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ABSTRACT

Reported are the results of a pilot study which attempted to determine general patterns of common course content for scientists and engineers, and what specific course content would be of most value to them. Questionnaires were mailed to biologists, chemists, physicists, and engineers in nine states. Over two hundred of these respondents were personally interviewed. An item analysis was made for each course in each specialization. Some of the significant trends noted in the study include: (1) identical course recommendations for different specializations might involve entirely different content and emphasis, (2) related specializations did not always recommend the same topics, (3) mathematicians were generally less selective than scientists and engineers in judging the importance of topics, (4) predictions were made for increased use of computers and applied statistics, and (5) most respondents wanted courses to integrate theory and applications. (RS)

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# AN ANALYSIS OF SPECIFIC MATHEMATICS COURSE CONTENT FOR SCIENTISTS AND ENGINEERS

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Edinboro State College
Edinboro, Pennsylvania 16412

November 1970

U. S. DEPARTMENT OF
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The research reported herein was performed pursuant to a grant with the Office of Education, U. S. Department of Health, Education, and Welfare. Contractors undertaking such projects under Government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official Office of Education position or policy.

U. S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

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## SUMMARY

### I. The Need for the Study

After completion of Phase I of the National Study of Mathematics Requirements for Scientists and Engineers (NSMRSE), in which course recommendations for 44 specializations were reported, the need for more definite course content became apparent. With the increased use of mathematics and the recommendations for additional courses in humanities and liberal arts, the amount of information for a specialist to learn has increased. Since all topics in mathematics are not useful for all specialists, it is necessary to determine which of the topics in the mathematics courses are of the most value and which could be omitted without any great loss. With this data, revisions can be made in the curricula for scientists and engineers so that they can have sufficient time to take all the necessary mathematics courses.

### II. Objectives

A. To determine general patterns of common course content for biologists, chemists, engineers, and physicists.

B. To determine the specific mathematics course content in major specializations which would be the most valuable for scientists and engineers in their research and/or professional responsibilities.

C. To determine the most desirable balance between applications and theory for each course in each specialization and among specializations, including alternate ways of relating theory and modern applications.

D. To determine any new trends in the use of specific mathematics courses or topics in each specialization and among specializations.

E. To obtain detailed data on mathematics content so that it can be used as a foundation for the revision of curricula in the training of scientists and engineers from the technician to the research specialist.

### III. Procedures

When Phase I of the National Study of Mathematics Requirements for Scientists and Engineers (NSMRSE) was completed, basic mathematics course requirements for 44 different specializations were listed in the final report. Since course recommendations do not indicate specific course content for each course, it became necessary to initiate a study in which detailed course content for each specialization would be considered.

Prior to the implementing of this study, a proposal was prepared and presented to the Office of Education. After funding was approved, the following format was initiated.

Mathematical consultants developed detailed course content sheets for the 33 most common mathematics courses indicated by respondents in the 44 different specializations from Phase I of the NSMRSE. The Board of Advisors was revised to include representation from more professional organizations which had an interest in the educational aspects.

These courses were sent to the Board of Advisors to obtain their reactions and suggestions for improvement. Visits to General Electric, IBM, DuPont, Westinghouse, and U. S. Steel were made and discussions were held with a number of their mathematicians, scientists, and engineers. Additional general considerations were discussed at two Board meetings in New York City and Washington, D. C. Revised materials were sent to local colleges, universities, and industry to obtain additional suggestions for improvements.

In order to keep the number of courses to a minimum and yet obtain satisfactory information, the decision was made to use only those courses which had a rating over 40 percent from Phase I recommendations.

After all the improvements were incorporated in the detailed course content sheets, an initial letter and instruction sheet were drafted and sent to the advisors for suggestions. The final revision was then completed after all suggested improvements had been received. Refer to Appendix C for sample forms.

During the middle of October 1969, the revised materials were sent to 318 respondents from Phase I of the study. Only those respondents from Pennsylvania, Ohio, Massachusetts, New York, Virginia, Connecticut, Maryland, Delaware, and the District of Columbia were selected due to the restriction on the wide area telephone coverage for use in interviews. Based on the recommendations of the Board of Advisors and other consultants, the specializations selected for the study were botany-zoology; genetics; microbiology; pharmacology; biochemistry; organic chemistry; physical chemistry; elementary particle physics; nuclear physics; chemical, electrical, mechanical, and metallurgical engineering. The materials were sent to 90 biologists, 89 chemists, 58 physicists, and 81 engineers. Telephone calls and returned letters established the fact that 45 could not be located, 3 were deceased, and 3 were from specializations other than those being considered. Twelve cases were left for experimental purposes in determining the value of telephoning versus follow-up letters. Of those who did not receive the follow-up telephone calls, 5 out of 12 returned their forms for a 37 percent return. After the follow-up letters and telephone calls, 92 percent of those respondents who were located sent in their forms. Thus, the definite advantage of telephone calls in increasing the percentage response seems to be clearly established.

Of those responding by sending in their forms, biologists sent in 99 percent; chemists, 93 percent; physicists, 85 percent; and engineers, 87 percent. The fact that such a high return was sent shows that these highly qualified scientists and engineers are very interested in presenting their recommendations on mathematics requirements for their specialization. This high degree of interest clearly indicates the value of the study to those who are actively involved in science and engineering.

After most of the forms had been received, the interviewing began. The first four questions of the interview dealt with information involving suggested improvements in the detailed course content and instruction sheets. The fifth was concerned with what mathematics topics would be most useful in the future. The sixth question involved potential trends in the particular specialization in the future, and the seventh question dealt with the proper balance between theory and practice for each specialization.

Over 200 respondents were interviewed. Almost all were exceptionally cooperative and only 7 did not want to be interviewed due to their extremely busy schedule at that time.

After the data arrived, the information was transferred to data processing cards and was then analyzed. An item analysis was made for each course for each specialization. Ratings of topics were compared among specializations and among areas in biology, chemistry, physics, and engineering.

IV. Analysis and Conclusions

Analysis of the detailed course content sheets showed a number of very significant trends. Due to the large variability in responses of this type, a greater number of respondents is necessary to determine more valid data. Therefore, only general results of the pilot study will be reported. Results of greater validity based on the larger number of respondents will be reported in the complete study. With the complete study, the significant differences and similarities among the 44 specializations will be considered.

The most significant trends noted in the pilot study were the following:

(1) Identical course recommendations by scientists and engineers in different specializations may involve courses with entirely different emphases. For instance, the first-year calculus sequence topic recommendations are much lower for biologists, biochemists, and organic chemists than those recommended by physicists and engineers who wanted almost all topics covered. The data from the study presents significant possibilities for course revisions; however, a much larger sample is necessary to counterbalance the variability of the respondents.

(2) There were a number of significant differences in topic recommendations in certain courses among specializations that were closely related.

(3) Many more similarities than dissimilarities in topic recommendations were noted among the specializations in all related areas of biology, chemistry, engineering, and physics. Also, there were a large number of similarities in course content in interdisciplinary specializations.

(4) There was a tendency for mathematicians, both pure and applied, to rate all topics in mathematics as either important or moderately valuable. Scientists and engineers were much more selective. This shows a definite distinction between the mathematical viewpoints of mathematicians and those of scientists and engineers.

The analysis of the previous studies and Phase I of the NSMRSE study shows that the NSMRSE study was the only research which was directly concerned with the mathematics course requirements for the major specializations, with the exception of the geology study (38). In addition, the present pilot study is obtaining data on detailed mathematical content in 12 different specializations in the areas of biology, chemistry, physics, and engineering. The highly significant rate of return of the detailed course content sheets from the selected scientists and engineers shows the wide acceptance of the need for this type of study. This excellent support from these active research specialists indicates that this type of study needs to be considered for all the major specializations so that the benefits of the information can be used in making necessary changes in curricula. Thus the proposed study, which would utilize the materials and experiences of the pilot study, would make an outstanding contribution to scientists and engineers in curricular changes from the technician to the research specialist.

I. The Study

A. The Need for the Study

In the last decade there has been what has been described as a "knowledge explosion" in the areas of science, engineering, and mathematics. Vast amounts of research data have been published in the professional journals and industrial reports. The number of different mathematics courses which are taught in the mathematics departments of colleges and universitites has more than doubled due to the addition of the new mathematics courses. In the larger universities one can select from well over 100 distinct mathematics courses. The major increase in the number of distinct courses is due to such new disciplines in mathematics as group theory, field theory, functional analysis, point set topology, algebraic topology, and their specialized topics which generate additional graduate courses. Due to the time limitations on the Ph.D. candidate and on those individuals who wish to improve their mathematical backgrounds, it is obvious that there is insufficient time to take all the courses which might be of some value.

Some answers to the question of what mathematics courses are best for a definite specialization have been provided with the completion of Phase I of the National Study of Mathematics Requirements for Scientists and Engineers (NSMRSE), which was funded by the Office of Education. In this study the basic mathematics requirements were reported for 44 different specializations. (For more details on this study, refer to the resume on page 8 and to the Final Report, which is listed in the Bibliography.) In addition, reports concerning the appropriate specializations appeared in professional publications such as Science, BioScience, Federation Proceedings, Journal of Engineering Education, Journal of Medical Education, and Nuclear News (refer to Appendix A - 20 to 36).

Although this data provided course recommendations which are valuable for scientists and engineers in their different specializations, it did not delineate the specific mathematics course content for each specialization. Some topics were listed for each course on the Course Content and Instruction Sheet in the study for the purpose of making certain that all the respondents referred to the same courses. However, this list of topics was for course identification purposes only; no consideration was given to detailed course content in Phase I.

Due to the increased use of mathematics, as well as the addition of new courses in mathematics, it is vital to establish the relative values of the topics in each course which are useful for each specialization and for more than one specialization. With this data it can be determined whether the present topics and courses should remain the same or be altered by adding or deleting the requisite material. What is needed now for curriculum planning and mathematics course development is a detailed analysis of the basic mathematics course content by specific topics. This data will assure that all the necessary mathematics can be considered for inclusion in appropriate courses for each specialization. Also, it is necessary to determine what content for mathematics courses is useful for a large number of specializations so that courses can be devised for technicians as well as research specialists. In addition to the increased use of mathematics, there have been a number of recommendations to add more humanities and liberal arts to the already crowded curriculum of scientists and engineers. These considerations place an even greater stress on the need for establishing suitable mathematics requirements and making certain that only the more useful mathematics is taught to those in their respective fields of interest.

The detailed analysis based on the considered opinions of a large number of qualified specialists provides the best means of identifying the important topics, applications, and theories for the specializations. While opinions of mathematicians are of value, it would appear that the active research scientist or engineer is best qualified to judge the topics in mathematics which are useful in solving his problems. The ideal method for curriculum planning is to obtain basic recommendations for course content in mathematics from a large number of specialists, and then have the scientists and engineers discuss ways of implementing these recommendations with mathematicians.

This study is designed to show the relative value of specific topics so that a better selection can be made for both the specialist and the mathematician preparing to instruct these courses. The selection of the most appropriate topics will provide him with the topics which he is more likely to use in the future rather than with a random assortment of topics taught in a course without any particular specifications.

Results of a study of this nature are relative. However, they will provide a much more reliable guide to valuable course content in mathematics than is available to specialists and mathematicians at the present time.

In order to prepare for mathematics which will be useful in the future and to prevent backgrounds in mathematics from becoming obsolete, it is necessary to ask active research specialists in science and engineering what trends they forsee in mathematics in the future. The problem of obsolescense in mathematics may not be too extensive since many active research specialists learn the mathematics on their own that they need in order to aid them in the solution of their problems or obtain the assistance of their colleagues. This potential observation was noted in the age group comparisons (5-year intervals) in Phase I of the NSMRSE. Only minor differences were observed in the six age groups between 35 and 65 in course recommendations. However, in some cases those in the lower age groups (the 30-to-34 and the under-30 age groups) recommended less mathematics. Therefore, it appears that it takes experience in the profession or in industry to develop some ideas on what is most useful in mathematics. However, checking with these research specialists for future mathematics courses will make it easier to anticipate what mathematics will be of potential value for the next few years.

A number of officials of the major professional organizations have been aware of the need for more information on mathematical content for their members in biology, chemistry, earth sciences, engineering, and physics. Some of these organizations are the American Association of Physics Teachers, American Geological Institute, American Institute of Biological Sciences, American Institute of Physics, American Society for Engineering Education, Federation of American Societies for Experimental Biology, and the Institute of Electrical and Electronics Engineers. They have provided much guidance and assistance to the NSMRSE in obtaining these goals (refer to Appendix B).

The development of curricula which involve new courses and materials in mathematics for specializations should be preceded by an analysis of detailed mathematical course content to be of maximum effectiveness since all curricular revision should be based on a foundation of what is most valuable and necessary for each specialization. Thus, Phase II of the NSMRSE will be primarily concerned with determining these relevant topics in mathematics for each specialization and among specializations. This information will provide the proper foundation of data for Phase III, the curricular revision phase, in which all appropriate problems involving curricular changes will be considered. A few examples of the types of problems which could be investigated are:

1. What courses already provide an excellent background in mathematics?

2. What new courses need to be developed?

3. What new techniques for teaching new and standard mathematical topics can be developed to improve the instruction of these topics?

4. How can retention of mathematics topics be improved?

Thus, Phase II (detailed course content stage) is a necessary prerequisite for Phase III.

The basic goal of Phase II of the study is to determine where similarities exist in topic agreement among specializations so that the appropriate course content can become part of a designated course. In cases of dissimilarity, widely divergent views would show that little could be done to prepare separate courses which would satisfy all specialists. Both types of information are of value in curriculum development. However, the primary goal of Phase II is to obtain data on detailed course content so that uniform courses which will be valuable for many specializations can be constructed in Phase III from the standard courses instructed at colleges and universities. Also, this data should be able to avoid a proliferation of courses by unifying the basic needs of scientists and engineers in a minimal number of suitable courses.

## B. Objectives of the Study

1. To determine general patterns of common course content for biologists, chemists, engineers, and physicists.
2. To determine the specific mathematics course content in major specializations which would be the most valuable for scientists and engineers in their research and/or professional responsibilities.
3. To determine the most desirable balance between applications and theory for each course in each specialization and among specializations, including alternate ways of relating theory and modern applications.
4. To determine any new trends in the use of specific mathematics courses or topics in each specialization and among specializations.
5. To obtain detailed data on mathematics content so that it can be used as a foundation for the revision of curricula in the training of scientists and engineers from the technician to the research specialist.

## C. Review of Related Research

### 1. Previous Studies

Since there has been much material published on studies which concern the curriculum of the basic sciences and engineering, only a brief resume of these studies can be indicated. All references will be in parentheses and will refer to Appendix A.

Until the past few years, the biological sciences have had the least amount of research in curriculum revision. The Biological, Management, and Social Sciences (BMSS) panel of the Committee on Undergraduate Programs in Mathematics (CUPM) of the Mathematical Association of America (8) conducted a study on the type of mathematics course work taken by students in zoology. It was not until 1964 that the Commission on Undergraduate Education in the Biological Sciences (CUEBS) (9) was formed to investigate the problem of how to improve the teaching of biology. The Commission has eleven panels assigned to assist in the analysis of many important problems in biology, such as junior college instruction and course content revision. The basic aims of the Commission are to close the gap between new research and teaching, to set minimum standards for faculties and facilities, and to integrate biology with other disciplines where new areas have been or are being developed. A number of articles and texts have been published on the biology program. These studies, however, have not been concerned with mathematics requirements in different specializations.

The chemists involved in the Bucknell Study (40) and those in the Advisory Council on College Chemistry (2) have conducted research on the curriculum in chemistry. In most cases these studies have been concerned with the problems of the general chemist or with the present curriculum for chemists. The Bucknell Study panel has recommended that there be a new emphasis on research and research techniques in the frontiers of chemistry, that inorganic and analytical chemistry be given more emphasis, and that students engage in more independent research on the undergraduate level. The BMSS panel (8) was responsible for an analysis of the mathematics requirements of a number of institutions. They reported the percent of institutions requiring specific mathematics courses for biochemistry majors. The Advisory Council and the Committee on the Undergraduate Program in Mathematics have recently published the results of their study on recommendations from a number of chemists entitled "The Undergraduate Mathematics Program of Students in Chemistry" (1). This study considers the basic mathematics program for chemists and provides a number of advanced topics for those who plan to pursue graduate work.

A number of conferences have been held in the area of physics, such as the First and Second Ann Arbor Conferences (7,11), the Princeton Conference (14), and the Denver Conference (12). These conferences studied the general problems of the physicist with mathematics course content as a minor consideration. However, specific course requirements for physics majors and suggested courses for graduate students in physics were recommended by the panel of Physical Sciences and Engineering of the CUPM with the close collaboration of the Commission on Physics (10). The mathematics course recommendations of the Commission were as follows: a. For all students - beginning analysis, linear algebra, functions of several variables, differential equations; b. For those going on to graduate school - probability and statistics, complex variables, algebraic structures, and partial differential equations. The latest publication dealing with graduate programs for physics has been printed by the American Institute of Physics, entitled "Graduate Programs in Physics and Astronomy" (4). This text lists all the graduate schools and the basic mathematics requirements for one wishing to enter these graduate programs.

Engineers have done the most research on curriculum revision. A few articles have been published concerning the programs for curriculum in chemical engineering and industrial engineering in which mathematics course requirements have been considered (18, 39). The American Society for Engineering Education (ASEE) devoted several articles to the need for a course in computers for engineers (15). As mentioned above, the CUPM Committee on Physical Sciences and Engineering gave recommendations for course work for: (a) all students, (b) research and development students, and (c) students who plan to pursue graduate work. The mathematics course requirements were essentially the same as for the physicists. An interesting report by the Feedback Committee of the Engineering College Administrative Council in coordination with the Relations with Industry Division of the ASEE (13) gave the choice of courses of over 7,000 people in industry. These courses are listed by preference with a breakdown by type of engineer.

The most extensive study of engineers has been that which was done by the Goals of Engineering Committee in conjunction with the ASEE. The Committee was organized in 1962 by the Executive Board of the General Council of ASEE under the direction of the Projects Operating Unit of the Society (5). It has carried out an extensive amount of research on engineering curriculum and has sent a questionnaire containing 72 questions to a large number of engineers asking very important questions covering many aspects of engineering, including course recommendations in mathematics for engineers. Although some modern branches of mathematics were considered, not all courses were included in the study. The important question of applied-theoretical emphasis was only indirectly covered. The results of the study have been analyzed and some of the basic recommendations are: Change from the four-year college degree to the five-year M. S. college degree in engineering, improve the liberal arts background of engineers, cooperate with industry, and increase emphasis on research. The final report has been published in the ASEE Journal of January 1968 (5).

The general requirements for earth scientists were recently reported by Reeves and Delo in a publication by the Council on Education in the Geological Sciences, which was sponsored by the American Geological Institute. The survey, containing a list of 290 topics, was sent to 2000 earth scientists. They checked whether the knowledge of the item was valuable in their work, whether they were competent in the topic, and whether it could be used in the future. Analysis by rank was reported for 15 specializations within earth sciences. The analysis of 23 mathematical skills were considered for the 15 specializations and ranked from 1 to 23 in order of preference.

2. The NSMRSE Study - Phase I (Course Recommendations)

The first step in the National Study of Mathematics Requirements for Scientists and Engineers was to obtain a Board of Advisors (see Appendix B). They were selected from nationally-known scientists and engineers who represented the universities, industry, government, and non-profit organizations. These individuals serve in an advisory capacity. Assistance was obtained through individual meetings, telephone conversations, and correspondence.

The major problem of selecting the best participants for the study was discussed in detail with the members of the Board and the mathematical consultants. The decision was made to select those who had received national recognition or were large contributors to the professional journals. Approximately 10,000 scientists and engineers were selected for the study and placed in two categories: (1) The Awards Group - those who were recipients of national honors or awards or were recommended by the members of the Board; and (2) The Abstracts Group - those who were exceptionally productive in their research, based on the number of journal articles listed from 1961 to 1966 in Biological Abstracts, Chemical Abstracts, Engineering Index, Physics Abstracts, and Scientific and Technological Aerospace Reports.

The NSMRSE Course Recommendation Form and the Instruction and Course Content Sheet were constructed with the aid of the Board of Advisors and the mathematical consultants. Forty courses were selected by the mathematical consultants for the study. In order to make sure that the basic content of the mathematics courses was the same for all respondents, a brief resume of each of the 40 courses was given.

The NSMRSE Course Recommendation Form consisted of 7 sections - a list of 38 specializations, orientation of work, highest degree obtained, type of employment, administrative or non-administrative capacity, age group, and the 40 courses. The courses were to be marked according to five categories - course length, applied-theoretical orientation, course level, knowledge, and use of course content in work.

The first letters were sent out during the latter part of February 1967, and follow-up letters were sent until October 1967. Each individual was sent a letter stating the importance of the study, the NSMRSE Course Recommendation Form, and an Instruction and Course Content Sheet. The respondent was asked to complete the 7 sections on the NSMRSE Form in accordance with the directions on the Instruction and Course Content Sheet. He was asked to recommend courses for the Ph.D. in his specialization only.

Approximately 78% of the scientists and engineers selected for the study responded. The analysis showed that 61% completed the form, 15% disqualified themselves due to inactivity, retirement, foreign background or lack of mathematical background; 1% indicated that they were too busy to send back the forms in complete detail; and 1% sent back the forms without completing them. The Course Recommendation Forms were completed for individuals in the major specializations of physics, chemistry, biology, and engineering, as well as in astronomy, the earth sciences, and the medical sciences. A total of 44 different specializations were considered. The data was analyzed and reported in quintiles for each specialization. (22)

Some of the general conclusions of the study for most specializations are as follows: (a) Mathematics courses should place a fifty percent emphasis on theory and fifty percent emphasis on applications; (b) With the exception of group theory, there was little need for courses such as functional analysis, modern algebra, and mathematical logic; (c) Most of the high recommendations for an emphasis on applications were for courses such as vectors, the many types of differential equations, applied statistics, and machine computation; (d) Comparisons of categories such as age group and place of employment within each specialization showed little differences in recommendations for most specializations.

These results on course recommendations in mathematics for all specializations are now available in the Final Report to the Office of Education (27). In addition, the analysis of the results have been published by many of the major professional journals such as Science (20), BioScience (21), Federation Proceedings (23), Journal of Engineering Education (28), Journal of Medical Education (3), and Nuclear News (32). (Refer to Appendix A.)

## II. Procedure

### A. Preparation of the Materials

Mathematical consultants were selected who had a great deal of experience and interest in working on mathematical problems of scientists and engineers. The consultants constructed the detailed Course Content Sheets and Instruction Sheet or checked the materials to make suggestions for improvements. The forms were sent to local scientists and engineers at Edinboro State College, Gannon College, and Behrend Campus of the Pennsylvania State University for completion in their area of specialization. After the forms were filled out, the faculty members were interviewed to eliminate deficiencies. The tentative forms were considered at visits to industry at Westinghouse Electric Company, General Electric Company, DuPont Chemical Company, IBM Corporation, and U. S. Steel Corporation to obtain suggestions for improvements. Some of the final improvements were made at the board meetings in New York and Washington when extensive discussions were held to determine the best procedures to use in sending out the forms and the best format for the detailed Course Content Sheets and Instruction Sheet. The final forms were sent to the Board of Advisors for additional suggestions. Their recommendations were considered along with those of the mathematical consultants and were incorporated in the final forms. Refer to Appendix C for some of the Course Content Sheets and the Instruction Sheet.

### B. The Sending of Materials

Those selected for the study were the respondents who participated in Phase I of the National Study of Mathematics Requirements for Scientists and Engineers. Recommendations for the selection of the respondents were considered by the Board of Advisors at the board meetings in New York and Washington and also by the educational consultants.

The size of the group was taken into consideration. The larger specializations were considered as one of the factors in the determination of the selection of the specializations. It was necessary to have a large enough group of participants since the Pilot Study was limited to the states of Pennsylvania, Maryland, New York, Massachusetts, Ohio, New Jersey, Virginia, West Virginia, and Washington, D. C. The restriction was due to the Watts line which was used for telephoning purposes.

Twelve specializations were selected in the areas of biology, chemistry, engineering, and physics. The respondents were sent an Instruction Sheet and detailed Course Recommendation forms for their specialization only. (Refer to Appendix C.) For example, biochemists were sent four forms and electrical engineers were sent twenty-three forms. The courses selected were those recommended by over 40% of those in the specific specialization, based on the data of Phase I of the NSMRSE. They were asked to give their viewpoints on the listed topics. Each topic for each course was to be checked for one of five categories: valuable, of moderate value, of little value, no opinion, not familiar with the topic. Important applications and theorems were included in the topics. In order to prevent obsolescence of the mathematical content, they were asked to indicate any new trends for the future.

Also, additional space was available to list topics that were omitted. Follow-up letters were sent to those who did not respond. If one follow-up letter did not obtain a response, the participants were telephoned to ascertain if they had any questions concerning the materials and to secure the data from them by means of a telephone interview. The value of the telephone in obtaining increased responses was very significant since an overall response of 92% was obtained.

C. Preparation of the Interviews and Interviewing

The initial telephone interview was used to determine whether or not a non-respondent could be located. For those who moved, an attempt was made to get their new address. Those who were located were asked if they had any questions on completing the form and were encouraged to send them in. Some of the respondents gave the information for the completion of the forms over the telephone. In order to avoid differences in interviewing techniques and obtain valuable feedback for the study, all interviewing was done by the director.

After the completed forms were received, a short interview was given to 1?% of the respondents. The basic interview items were constructed by the educational consultants in conjunction with the director. The board was asked to suggest items for interviewing. Since this was an initial pilot study, only seven basic questions were considered. These questions checked on the reaction of the respondents to the questionnaire in order to obtain additional improvements and to satisfy the objectives of the study. The questions are indicated in Section III-D where the analysis of the interviews is considered.

D. Symposia

In order to obtain additional viewpoints from scientists and engineers in other specializations, symposia were held to discuss specific mathematical content of the courses and their applied and theoretical emphasis. Arrangements were made with the American Institute of Biological Sciences (AIBS) and the American Society for Engineering Education (ASEE) to have symposia on different specializations. The symposium on mathematics for biologists was held at the annual meeting of the AIBS in September 1968 and dealt with the specializations of ecology, genetics, and zoology. The symposium on mathematics for engineers was held at the ASEE national convention in June 1969 and considered the specializations of electrical, metallurgical, and chemical engineering. In addition, a symposium for chemists and engineers was held at Case-Western University in March 1970 in which the specializations of inorganic, organic, and physical chemistry and chemical, electrical, and mechanical engineering were discussed. A series of yearly symposia on "Mathematics for Industry" was initiated in May 1970 at Edinboro State College. A number of scientists and engineers from the tri-state area contributed to the symposium. Basic details of the various symposia are given in Appendix D. The information on these symposia is scheduled to be published in the next few months. Almost all of the basic recommendations and viewpoints are already included in Phase I of the NSMRSE and the present report.

## III. Analysis and Conclusions

### A. Background of Respondents

Fourteen specializations were chosen for the study from the states of Pennsylvania, Ohio, Massachusetts, New York, Virginia, West Virginia, Maryland, Delaware, and the District of Columbia. These specializations were taken from the four major areas of Phase I: (1) Biology - anatomy, genetics, microbiology, pharmacology, and zoology; (2) Chemistry - biochemistry, organic chemistry, and physical chemistry; (3) Engineering - chemical, electrical, mechanical, and metallurgical engineering; (4) Physics - elementary particles and nuclear physics. The median age for those in biology was 45; in chemistry, 45; in engineering, 46; and in physics, 41. The overall median age for all specialists was 44. Most of the areas had specialists who indicated that they were a combination of applied and theoretical specialists. The areas having the highest theoretical interests were biology and physics with 39% and 44% respectively,

The academic and non-academic comparisons showed some variation. The chemists were composed of those in academic employment and industry. The biologists and physicists worked primarily in the university with a minor portion working in non-profit and government organizations. The engineers were employed mainly in the academic world and industry with a minor portion in government and non-profit organizations.

Responses were received from 78 biologists, 73 chemists, 63 engineers, and 47 physicists for a total of 261 respondents.

### B. The Findings

After the collection of the data, each course for each specialization was analyzed and reported in percentages for each topic. The deciles for the topic ratings of valuable and of moderate value were computed for each topic in each course since these ratings represented the important information. A sample of this data for 10 of the specializations is provided in Table R on page 12-A. The ratings of little value, no opinion, and not familiar with the topic were not considered. In order to simplify the data, the deciles of the recommendations for valuable ratings in all topics were averaged and the median decile reported for each course. These average deciles appear in Table I (page 12-B) and show the combined rating of all topics in a given course. This table is very useful for comparative purposes. In addition, intervariability of the specializations within each major group was checked, as well as the total variability among all specializations.

Since there was a wide variability in the responses of those within each specialization concerning a number of recommendations for the study, the data for the specializations, due to the smaller number of respondents, may not be sufficiently valid to verify the trends. In order to present more valid data, combined responses of the specializations for the major areas of biology, chemistry, engineering, and physics will be reported in the analysis unless the differences among specializations are highly significant.

### C. Course Analysis

#### 1. Biology

The detailed course content sheets which were sent to the following specializations in biology were:

TABLE R*

Raw Data on Deciles for Valuable and Moderately Valuable Ratings for Specific Topics for Certain Specializations for Course I - First-Year College Mathematics

| | 4** | 5 | 10 | 14 | 15 | 22 | 25 | 30 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|
| Basic set theory | 4-3+ | 3-1 | 1-1 | 1-3 | 3-2 | 0-3 | 2-4 | 6-2 | 1-3 | 2-0 |
| Basic logic | 3-2 | 3-1 | 1-2 | 0-2 | 3-2 | 0-1 | 1-3 | 6-2 | 1-2 | 1-3 |
| Functions and graphs | 8-0 | 8-1 | 5-1 | 7-2 | 8-0 | 8-0 | 9-0 | 9-0 | 9-0 | 9-0 |
| Basic operations-rational numbers | 7-2 | 7-1 | 4-1 | 7-1 | 8-0 | 8-0 | 9-0 | 9-0 | 8-0 | 8-1 |
| Basic operations-real numbers | 8-1 | 7-1 | 4-2 | 8-1 | 8-1 | 8-0 | 9-0 | 9-0 | 8-0 | 8-1 |
| Basic operations-complex numbers | 5-1 | 6-2 | 3-2 | 5-1 | 7-1 | 9-0 | 8-1 | 8-0 | 7-1 | 8-0 |
| Basic laws-exponents | 9-0 | 7-2 | 3-3 | 9-0 | 9-0 | 9-0 | 9-0 | 9-0 | 8-1 | 9-0 |
| Products and factoring | 9-0 | 7-2 | 3-3 | 8-1 | 9-0 | 9-0 | 9-0 | 9-0 | 8-0 | 7-2 |
| Solutions of quadratic equations | 9-0 | 5-1 | 2-2 | 6-1 | 9-0 | 9-0 | 8-1 | 9-0 | 9-0 | 8-1 |
| Solutions of polynomials | 5-4 | 5-1 | 0-3 | 4-3 | 7-2 | 7-1 | 6-2 | 8-0 | 7-0 | 8-1 |
| Systems of equations | 6-3 | 3-2 | 0-4 | 3-4 | 8-1 | 9-0 | 8-1 | 9-0 | 8-1 | 7-1 |
| Approximation of real roots | 5-1 | 4-1 | 2-1 | 4-3 | 9-1 | 5-2 | 5-3 | 8-2 | 6-1 | 6-2 |
| Graphing of polynomials | 3-4 | 5-1 | 2-3 | 5-2 | 6-2 | 6-3 | 7-1 | 4-1 | 7-1 | 9-0 |
| Determinants | 3-0 | 1-1 | 0-1 | 2-0 | 6-2 | 8-0 | 7-0 | 4-2 | 2-5 | 4-0 |
| Matrices through inverses | 4-1 | 1-1 | 0-2 | 2-1 | 7-2 | 9-0 | 9-0 | 5-4 | 4-4 | 5-1 |
| Permutations and combinations | 9-0 | 4-2 | 2-3 | 3-3 | 7-0 | 7-2 | 7-1 | 8-2 | 3-4 | 4-3 |
| Probability | 9-0 | 8-1 | 5-1 | 6-2 | [illegible]-1 | 8-1 | 7-1 | 9-0 | 6-2 | 7-1 |
| Mathematical expectation | 7-1 | 5-1 | 4-2 | 4-1 | 4-1 | 7-1 | 5-2 | 6-2 | 3-1 | 4-0 |
| Exponential equations | 6-2 | 6-2 | 1-4 | 6-2 | 6-1 | 8-0 | 7-2 | 7-2 | 6-1 | 8-0 |
| Basic trig. functions-triangles | 4-2 | 4-2 | 0-3 | 3-3 | 7-1 | 8-0 | 8-1 | 8-0 | 8-1 | 9-0 |
| Basic trig. functions-circular | 3-2 | 3-2 | 0-3 | 3-2 | 6-1 | 9-0 | 8-0 | 8-0 | 6-1 | 7-1 |
| Properties of trig. functions | 4-1 | 4-1 | 0-5 | 3-4 | 8-0 | 9-0 | 9-0 | 9-0 | 7-1 | 8-0 |
| Properties of logs. (base 10) | 6-2 | 8-1 | 2-4 | 9-0 | 8-1 | 8-1 | 7-1 | 8-1 | 8-1 | 9-0 |
| Properties of logs. (base e) | 6-3 | 7-1 | 2-3 | 7-2 | 9-0 | 9-0 | 8-0 | 8-1 | 7-1 | 9-0 |
| Basic computations with logs. | 7-2 | 7-2 | 2-4 | 7-2 | 8-0 | 8-1 | 7-1 | 8-0 | 7-1 | 9-0 |
| Solution of rt. triangles | 4-1 | 2-2 | 2-3 | 4-2 | 4-2 | 7-1 | 7-1 | 7-2 | 7-1 | 8-0 |
| Solution of oblique triangles | 4-1 | 1-2 | 1-3 | 3-3 | 5-2 | 7-1 | 7-1 | 8-2 | 6-1 | 7-1 |
| Double and half angles | 1-2 | 0-2 | 0-1 | 2-1 | 6-2 | 7-1 | 6-2 | 6-2 | 5-4 | 7-0 |
| Graphing of sine through cosecant | 1-3 | 0-2 | 0-1 | 3-2 | 5-1 | 7-1 | 7-0 | 7-2 | 4-4 | 6-1 |
| Graphing of inverse functions | 1-3 | 0-2 | 0-1 | 3-1 | 4-2 | 5-3 | 5-2 | 6-0 | 3-5 | 5-2 |
| Graphing of more complicated funcs. | 0-2 | 0-2 | 0-1 | 1-2 | 4-1 | 4-3 | 4-2 | 6-2 | 2-3 | 5-0 |
| Conditional equations | 1-1 | 0-2 | 0-1 | 2-0 | 3-1 | 3-3 | 3-1 | 6-2 | 2-4 | 5-1 |
| Logarithmic equations | 3-4 | 2-4 | 1-4 | 5-1 | 5-0 | 5-3 | 3-2 | 6-2 | 4-5 | 6-2 |
| Inequalities | 3-4 | 1-2 | 0-2 | 3-1 | 6-1 | 8-1 | 7-2 | 8-2 | 5-3 | 7-0 |
| Arithmetic and geometric progs. | 6-2 | 4-3 | 2-4 | 4-3 | 7-1 | 8-0 | 7-1 | 7-2 | 5-3 | 7-0 |
| Average Decile Value for each specialization | 4+ | 4 | 1+ | 4 | 7 | 6 | 7 | 8 | 6 | 7 |

*This table represents values based on a very small sample of scientists and engineers for 10 of the 15 specializations covered in this study. This data would have low validity for curriculum revision.

** This number represents the coding for the following specializations: 4-genetics, 5-microbiology, 10-zoology, 14-organic chemistry, 15-physical chemistry, 22-elementary particle physics, 25-nuclear physics, 30-chemical engineering, 32-electrical engineering, 36-metallurgy.

+ The left-hand digit represents the decile for the valuable rating and the right-hand digit, the moderately valuable decile rating.

TABLE 1

Average Decile Topic Ratings for Each Course by Specialization

| | Botany | Genetics | Microbiology | Pharmacology | Zoology | Biochemistry | Organic Chem. | Physical Chem. | Elementary Particles | Nuclear Phys. | Chemical Engineering | Electrical Engineering | Mechanical Engineering | Metallurgy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. 1st Yr. College Math | 3+ | 4+ | 4 | 3+ | 1+ | 3+ | 4 | 7 | 8 | 7 | 8 | 6 | 6 | 7 |
| 2. 1st Yr. Calculus | 3 | 3 | 3 | 3 | 0+ | 4 | 4 | 6 | 8 | 8 | 8 | 6+ | 6+ | 7 |
| 3. 3rd Semester Calculus | | 2 | 0 | 1 | | 2 | 1+ | 6- | 8 | 8 | 7 | 6 | 5 | 5+ |
| 4. Vectors | | | | | | | | 5- | 9- | 7+ | 7 | 7 | 5+ | 5+ |
| 5. Tensor Analysis | | | | | | | | 1+ | 5+ | 4 | 3- | 2- | 2- | 3 |
| 6. Elem. Diff. Equations | | | 0 | | | 1 | 2- | 4- | 7 | 6 | 5- | 5 | 4+ | 4+ |
| 7. Interm. Ord. D. E. | | | | | | | | 3 | 7- | 5- | 4+ | 5 | 2+ | 2 |
| 8. Adv. Ordinary D. E. | | | | | | | | | 2+ | 2+ | 2+ | 4+ | 1 | |
| 9. 1st Cr. Partial D. E. | | | | | | | | 2+ | 5+ | 6- | 4+ | 5- | 3 | 3 |
| 10. Adv. Partial D. E. | | | | | | | | | 3+ | 3+ | 3 | 4 | 2 | |
| 11. Num. Sol. of D. E. | | | | | | | | | 0+ | 2+ | 4 | 2+ | 3 | 1 |
| 12. Advanced Calculus | | | | | | | | 5 | 8- | 7 | 6 | 6 | 3+ | 4+ |
| 13. 1st Cr. Real Variables | | | | | | | | | 2+ | | | | | |
| 16. Calculus of Variations | | | | | | | | | 1- | 2 | | 1 | 1 | |
| 17. Elem. Complex Var. | | | | | | | | 3- | 7+ | 6 | 5 | 5 | 3 | |
| 18. Complex Variables | | | | | | | | | 3 | 2+ | | 3 | | |
| 19. Survey of Modern Algebra | | | | | | | | | 2- | | | | | |
| 20. Group Theory | | | | | | | | 1- | 1- | 1- | | | | |
| 21. Group Representations | | | | | | | | | 3+ | | | | | |
| 22. Lie Algebras and Groups | | | | | | | | | 2+ | | | | | |
| 23. Matrix Theory | | | | | | | | 4+ | 8 | 8 | 4+ | 4+ | 2 | |
| 25. Elementary Probability | | 7 | | | | | | 5+ | 7+ | 7 | 7 | 5+ | | 3+ |
| 26. Advanced Probability | | | | | | | | | | | | 5 | | |
| 27. Applied Statistics | 8- | 7+ | 6 | 8+ | 7+ | 8 | | | | | 8 | | 5- | 6 |
| 28. 1st Cr. Math. Statistics | | 5- | | | | | | | | | | 5- | | |
| 30. Machine Computation | | | | | | | | 4 | 4 | 5 | 6 | 4+ | 4+ | 4 |
| 31. 1st Cr. Numer. Analysis | | | | | | | | | | | 4+ | 5 | 3- | |
| 35. Special Functions | | | | | | | | | 5+ | | | | | |
| 38. Analytic Mechanics | | | | | | | | | 7- | 6 | | | | |
| 39. Integral Transforms | | | | | | | | | | | | 2+ | | |

<u>Botany and Zoology</u> - first-year college mathematics, first-year calculus, and applied statistics
<u>Genetics</u> - the calculus sequence (first-year college mathematics, first-year calculus, and third-semester calculus), elementary probability, applied statistics, and the first course in mathematical statistics
<u>Microbiology</u> - the calculus sequence, elementary differential equations, and applied statistics
<u>Pharmacology</u> - the calculus sequence and applied statistics

The first course in college mathematics was recommended very highly in Phase I, but the topics in trigonometry involving solution of triangles and working with multiple angles, along with other topics in trigonometry, received low ratings. There was a heavy emphasis upon graphing, exponents, probability, and logarithms, including computations with logarithms.

First-year calculus did not receive high ratings when all the topics were considered. The most useful topics were the standard topics of limits and functions, extreme values, differentials, definite and indefinite integrals, and differentiation of the logarithmic and exponential functions. Most of the more difficult topics in integration and differentiation did not receive high ratings.

All biologists rated the topics in applied statistics very highly.

Geneticists gave very high ratings to most of the topics in the courses of probability and mathematical statistics.

There was wide variability among the recommendations of the different specializations. However, much of this was due to the recommendations of the zoologists sampled. Since the sample was so small, the data needs to be verified or rejected, based on a much larger sample of biologists in each individual specialization.

2. Chemistry

The detailed course content sheets sent to those in the following specializations of chemistry were:

<u>Biochemistry</u> - the calculus sequence (first-year college mathematics, first-year calculus, and third-semester calculus), elementary differential equations, and applied statistics
<u>Organic Chemistry</u> - the calculus sequence and elementary differential equations
<u>Physical Chemistry</u> - the calculus sequence, vector and tensor analysis, elementary and intermediate ordinary differential equations, first course in partial differential equations, advanced calculus, elementary complex variables, group theory, matrix theory, elementary probability, and machine computation.

There were distinct differences when the recommendations of organic chemists and biochemists were compared with the recommendations of physical chemists. The topic recommendations of the biochemists and organic chemists were similar to those of the biologists, and those of the physical chemists were similar to those of the physicists.

The recommendations of the biochemists and organic chemists for first year college mathematics were approximately the same as those of the biologists in the previous section. These highly recommended topics were basic functions, graphing, solution of equations, solution of logarithms, and computations with logarithms. They also gave low recommendations to the sections of trigonometry which deal with multiple angles and the graphing of trigonometric functions.

First-year calculus course recommendations of the biochemists and organic chemists were similar to those of the biologists. The major topics receiving high recommendations were: functions, limits, analytical geometry, derivatives of polynomials through products and quotients, and determination of extremes. They gave slightly higher recommendations to the sections on related rates and differentials than did the biologists. More difficult integration and differentiation were given lower ratings.

In third-semester calculus the most used topics were sequences and series, partial derivatives, and computation of extremes. These topics were used more frequently by the biochemists and organic chemists than by the biologists.

The use of the basic topics in elementary differential equations were given the high recommendations. These topics were separation of variables, integrable combinations, homogeneous equations, and linear equations of the first order.

The biochemists gave extremely high ratings to just about all the topics in applied statistics.

The physical chemists gave high ratings to most of the topics in the calculus sequence, elementary differential equations, intermediate differential equations, advanced calculus, matrix theory, mathematical statistics, and machine computation.

Only a small number of the basic topics in group theory were recommended by the physical chemists.

The variability among the topics for biochemists and organic chemists in their recommended courses was very minimal. The obvious larger patterns of variability were noted between the physical chemists and the biochemists-organic chemists.

3. Engineering

The course content sheets which were sent to the participants in the study were:

Chemical Engineering - the calculus sequence (first-year college mathematics, first-year calculus, and third-semester calculus); vector and tensor analysis; elementary, intermediate, and advanced ordinary differential equations; first course in partial differential equations; advanced partial differential equations; numerical solutions of differential equations; advanced calculus; elementary complex variables; matrix theory; elementary probability; applied statistics; machine computation; and the first course in numerical analysis.
Electrical Engineering - the calculus sequence; vector and tensor analysis; elementary, intermediate, and advanced ordinary differential equations; first course in partial differential equations; advanced partial differential equations; numerical solutions of differential equations; advanced calculus; calculus of variations; elementary and complex variables; matrix theory; elementary and advanced probability; first course in mathematical statistics; machine computation, first

course in numerical analysis; integral equations; and integral transforms.
Mechanical Engineering - the calculus sequence; vector and tensor analysis; elementary, intermediate, and advanced differential equations; first course and advanced partial differential equations; advanced calculus; calculus of variations; elementary complex and complex variables; matrix theory; advanced probability; applied statistics; first course in mathematical statistics; machine computation; and the first course in numerical analysis.
Metallurgical Engineering - the calculus sequence; vector and tensor analysis; elementary and intermediate ordinary differential equations; first course in partial differential equations; numerical solutions of differential equations; advanced calculus; elementary probability; applied statistics; and machine computation

The above courses received high ratings in Phase I. In Phase II (the detailed course content phase) most of the topics of these courses received high ratings. Those courses which had the highest topic ratings were the calculus sequence, vectors, elementary differential equations, intermediate differential equations, the first course in partial differential equations, advanced calculus, elementary complex variables, matrix theory, elementary probability, and machine computation. Those courses which had moderate recommendations were tensor analysis, advanced ordinary differential equations. advanced partial differential equations, complex variables, and the first course in numerical analysis.

There was a moderate amount of variability among the topic recommendations for the courses in engineering. However, most of this variability was due to the lower recommendations given to the topics by those in mechanical and metallurgical engineering.

4. Physics

The detailed course content sheets sent to those in physics were:

Elementary Particles - the calculus sequence (first-year college mathematics, first-year calculus, and third-semester calculus); vector and tensor analysis; elementary, intermediate, and advanced ordinary differential equations; first course and advanced partial differential equations; numerical solutions of differential equations; advanced calculus; first course in real variables; calculus of variations; elementary complex variables and complex variables; survey of modern algebra; group theory; group representations; Lie algebras; matrix theory; elementary probability; machine computation; special functions; integral equations; and analytic mechanics
Nuclear Physics - the calculus sequence; vector and tensor analysis; elementary, intermediate, and advanced ordinary differential equations; first course and advanced partial differential equations; numerical solutions of differential equations; advanced calculus; calculus of variations; elementary complex variables and complex variables; group theory; matrix theory; elementary probability; machine computation; and analytic mechanics.

The topics in most of the courses received high recommendations. Very high topic recommendations were given in the calculus sequence, vector and tensor analysis, elementary and intermediate ordinary differential equations, first course in partial differential equations, advanced calculus, matrix theory, elementary probability, machine computation, and analytical mechanics. Other courses of moderate recommendations were advanced ordinary differential equations, advanced partial differential equations, numerical solutions of differential equations, complex variables, and special functions.

Comparisons in Table I show that the average decile ratings for the courses are fairly closely related. When one checks on the variability between the two specialitions, one finds nearly identical topic ratings in the calculus sequence, elementary differential equations, advanced ordinary differential equations, advanced partial differential equations, elementary probability, and analytical mechanics. The closeness of the agreement on the topics may be due to the fact that the basic foundations of the specializations are very similar.

D. Interviewing

The interviewing of the respondents was completed by the director of the study in order to insure uniform techniques. There were seven basic questions which each respondent was asked to answer.

The first four dealt with the potential improvement of the questionnaires: (1) Did you find the topics in each of the courses which you received to be sufficiently complete? (2) Did you find the detailed course content sheets too detailed for the purposes of the study? (3) Were there any other topics or courses which you thought should be included in the study? (4) What was the length of time that you spent in completing the forms?

The next two questions dealt with future trends: (5) What trends in mathematics courses or topics do you foreseein the next few years for your specialization? (6) What non-mathematical trends in your specialization do you foresee in the next few years?

The seventh question was concerned with establishing the respondent's viewpoints on the proper balance of theory and application. The definition of a "pure" mathematics course was one which was all theory with no applications. This orientation was needed to gain insights into differences in recommendations between courses that contain both theory and applications and those that are completely theoretical.

The general comments concerning the quality of the detailed course content sheets were favorable. Most of the scientists interviewed stated that the detailed course content sheets were very complete and that sufficient details were included to make sure that all topics were considered and registered by the respondents. The average time for completing the forms was approximately 20 minutes for the biologists, organic chemists, and biochemists and about 35 minutes for the physicists and engineers. Most of the forms were completed in less time than the above averages, but a few individuals spent a great amount of time answering the questions in detail.

A few individuals investigated the topics that they did not know by consulting colleagues and found that they did not use them either. Thus, the assumption that those topics with which an individual is not familiar are of little value is substantiated by these observations.

The analyses of each area were considered with the following results.

1. Biology

a. A number of biologists indicated that biology was getting more biochemical in its approaches. They indicated that there would be more emphasis in the future on the courses in computer analysis and statistics.

b. For the applied-theoretical orientation, most biologists indicated that there should be a better balance between theory and practice. Applications were needed to stimulate interest in place of pure theory. Some suggested that courses should be developed which stress applications with their mathematics co

c. Those who like pure mathematics were encouraged to continue with their study in mathematics. However, most biologists limited the number of pure mathematics courses to a maximum of one or two.

d. There were a few biologists who gave strong support to pure mathematics and a few who were opposed to any pure mathematics at all. Some individuals indicated that they saw no value whatsoever in pure mathematics.

e. Some biologists feel that pure mathematics develops the mind and trains one to think logically.

f. Mathematics departments were sometimes criticized for not meeting the needs of the biologists. Some thought that they could not teach the mathematics needed because they really do not understand the problems of the biologist. They did think that the mathematics departments should give them more assistance with mathematical problems which do arise.

Some selected comments from the biologists on the topic of applied-theoretical orientation were as follows:

"One needs to know just about enough theory to make an application so that he can solve his problem."

"We don't need to know the proofs; we will take the mathematician's word for it."

"Too much theory turns the students off."

"Biologists should have the rigor of engineers, not that of mathematicians."

2. Chemistry

a. Although there were some differences in recommendations in courses between the biochemists - organic chemists and physical chemists, the basic recommendations obtained from interviewing were about the same.

b. The insights into the future courses registered extensive use of computers. Many mentioned future emphasis on the courses of matrix theory, quantum mechanics, group theory, and statistics.

c. Pure mathematics was observed to help in analysis of problems by a few scientists and to be an aid in appreciation of mathematics. Only a maximum of one to three courses in pure mathematics was recommended for those who were adept in mathematics and were theoretical chemists.

d. There seemed to be many more chemists who thought that pure mathematics was too dull for students and that all courses should have applications integrated with theory.

e. A few individuals recommended that the chemists take their problems to mathematicians when they needed assistance. These individuals were primarily in government or non-profit organizations which hired applied mathematicians to assist them.

f. It was noted that mathematicians did not want to get interested in the type of problem which they presented. These comments usually came from scientists in the university.

g. A number of chemists noted that pure mathematics turns the students off.

h. A few theoretical chemists reported that they took pure mathematics courses and found them of little value.

Some selected comments from chemists were as follows:

"Pure mathematics develops the intellect."

"Creative applications research must be developed."

"All courses should have applications."

"Pure mathematics should be given priority over applications."

"Mathematicians should feel their responsibility to scientists and not flunk out 50 percent of their students."

"The only pure mathematics that is useful is that which helps in solving problems."

3. Engineering

a. Many engineers thought that computers would be used much more in the future than they are presently. There were predictions of greater importance for statistics and model theory.

b. A much larger number of engineers than chemists and biologists indicated that pure mathematics courses were of little value, including those who had taken pure mathematics courses. Many indicated that pure mathematics courses turned engineering students against mathematics.

c. There were a number of complaints that the mathematics departments do not teach the type of material that they want to be instructed. Some engineers indicated that the mathematicians are not interested in teaching mathematics to assist in solving the problems of engineers. Some mentioned the fact that their departments now teach their own mathematics because of this trend.

d. There were a few engineers who recommended that students do take pure mathematics but only a maximum of two courses, and then only when they are combined with applications.

e. Only one or two indicated that pure mathematics would be of value for the engineer and that the mathematics courses helped them to think more logically. They indicated that engineers soundly gounded in mathematics can do a better job.

f. Most engineers indicated that it is best to have applications integrated with the theory. Some suggested that there should be just enough mathematics to make them understand the process and be able to solve their problems. They must learn how to apply basic theorems.

g. The engineering and mathematics departments must learn how to cooperate with each other.

Some selected comments of engineers are:

"The scientist needs to have the ability to get the problem and set up the solution for the problem."

"Our mathematics department refuses to teach applications for engineers and flunks 50 percent of our students."

"Mathematicians do not know what goes on in physical applications and therefore are not able to assist the engineers."

"So many instructors deal so much in rigor that rigor mortis sets in."

"An instructor in mathematics should be dismissed if he teaches a pure mathematics course when he was supposed to teach with applications."

"There is a problem of adjusting to the new language in mathematics. The names of the courses have changed and a new language is used."

"Pure mathematics has gone too far."

"Our students took an advanced calculus course and couldn't integrate when they completed the course."

"We must get a way to make information easily available for use in ways that make sense."

"One needs to know the background of theorems in order to select the proper technique to solve the problem."

4. Physics

a. The courses predicted for future emphasis were group theory and complex variables.

b. Every pure mathematics course should have examples for physicists. Courses should contain applications from physics. All courses should integrate theory and applications.

c. Pure mathematics is good for some but not for all.

d. Pure mathematics is valuable as it provides one with an appreciation of the mathematics structure and formulation of proofs.

e. A few individuals indicated that they use very little pure mathematics and that the value of the rigor is limited. Most of those who took pure mathematics courses presented similar opinions.

f. A few physicists recommended that the gulf between the mathematicians and the physicists must be overcome.

g. Physicists need to know whether a theorem can be proved or whether a solution exists. Students must be shown how to be careful not to overlook major mathematical pitfalls.

A few selected quotes from physicists are:

"It is false that if a person learns the theory he can pick up the applications on his own."

"The mathematics department does not teach proper mathematics. They teach mathematics only for mathematicians."

"One school had to change to teaching mathematics in the engineering department since the mathematicians did such a poor job."

"If you like pure mathematics, take as much as you can get. However, make the requirements in pure mathematics general and flexible."

E. General Observations for All Specializations

There were a number of general trends observed in the data for course analysis and interviewing. Only the significant patterns appearing in a large number of specializations will be reported. These trends are:

1. Most of the predictions of courses in the future showed that there will be much more use of computers than at the present time. Another course which received high predictions of greater use in the future is applied statistics.

2. In Phase I of the NSMRSE, most research specialists in biology, chemistry, physics, and engineering gave the same overall maximum rating to the first-year calculus. Analysis of the data in the present study shows that there were significant differences in the ratings of topics between biologists and related areas (organic chemistry and biochemistry) and those of the engineers and physicists. The biologists recommended only about 30 percent of the topics while the engineers and physicists recommended well over 80 percent of the topics.

3. There was a noticeable tendency on the part of many specialists to recommend very flexible requirements for mathematics courses. There were a few scientists who recommended much pure mathematics, but many more thought that pure mathematics was not worth the time which was spent on learning it.

4. Most scientists and engineers indicated that they would prefer all courses to integrate theory and applications. Many only wanted to have sufficient theory to be able to understand the mathematical principles involved so that they could solve their problems.

5. The course in applied statistics showed slightly lower ratings than a first course in calculus in Phase I recommendations, yet only 30 percent of the basic topics of calculus were recommended while over 80 percent of the statistical topics were given high ratings for biologists, organic chemists, and biochemists. This data shows that statistics seems to be more important than calculus for these specializations.

6. There were numerous suggestions that there should be greater cooperation between the mathematics departments and science and engineering departments so that the appropriate course content could be selected. Many specialists wanted a considerable deemphasis on the amount of theory which is taught to their students in mathematics courses.

7. For those who like mathematics, the recommendation was to take a maximum of one to three courses in pure mathematics. A few theoretical specialists indicated that they should take as much theory as possible although most theoretical specialists cautioned against taking too many pure mathematics courses and stipulated that the theory should always be combined with applications.

8. There were indications that in certain colleges and universities the mathematics departments are not providing the type of mathematics which is requested by the scientists and engineers.

9. The analysis of the twelve specializations shows that the course content recommendations fall into two basic classifications of similar course content. Those requiring less mathematics were biologists, biochemists, and organic ch... Those requiring more mathematics were engineers, physicists, and physical chemis...

10. A number of the specialists in all areas questioned the ability of anyone in trying to predict what courses would be useful in the future. They seemed to indicate that it was too difficult to make such predictions due to the variability of the scientific interests within each specialization.

11. The total variability on such courses as first-year calculus and first-year college mathematics showed extremely high variability in the seven and eight decile range for almost all topics when the range of variability was compared with all the specializations.

12. There were some significant differences in topic recommendations in a number of courses among specializations that were very closely related, such as biochemistry and biology.

13. In the formulation of the detailed course content sheets, it was noted that the mathematicians rated practically all topics in all courses as very valuable or valuable. However, this classification differed considerably from the viewpoint of the scientists and engineers who were much more selective in their ratings of topics.

14. Many respondents reported their awareness that teaching a course with little or no use or application of valuable theorems was undesirable. They stated that such "cook book" courses are not as valuable as integrated courses since the individual has to know the theory in order to solve many difficult problems.

IV. Recommendations

Based on the analysis of the data and the comments in the interviews, the following recommendations can be made.

1. The courses in computer computation and statistics should be given more emphasis than they are given presently. Larger numbers of specialists need to be sampled to obtain more valid information to verify other future trends in the specializations not considered in this study, as well as to reverify the trends noted in the present study.

2. Pure mathematics courses seem to be of little value to most biologists and chemists (organic and biochemists) and should be deemphasized in their courses.

3. Pure mathematics is of limited value for most scientists and engineers in physics, engineering, and physical chemistry, particularly those in the applied or experimental areas. Those who are theoretically inclined should have one to three pure mathematics courses to give them insights into the mathematician's method of proof and to utilize this information in the solution of his problems. It would appear that taking more than three or four courses in pure mathematics would be of relatively little value to practically all scientists and engineers except for those who can master applied and theoretical mathematics as well as their area of specialization. The only exceptions would be those who work completely in the theoretical realms and use the latest mathematics in developing their theories.

4. Courses need to be developed in which the theory is integrated in a very meaningful way with applications for science and engineering where such courses are not available.

5. The analysis of the data shows that in some universities there is harmony between the departments of mathematics and those of science and engineering. Also, the data shows that a number of universities lack such cooperation. It would be of value to find ways to determine how to obtain cooperation between departments. Additional data on topic recommendations from large samples of specialists would give both the mathematicians and scientists and engineers some common ground to start their discussions.

6. The wide variability among topic recommendations in courses such as first-year mathematics and first-year calculus points very clearly to the difficulties involved in trying to determine a course which is best for all specializations. The data seems to indicate that there should be two types of courses taught: one for the biologists and related specializations and another for the physicists, engineers, and physical chemists. This wide variation may explain why the mathematicians cannot satisfy the departments with the same course for all students in science and engineering.

7. The analysis of the interviews gives a better picture of what the scientists and engineers mean by a 50-50 breakdown between theory and practice obtained in Phase I. It would appear that they mean by this 50-50 combination an integration of theory with applications in all courses, as well as working with the valuable theorems to provide meaningful solutions to their problems.

8. Phase II provided additional insights into the recommendations made in Phase I as in the case of finding that statistics seems to be more valuable than

calculus to biologists. This observation establishes the importance of a study of this type. While names of courses are important, the detailed course content provides much more valuable data. Therefore, more specialists should be provided with an opportunity to complete the forms and be interviewed in order that more important findings might be discovered.

9. The alternate possibility to learning more mathematics is to have scientists and engineers take general courses to acquaint them with the types of mathematics that can be useful to them so that they can obtain assistance from a mathematician or computer specialists based on the mathematics learned in such courses. This technique is used in many government and non-profit organizations.

10. The solution of the problem of making suitable course content requirements is very necessary in some schools since the overabundance of theory is responsible for rejecting a number of highly qualified research specialists. Courses should be constructed in conjunction with the cooperation of all departments concerned so that proper course content can be presented for each area.

11. Since this study only partially investigated 12 of the 44 major specializations, it is necessary that a study be devised to follow up all of the specializations and to have larger samples in each specialization (a minimum of 5 percent of the Ph.D.'s in the specialization, or at least 50 in the smaller specializations and a minimum of 100 in each of the larger specializations) to obtain more valid data. This large sample would provide the necessary coverage in each specialization so that comparisons among specializations can be made and be assured that the data is very valid.

12. The study must be carried out with the cooperation of as many professional organizations as is possible so that maximum benefit can be obtained from the results of the study. Once the data is obtained, there will be a common source of information which mathematicians and specialists can use in their discussions for the construction of the appropriate courses for scientists and engineers.

13. One should always be aware that although the scientists and engineers may make their recommendations, it may be difficult to provide this information without giving the proper background which would require more mathematics than they requested. For instance, it is possible to teach the manipulations of calculus without even proving a theorem or giving the development of the limit process by the delta process. However, the student with the necessary theory and practice integrated together should be able to analyze the problems better than those who have the "cookbook" approach. This observation was noted by a number of scientists and engineers in all specializations. Thus, a study is needed in which the appropriate topics can be analyzed along with the proper degree of theory. This data would provide the foundations on which those in science and engineering could arrive at a better consensus with those in the mathematics department.

14. A significant problem which should be considered in such a study is the finding of basic viewpoints on what is the proper training for a scientist or engineer. Ideally, he should be trained to be as knowledgeable and as flexible as possible in mathematics. However, in a number of specializations very little mathematics is needed and many entering these specializations are not very adept in mathematics. Therefore, the question arises as to what should be the minimal requirements for a specialization. Should they be high or low? Answers to such questions are

most easily obtained by means of the interview, and therefore interviewing should be a major technique to arrive at the solution of this most perplexing but important problem.

15. The data of the larger study should be used to establish a minimal number of courses for all specializations so that an overproliferation of different courses can be avoided.

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APPENDIX B

BOARD OF ADVISORS AND CONSULTANTS

Board of Advisors:

The Board of Advisors is composed of nationally-known scientists and engineers from biology, chemistry, earth sciences, engineering, and physics. They assist in the study by providing suggestions for improvement and in offering advice on problems which arise in their area of specialization. The Board and their assistants have given a great number of excellent suggestions on the improvement of the study. All information is obtained by correspondence, telephone conversations, and individual and group meetings. The most active members of the Board are those members of the professional organizations and industry who provide either direct assistance or relay the problems to the appropriate personnel.

Two meetings of the Board were held in Washington, D. C., and New York during the summer of 1969. Meetings of the Board are planned for at least once a year to cover the progress of the study and to discuss improvements in the procedure of the study. Meetings of the Board are kept to a minimum due to the fact that most Board members are very active professionally and can come only if their schedule permits.

A number of members of the Board provide a minimal amount of direct aid to the study because of their extremely busy schedules. However, all are in agreement with the basic goals of the study and assist by letting those selected for the study know that they consider the information of value. Their support is undoubtedly responsible for the excellent returns on all parts of the NSMRSE studies.

For reasons of economy, the meetings of the Board are held at the professional organizations in New York and Washington, D. C., where there is the greatest concentration of members. Requests for travel funds for Board members were omitted in earlier phases to keep costs at a minimum and since all details could be handled satisfactorily by correspondence and telephone.

Biological Sciences

Dr. Constantine Alexopoulos, Professor, University of Texas
Dr. Earl L. Green, Director, The Jackson Laboratory
Dr. H. O. Halvorson, Professor, University of Minnesota
Dr. Cadet H. Hand, Jr., Professor, University of California
Dr. J. F. A. McManus, Executive Director, Federation of American Societies for Experimental Biology
Dr. William A. Nierenberg, Director, Scripps Institution of Oceanography
Dr. John R. Olive, Executive Director, American Institute of Biological Sciences
Dr. Jerry S. Olson, Oak Ridge National Laboratory-University of Tennessee
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Dr. C. F. Curtiss, Professor, University of Wisconsin
Dr. Lawrence S. Darken, U. S. Steel Corporation
Dr. I. M. Kolthoff, Professor, University of Minnesota
Dr. Robert S. Mulliken, Professor, Florida State University
Dr. John D. Roberts, Professor, California Institute of Technology

Dr. H. E. Simmons, E. I. du Pont de Nemours and Company
Dr. E. L. Tatum, Professor, Rockefeller University
Dr. Henry Taube, Professor, Stanford University
Dr. F. T. Wall, Executive Director, American Chemical Society

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Dr. Paul F. Chenea, Vice President, General Motors Corporation
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Dr. D. Welty LeFever, Professor Emeritus of Educational Psychology, University of Southern California

Experience:

1. Member, California Advisory Council on Educational Research.
2. Chairman, Board of Trustees, HEAR Foundation (Research Organization for Deaf Children).
3. Director of Research, Southern California Teacher Education Project (Fund for Advancement of Education).
4. Director of Evaluation of Anaheim Closed Circuit Project (research grant from Ford Foundation).
5. Faculty Associate, Youth Studies Center (research grant from Ford Foundation).
6. Consultant for NSMRSE (The National Study of Mathematics Requirements for Scientists and Engineers).

Dr. John K. Fisher, Professor of Psychology and Assistant Dean of the Graduate School, Edinboro State College, Edinboro, Pennsylvania

Experience:

1. Project Director, Northwestern Pennsylvania Science and Engineering Study (Pennsylvania Science and Engineering Foundation).
2. Director of Evaluation, Operation Reach, Maryland State Department of Education.
3. Director of Evaluation, Upward Bound Project, Lock Haven State College (Office of Education).
4. Director, National Study of Pupil Personnel Roles, National Institute of Mental Health.
5. Director of Interviewing Workshops, U. S. Employment Agency.

Mathematical Consultants:

The mathematical consultants are responsible for the construction of the detailed course content sheets. The mathematicians listed below served on the pilot study. They constructed the detailed course content forms, suggested improvements, or they checked to make sure the courses were concise and yet complete.

Dr. Richard Andree, Department of Mathematics, University of Oklahoma
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Dr. Everett Pitcher, Department of Mathematics, Lehigh University
Professor William E. Restemeyer, Department of Mathematics, University of Cincinnati
Dr. R. E. Schwartz, Department of Electrical Engineering, University of Pennsylvania

2. FIRST-YEAR CALCULUS AND ANALYTIC GEOMETRY

| BASIC TOPICS | V | MV | LV | NF |
|---|---|---|---|---|
| 1. Basic logic and set theory | | | | |
| 2. Basic properties of functions | | | | |
| 3. Basic properties of limits | | | | |
| 4. Delta process | | | | |
| 5. Simple analytic geometry concepts (slope, distance between 2 points) | | | | |
| 6. Properties of the line and conics (i.e., parabola, etc.) | | | | |
| 7. Translation of axes | | | | |
| 8. Derivatives of polynomials, products, quotients | | | | |
| 9. Implicit functions, derivatives of higher order | | | | |
| 10. Extremes (maximum and minimum points, points of inflection) | | | | |
| 11. Velocity, acceleration and rectilinear motion | | | | |
| 12. Related time rates | | | | |
| 13. Differentials | | | | |
| 14. Indefinite integral | | | | |
| 15. Definite integral | | | | |
| 16. Plane area (including area between curves) | | | | |
| 17. Volume (washer, cylindrical shell methods) | | | | |
| 18. Volume (revolution by circular disks, slicing) | | | | |
| 19. Differentiation of logarithmic and exponential functions | | | | |
| 20. Differentiation of trigonometric and inverse trigonometric functions | | | | |
| 21. Integral formulas (power, logarithmic, exponential, trigonometric) | | | | |
| 22. More difficult integral formulas (trigonometric substitutions, quadratic equations, integration by parts, partial fractions, other substitutions, integration table) | | | | |
| 23. Properties and graphs of parametric equations | | | | |
| 24. Properties and graphs of polar coordinates | | | | |
| 25. Derivatives of parametric equations | | | | |
| 26. Plane area in polar coordinates | | | | |
| 27. Length of plane arc and area of surface of revolution | | | | |
| 28. Centroids and moment of inertia | | | | |
| 29. Liquid pressure, work | | | | |
| 30. Improper integrals (when 1 or both limits of integration are infinite) | | | | |
| 31. L'Hôpital's Rule and intermediate forms | | | | |
| 32. Hyperbolic functions | | | | |
| 33. Derivatives of vectors and curvature | | | | |
| 34. Newton's method of solving equations | | | | |
| 35. Determinants and matrices | | | | |
| 36. Eigenvalues and eigenvectors | | | | |

| BASIC THEOREMS AND PROOFS | V | MV | LV | NF |
|---|---|---|---|---|
| 1. Proof of limits | | | | |
| 2. Proof of continuity | | | | |
| 3. Analytic proofs of geometric theorems | | | | |
| 4. Rolle's theorem | | | | |
| 5. Mean value theorem for derivatives | | | | |
| 6. Mean value theorem for integrals | | | | |
| 7. Fundamental theorem of calculus | | | | |
| 8. Cauchy's theorem | | | | |
| 9. Delta-epsilon process | | | | |

## 6. ELEMENTARY DIFFERENTIAL EQUATIONS

| BASIC TOPICS | V | MV | LV | NF | N |
|---|---|---|---|---|---|
| 1. Separable variables | | | | | |
| 2. Integrable combinations | | | | | |
| 3. Homogeneous equations | | | | | |
| 4. Linear equations of the 1st order | | | | | |
| 5. Equations of orders higher than the first | | | | | |
| 6. Integrating factors | | | | | |
| 7. Integration in series | | | | | |
| 8. The linear second order differential equation with constant coefficients | | | | | |
| 9. The particular integral | | | | | |
| 10. The complementary function | | | | | |
| 11. Introduction to operators | | | | | |
| 12. Orthogonal trajectories | | | | | |
| 13. Electric potential | | | | | |
| 14. Hyperbolic functions | | | | | |
| 15. The Wronskian | | | | | |
| 16. The nth derivative of a product | | | | | |
| 17. Nonhomogeneous equations: undetermined coefficient | | | | | |
| 18. Solution by inspection | | | | | |
| 19. Nonhomogeneous equations: Operational methods | | | | | |
| 20. Exponential shift: the operator 1/f(D) | | | | | |
| 21. Vibration of a spring, damped vibrations, and critical damping | | | | | |
| 22. Forced vibrations and resonance | | | | | |
| 23. The simple pendulum | | | | | |
| 24. Electric circuits and networks | | | | | |
| 25. Circuits and simple networks | | | | | |
| Linear equations of second order with variable coefficients | | | | | |
| 26. [ Dependent variable missing | | | | | |
| 27. [ Independent variable missing | | | | | |
| 28. Green's function | | | | | |
| 29. Coupled equations | | | | | |
| 30. Method of Frobenius | | | | | |
| 31. Chemical and Biological Applications | | | | | |

| BASIC THEOREMS AND PROOFS | | | | | |
|---|---|---|---|---|---|
| 1. The existence of solutions | | | | | |
| 2. Existence theorems for the solutions of a particular equation | | | | | |

## 30. MACHINE COMPUTATION

| BASIC TOPICS | V | MV | LV | NF | NO |
|---|---|---|---|---|---|
| 1. Language and notations | | | | | |
| 2. Elements of a practical language | | | | | |
| 3. Statements and flow charts | | | | | |
| 4. Number systems and arithmetic | | | | | |
| 5. Computational error | | | | | |
| 6. Taylor's series and divided differences | | | | | |
| 7. The solution of equations | | | | | |
| 8. Arrays | | | | | |
| 9. Relocatable programs | | | | | |
| 10. Interpolation | | | | | |
| 11. Numerical integration | | | | | |
| 12. Simultaneous equations | | | | | |
| 13. Approximation | | | | | |
| 14. Non-numerical problems | | | | | |
| 15. Sorting and listing | | | | | |
| 16. Machine logic | | | | | |
| 17. Fortran language | | | | | |
| 18. Programming | | | | | |
| 19. Statistical computations | | | | | |
| 20. Algorithms | | | | | |
| 21. Curve fitting | | | | | |
| 22. Subprograms | | | | | |
| 23. Compilers | | | | | |
| 24. Tape and disk operations | | | | | |
| 25. Monitors and supervisors | | | | | |

**BASIC THEOREMS AND PROOFS**

# INSTRUCTION SHEET

Please complete each form by checking the appropriate square for each topic in each course. These topics should be of value for those pursuing the Ph.D. today as well as in the future for your specialization. Your own personal opinion of realistic mathematics content based on its use in your research experience for your present specialization is the type of information which is desired.

The abbreviations in each of the columns refer to the following categories:

V - Valuable
MV - Of Moderate Value
LV - Of Little Value
NF - Not Familiar with the topic
NO - No Opinion

Make your best judgment for each topic. Since the detailed course content sheets have been constructed to contain the complete range of topics for each course, it is highly probable that most individuals will not be familiar with all of them. Such topics should be marked in the NF column. If you are familiar with the topic but have no opinion one way or the other, please mark the NO column. Since we are interested in your relative judgments of these topics, please use the NO response as few times as possible.

If you observe any important useful topics, applications, or theorems that have been omitted, please list them in the blank spaces. Additional comments may be written on the back of the detailed course content sheets. Short comments for a specific topic may be written beside the topic. If you observe that certain important courses relevant to your specialization are missing and would like to rate the topics in those courses, please write to us so that we can send you the detailed course content sheets for those courses. The original numbers and content summaries of the courses from Phase I are listed on the reverse side.

If you desire to provide more specific evaluations of each topic, you may use the following codings on the left-hand side of the five columns.

T - Too advanced for this course
U - A very valuable topic which I Use often in my work
W - I do not have the background for this topic but Wish I had
D - This topic will probably be valuable in the next Decade
C - Although I do not use this topic, many of my Colleagues find it of value

When you have completed the forms, please place them in the return envelope and mail to the NSMRSE Center.

## CONTENT OF COURSES

(Note: Numbers after prerequisite refer to courses on this sheet.)

1. **First Year College Mathematics** — Number systems, linear and quadratic equations, exponents, logarithms, binomial theorem, progressions, theory of equations, mathematical induction, functions and graphs. Plane trigonometry through identities and inverse functions. Pre: 4 yrs. H.S. math (no calculus)
2. **First Year Calculus and Analytic Geometry** — Limits, differentiation, integration, methods of integration, applications, parametric and polar equations, improper integrals. Pre: 1
3. **Third Semester Calculus** — Analytic geometry of 3-space, infinite series, partial differentiation, multiple integrals Pre: 2
4. **Vectors** — Algebra and calculus of vectors with applications to analysis, geometry and physics. Pre: 2
5. **Tensor Analysis** — Algebra and calculus of tensors. Applications to theory of relativity, elasticity, etc. Pre: 12
6. **Elementary Differential Equations** — Similar to first few chapters of Kells. Pre: 2
7. **Intermediate Ordinary Differential Equations** — Series solutions, systems treated by means of matrix theory, boundary value problems and eigenfunction expansions, stability, some existence theory. Pre: 6
8. **Advanced Ordinary Differential Equations** — Existence theorems, linear systems, singular points of analytic linear systems, Sturm-Liouville Theory, stability, asymptotic behavior, periodic solutions, Lyapunov's method. Pre: 7
9. **First Course In Partial Differential Equations** — Wave equation, Laplace equation, heat equation, separation of variables, Fourier transform methods, Laplace transform methods, approximation methods. (E.g., H. F. Weinberger. A First Course in Partial Diff. Equations.) Pre: 6
10. **Advanced Partial Differential Equations** — First order equations and their characteristics for hyperbolic equations, elliptic equations and potential theory. Existence problems and connections with functional analysis. Pre: 9
11. **Numerical Solutions of Differential Equations** — Convergence and stability of finite difference methods, variational methods. Pre: 12
12. **Advanced Calculus** — Calculus of several variables, proper and improper Riemann integrals, line and surface integrals, Jacobians, boundary value problems by separation of variables, Fourier analysis, Laplace transforms, Bessel's and Legendre's functions. Pre: 3
13. **First Course in Real Variables** — Analysis of the number system, limits, functions, continuity, differentiability, integration in several variables, including some elements of the theory of Stieltjes integrals, Lebesgue integrals, measure (E.g., W. Rudin, Principles of Mathematical Analysis.) Pre: 3
14. **Real Variables** — Lebesgue theory of measure, integration, other measures. Some aspects of linear spaces (Banach, Hilbert). Pre: 12
15. **Functional Analysis** — Banach spaces, Banach algebras, Hilbert space, distributions. Pre: 14
16. **Calculus of Variations** — First variation, Euler-Lagrange equation, sufficient conditions, direct methods, constraints, connection with control theory. Pre: 12
17. **Elementary Complex Variables** — Elementary functions, conformal mapping, integration, residues. Pre: 3
18. **Complex Variables** — Analytic functions, Riemann's Mapping Theorem, uniform approximation by polynomials and rational functions, elliptic functions. Pre: 12
19. **Survey of Modern Algebra** — Fields, rings, groups, homomorphisms, isomorphisms, polynomial equations. Pre: 2
20. **Group Theory** — General properties of finite groups, structure of Abelian groups, Sylow theorems, group extensions, defined by generators and relations, examples. Pre: 19, 23
21. **Group Representations** — The group algebra of a finite group, Wedderburn theorems on associative algebras, classification of the representations of a finite group, induced representations, characters, explicit computations. Pre: 20
22. **Lie Algebras and Lie Groups** — Classification of semi-simple Lie algebras over the complex field and their irreducible representations. The classical groups, their Lie algebras, representations, and characters. Analytic manifolds, analytic groups, semi-simple Lie groups. Pre: 20
23. **Matrix Theory or Linear Algebra** — Linear algebra and matrices over the real and complex field leading up to the canonical forms for matrices. Pre: 2
24. **Multilinear Algebra** — Tensor products of vector spaces, exterior algebras, tensor representations of the general linear group. Clifford algebras and orthogonal groups, spinors. Pre: 5, 23
25. **Elementary Probability** — Combinatorial analysis, conditional probability, independence, Laplace limit theorem, Poisson distribution law of large numbers. Pre: 2
26. **Advanced Probability** — Markov chains, stochastic processes. Pre: 12, 25
27. **Applied Statistics** — Statistics for each area (biostatistics, statistics for chemists, etc). Pre: 2
28. **First Course in Mathematical Statistics** — Some elementary probability, least squares, analysis of variance, experimental design, orthogonal polynomials. Pre: 2
29. **Advanced Mathematical Statistics** — Multivariate analysis, sequential analysis, nonparametric inference. Pre: 28
30. **Machine Computation** — Programming, Boolean Algebra, machine language. Pre: 2
31. **First Course in Numerical Analysis** — Finite differential calculus, roots of polynomials, polynomial approximations, least squares, numerical quadrature, numerical methods for differential equations. Pre: 3, 6
32. **Mathematical Logic** — Formal characterization of logical truth and deductive inference. Construction of symbolic systems in axiomatic form. Pre: 2
33. **Linear Programming** — Simplex methods, transportation problems, parametric programming. Pre: 23
34. **Game Theory** — Von Neumann's Theory, problems of strategy, decision functions. Pre: 23
35. **Special Functions** — Series and integral representations, differential equations, functional equations, generating functions, orthogonality properties for hypergeometric, Bessel, Legendre, Laguerre, Gamma functions, etc. Pre: 6, 12
36. **Integral Equations** — Standard Theory of Volterra and Fredholm integral equations. Elements of nonlinear and singular integral equations. Pre: 12
37. **Approximation Theory** — Interpolation and approximation by interpolation, uniform approximation, best approximation in normed linear spaces, orthogonal polynomials, computational procedures. Pre: 14, 23
38. **Analytic Mechanics** — Classical mechanics of rigid bodies, Hamilton-Jacobi Theory, applications to celestial mechanics, qualitative theory of Hamiltonian systems. Pre: 12, 23
39. **Integral Transforms** — Laplace, Fourier, Hankel, Mellin transforms and others. Pre: 6, 12
40. **Geometric Algebra** — The structure of the general linear groups, orthogonal groups, unitary groups and symplectic groups. Pre: 19, 23

# APPENDIX D

## SYMPOSIA

Symposium at the American Institute of Biological Sciences Meeting, Columbus, Ohio, September 6, 1968

| | |
|---|---|
| 1:00 PM | "What Are the Minimal Mathematics Requirements to Produce Quality Research in Botany and Zoology?" Dr. William L. Pak, Purdue University, and Dr. Charles Ray, Jr., Emory University. |
| 1:45 PM | Discussion between panel members |
| 2:00 PM | Open Discussion |
| 2:30 PM | "What Mathematical Theory in Basic Mathematics Courses is of Value to Research Specialists in Botany and Zoology?" Drs. Pak and Ray. |
| 2:45 PM | Open Discussion |
| 3:00 PM | "What Are the Minimal Mathematics Requirements to Produce Quality Research in Ecology?" Dr. William E. Martin, Battelle Memorial Institute, and Dr. Robert V. O'Neill, Oak Ridge National Laboratory. |
| 3:45 PM | Discussion between panel members |
| 4:00 PM | Open Discussion |
| 4:30 PM | "What Mathematical Theory in Basic Mathematics Courses is of Value to Research Specialists in Ecology?" Drs. Martin and O'Neill. |
| 4:45 PM | Open Discussion |

Symposium at the American Society for Engineering Education Meeting, The Pennsylvania State University, June 24, 1969

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|---|---|
| 1:45 PM | "Mathematics for the Mechanical Sciences" - R. M. Haythornthwaite, The Pennsylvania State University |
| 2:05 PM | "Mathematics for the Electrical Engineer" - W. H. Huggins, Johns Hopkins University |
| 2:25 PM | "Mathematics for the Metallurgy Engineer" - D. J. Montgomery, Michigan State University |
| 2:45 PM | "Mathematical Theory for the Mechanical Sciences" - R. M. Haythornthwaite, The Pennsylvania State University |
| 2:50 PM | "Mathematical Theory for the Electrical Engineer" - W. H. Huggins, Johns Hopkins University |
| 2:55 PM | "Mathematical Theory for the Metallurgy Engineer" - D. J. Montgomery, Michigan State University |
| 3:00 PM | Open Discussion |

Symposium on Mathematics for Engineers and Chemists Case-Western Reserve University, February 27, 1970

A. Mathematics for Engineers

| | |
|---|---|
| 9:00 AM | "Mathematics for the Mechanical Engineer" - Dr. S. Ostrach, Case-Western Reserve University |
| 9:30 AM | General Discussion |
| 10:00 AM | "Mathematics for the Chemical Engineer" - Dr. J. Cummings, Cleveland State University |
| 10:30 AM | General Discussion |
| 11:00 AM | "Mathematics for the Electrical Engineer" - Dr. Yoh-han Pao, Case-Western Reserve University |
| 11:30 AM | General Discussion |

B. Mathematics for Chemists

1:00 PM "Mathematics for Organic Chemists" - Dr. E. Nordlander, Case-Western Reserve University
1:30 PM General Discussion
2:00 PM "Mathematics for the Inorganic Chemist" - Dr. F. Urbach, Case-Western Reserve University
2:30 PM General Discussion
3:00 PM "Mathematics for the Physical Chemist" - Dr. F. J. Bockhoff, Cleveland State University
3:30 PM General Discussion

Sympc ium on Mathematics for Industry
Edinl oro State College, May 14, 1970

A. General Session

1:00 PM "Mathematics for Metallurgists" - Dr. W. E. McKewan, U. S. Steel Corp., "Kinetics of Iron Oxide Reduction"
1:25 PM Mathematics for Chemical Engineers - Mr. Martin Hess, Koppers Company - "Mathematical Models in Fluid Flow"
1:45 PM Mathematics for Electric Engineers - Dr. T. A. Lipo, General Electric Company - "Systems Analysis in Electrical Engineering"
2:05 PM Mathematics for Mechanical Engineers - Mr. Glen Warnaka, Lord Corporation, "Mathematics of Acoustics"
2:25 PM General Discussion

B. Section I - Chemistry and Chemical Engineering

3:00 PM "Mathematics for Chemical Engineers - Time Sharing" - Mr. Frank C. Alexander, Jr., FMC Corporation
3:15 PM "Mathematics of Reactor Control Simulation" - Mr. W. R. Ludwig, Hughson Chemical Company
3:30 PM "Mathematics of Data Reduction on Polymer Rheology" - Dr. J. I. Nutter, Lord Corporation
3:45 PM "Mathematics of Materials Engineering," - Mr. H. R. Sheppard, Westinghouse Electric Corporation

C. Section II - Electronics and Electrical Engineering

3:00 PM "Mathematical Computer Techniques in Electrical Engineering" - Mr. W. G. Chambers, Westinghouse Electric Corporation
3:15 PM "Mathematics of Magnet Design" - Mr. James Floros, Eriez Magnetics
3:30 PM "Mathematics of Quality Assurance for Ceramic Capacitors" - Dr. Lowell Savage, Erie Technological Products
3:45 PM "Mathematics of Control Systems" - Mr. Thomas Stitt, General Electric Company
4:00 PM Open Discussion

D. Section III - Physics and Mechanical Engineering

3:00 PM "Mathematics of Sound Absorbtion in a Lined Duct" - Mr. M. W. Ferralli. Lord Corporation
3:15 PM "Mathematics for Mechanical Engineers - Optimizational Techniques" - Mr. D. R. May, Lord Corporation
3:30 PM "Mathematics of Vibration Analysis" - Mr. Robert Visalli, FMC Corporation
3:45 PM "Mathematics of Stress Analysis" - Mr. D. E. Witkin, National Forge
4:00 PM Open Discussion

E. Section IV - General Topics

3:00 PM "Should Engineers Learn Tensor Analysis?" - Dr. K. L. Cheng, Lord Corporation
3:15 PM "Mathematics of Tool Design" - Mr. R. A. Parker, Parker White Metal Company
3:30 PM "Mathematics of Thermal Circuits" - Mr. Jacob A. Chiera, General Electric Company
3:45 PM "Mathematics of European Engineers" - Mr. Wolf Conrad, Erie Marine
4:00 PM Open Discussion