchers and scholars in selected fields. How many of these aspirants attend the university will be a measure of appeal, if not the distinctiveness, achieved by the university in these fields.

Research and Related Activities

Research by graduate students or faculty is of course not a plannable affair. One would expect to see research activity on selected topics of interest and within the capabilities of the university unit.

But there are related activities that may be arbitrarily categorized as research having to do with (a) the development of new disciplines, (b) the incorporation of information developed by research into the curriculum. Thus, since a well established discipline usually has - (1) a well established terminology; a glossary exists, (2) been axiomatized, (3) text books, treatises, handbooks, journals, organizations - one should expect to see the research (as well as the instruction) faculty engaged in establishing terminology, axiomatizing a field, writing or editing books, journals, etc., and even helping to organize professional societies.

Like the instruction faculty, the research faculty will be dedicated, enthusiastic and competent. Their facilities and support will be adequate. The research faculty will be paid on the basis of experience and competence on a scale roughly matching that of industry.

The distinguished university center of (data processing, or computers, or statistics, or applied mathematics, or whatever) will have an organizational entity devoted to it, where faculty and graduate students are researching phases of their interest, the disciplines are being developed and new instructional material is being organized and incorporated into the curriculum as research results become available.

Computing - Equipment - Services - Functions

The computing equipment will be of adequate quantity and quality to implement the needs of the researchers and teachers within the organizational unit and the users from other units in the university. Most users will know how to use the equipment optimally as both mechanical and mental aids. Instruction for all faculty in equipment use and model making will always be available. The equipment will be convenient geographically. It will always be recognized that the research output of the university as a whole can be affected favorably not solely because equipment is available - but because it is utilized properly.

It will also be recognized that the current arrangements and organization are designed around making one or two large expensive equipments available and that this organization for service will change as computers get cheaper, perhaps smaller, and the university may reasonably be in possession of several computers scattered over its departments.

The equipment administrators will not be responsible for showing a profit.

Financing

The organizational unit will be adequately financed by endowments, gifts, tuition and other fees, fellowships, scholarships, grants and research contracts from government, industry, business, alumni, the student body, foundations, etc., in accordance with an unambiguous budget policy that tries to cover at least five years. The budget policy will of course be integrated with the policies on curriculum, research, faculty, student body, equipment, facilities, etc.

Section VII

RECOMMENDATIONS TO STANFORD UNIVERSITY

A new graduate school called the Graduate School of Computer Science should be formally created by September 1958. A policy committee including the dean, his academic and service department heads should be appointed as soon as practicable with their primary function to set and implement policy and budget on the function of the school, the topics it will cover in an integrated program of instruction and research, its relation to other schools and departments of the university and other pertinent points, including financing. A five-year plan should be available by September 1958 and the school should begin its formal existence then too.

The dean of the school should report to the president. The declared policy of the school concerning its fields of interest should be that it is interested in instruction and extension of knowledge in all fields that provide quantitative models or provide techniques for solutions of problems in quantitative models for phenomenon of interest to the scholar. The theoretical and experimental fields enumerated earlier in this report are examples of these fields.

Since it is recognized that some of these fields are disciplines in themselves as well as tools for use by other fields, the business school, industrial engineering, electrical engineering, mathematics, physics, psychology, etc., should be encouraged, when they find it desirable, to give courses and even do research in fields normally covered by the new graduate school. But, as indicated above, it is the responsibility of the new school to program an integrated activity for the University.

The declared and announced policy of the school should be that its function is fourfold: 1) TO TRAIN PROFESSIONAL SCIENTISTS, 2) TO TRAIN SCHOLARS, 3) TO DO EXPLORATORY RESEARCH, 4) TO DEVELOP THE NEW DISCIPLINES.

These are some policies recommended for adoption. It cannot be emphasized too strongly, though, that the significant recommendation here is not so much in the detailed recommendations enumerated above but in the RECOMMENDATIONS FOR DELIBERATE NON-OPPORTUNISTIC POLICY MAKING AND POLICY REVIEW ON THESE MATTERS.

Departmental Structure

The departmental structure of a new school must of necessity be arbitrary. One structure for consideration would consist of four departments as follows:

Department 1 - Computer Department

This department would include groups concerned with equipment and service, faculty instruction in programming and computational models, model making, automatic programming, logic, computer organization, computer mathematics, computational models, computer theory, component and circuit research (hardware) if not covered in other departments, systems research (hardware) if not covered in other departments, etc.

Instruction and research in these fields will fall in this department. The computer equipment used in a service bureau or for instruction or research will be under the cognizance of the computer department head.

The 650 presently on campus is probably adequate now.

It is not recommended that the university try to build its own computer equipment.

Computation Center

The purpose of the "computation and data processing center" is to provide the tool for solutions of problems that have been cast into computational models by members of the university community.

The head of this center, who should be a scholar primarily, is charged with the responsibility of organizing to maximize the efficiency of this operation. This will involve educating the general faculty, providing programming and operating assistance, and research and development of automatic programming and handling techniques, as well as assistance in the creation of computational models. By whatever means the equipment and facilities and personnel are financed, the head of the computing center should not be obligated to show an operating profit. For if the latter is a prerequisite, that individual should by all means, go into business for himself. Functionally the computer center should be organized into groups individually responsible for (1) faculty education, (2) programming, coding, operation assistance, (3) model construction assistance, (4) research in automatic coding, handling, etc., besides (5) a planning, scheduling and monitoring activity.

The future demand for the product/s and services made available by a computing center depend, of course, on the willingness and ability of the research faculty at the university to use them properly as well as the utility and applicability of computational models in their work. It is true now that there is hardly a field in the physical, mathematical, biological or social sciences that has not used computational models for research purposes. It is abundantly clear that future researchers in these fields will be using computational models more and more. In fact, say the present dreamers, there will be an electronic digital computer on every researcher's desk. Until this dream comes true, a computing center will fill an important need on the university campus. As a matter of fact, it may be said that to the extent that a researcher does not use such facilities when they are aplicable and potentially, useful, to this extent this researcher is not doing a competent job.

Department 2 - Operations Research

This department will cover instructional and research activities in operations research, linear programming, dynamic programming, game theory, queueing theory, decision theory.

Department 3 - Information - Communication

This department will cover instruction and research activities in information theory, switching theory, coding theory, automata theory, artificial intelligence, learning, language translation, theory of simulation.

Department 4 - Systems

This department will cover instruction and research activities in management science, econometrics, psychometrics, systems theory, information classification, indexing and retrieval, model theory.

Consideration should be given to incorporating the present Statistics Laboratory as a Department in the Graduate School.

Faculty

One of the reasons for recommending an independent entity like a graduate school, rather than a department in an already existing school or an interdepartmental committee, is to allow a freedom of choice in policy that can respond to the practicalities of the situation faced by the university today without the constraints imposed by an existing structure designed to cope with situations which no longer exist. Thus, the department heads, if not others, may command on the order of $15,000 per year for their services in today's competitive market. If this is indeed so, then the school should plan to put itself in a position to obtain these people and pay such prices.

Financing and Student Body

Specific recommendations for sources of funds are not made here. But the strong conviction exists that the present and probably growing demand for this kind of activity by business, industry and the government is so great, that students and money should be knocking on the door if such a program were available.

Stanford University - A Distinguished Center of Learning

I believe that these recommendations include the essential ingredients for making Stanford University a distinguished center of learning in those fields that it selects for concentration.

Appendix A

PARTIAL LIST OF PERSONS INTERVIEWED

Name	Affiliation	
G. Lieberman	Industrial Engineering Dept.	Stanford University
A. Perlis	Head, Computation Center	Carnegie Institute of Technology
J. Carr	Dept. of Mathematics	University of Michigan
A. Kranzley	Business Administration	Drexel Institute of Technology
P. Brock	Director of Computer Center	Purdue University
M. Mengel	Vice President, Product Planning	Burroughs Corporation
G. Brown	Director, Western Computing Center	UCLA
E. Calhoun	Data Processing Consultant	Stanford Research Institute
J. Busby	Instructor, Business Administration	Temple University
A. Matheson	Dean, Business Administration	Drexel Institute of Technology
A. Hutchinson	Dept. of Engineering Mathematics	University of Colorado
A. Bowker	Assistant Provost	Stanford University
G. Ireson	Industrial Engineering	Stanford University
A. Petersen	Electrical Engineering	Stanford University
O. Nielsen	Business School	Stanford University
J. Pettit	Electrical Engineering	Stanford University
R. Oakford	Industrial Engineering	Stanford University
J. Herriott	Mathematics Dept.	Stanford University
R. Berkowitz	Electrical Engineering	University of Pennsylvania
J. Kravor	Business Administration	Drexel Institute of Technology
J. Brant	Education Dept.	IBM
F. Heart	Electrical Engineering	Northeastern University, MIT
J. Kappel	Graduate Student	Drexel Institute of Technology
W. Leubbert	Captain	U. S. Signal Corps
R. Gildea	Mathematician	RCA Laboratories
T. Keenan	Mathematics Dept.	University of Rochester
E. Stewart		U. S. Naval Postgraduate School
C. Perry	Engineering Division	Stanford Research Institute
M. Aitel	Systems Division	RCA, Moorestown, New Jersey

Appendix B

BIBLIOGRAPHY

1. The Language of Taxonomy - John R. Gregg, Columbia University Press, 1954

2. Report on "A Survey of Training and Research in Applied Mathematics in the United States" - F. J. Weyl. Published by SIAM, 1956

3. Proceedings of First Conference on Training Personnel for the Computing Machine Field, edited by A. W. Jacobson, Wayne University Press, 1955

4. Book Review - Nov., 1956, AMS Bulletin

5. The Computer's Challenge to Education - Clarence R. Hilberry, Wayne State University, Detroit, Michigan

6. "Computers and Automation," A Survey of Office Automation in Europe and Asia - E. S. Calhoun, Stanford Research Institute

7. Thesis (not yet published) - Drexel Institute of Technology, J. Kappel

8. The Aims of Education, Alfred North Whitehead, MacMillan Co., 1949

9. The Technique of Theory Construction - J. H. Woodger, Foundations of the Unity of Science, Volume II, Number 5

10. An Outline of General System Theory - Ludwig von Beetalanffy, British Jnl. Philo. Sci. 1:134-165

11. Computers Challenge Engineering Education - F. C. Lindvall, Proceedings of Western Joint Computer Conference held March 1-3, 1955. pp 41-43

12. The Higher Learning in America - Thorstein Veblen, Sagamore Press, 1957

13. Education - W. O. Smith, Pelican Books A380, 1957

14. Confluence - Volume 6, No. 2, Summer, 1957

15. Research Center in an Institute of Technology - James E. Boyd, IRE Trans. on Engineering Management - Volume EM-4, No., 3, Sept. 1957, pp. 99-100

16. Education for Operations Research - Leroy A. Brothers, Operations Research, Vol. 4, No. 4, August, 1956. pp. 415-421

17. Data Link, Dec. 1956 - A Predicted Need for 2,000,000 Programmers in Ten Years

18. A Compilation of Theses Written at MIT in the Computer and Data-Processing Field, 1953-1956 inclusive.