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A NATIONAL STUDY OF MATHEMATICS REQUIREMENTS FOR SCIENTISTS AND ENGINEERS. FINAL REPORT.

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The National Study of Mathematics Requirements for Scientists and Engineers is concerned with establishing the mathematics experiences desired for the many specializations in science and engineering, such as microbiology, organic chemistry, electrical engineering, and molecular physics. An instruction and course content sheet and a course recommendation form were sent to over 9,000 scientists and engineers. The data were analyzed and are reported in quintiles for each specialization. Some of the general conclusions were as follows: (1) mathematics courses should have equal emphasis on theory and application, (2) with the exception of group theory, there was little need for courses such as functional analysis, modern algebra, and mathematical logic, (3) most of the high recommendations were for applied courses such as vectors, the many types of differential equations, applied statistics, and machine computation, and (4) comparisons of categories within each specialization showed little differences in recommendations for most specializations. (RP)

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March 1968

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

Office of Education
Bureau of Research

Final Report

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A National Study of Mathematics Requirements for Scientists and Engineers

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Cookeville, Tennessee

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

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1. The Board of Advisors and Consultants (Appendix B).

2. Professional organizations - American Association for the Advancement of Science, American Chemical Society, American Institute of Biological Sciences, American Physical Society, Engineers Joint Council, Federation of American Societies for Experimental Biology, and Institute of Electrical and Electronics Engineers.

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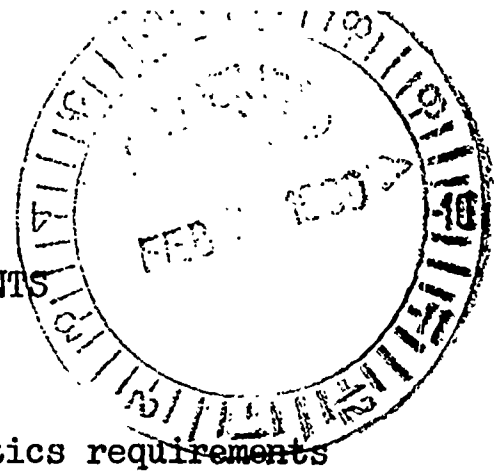

I. SUMMARY

THE NATIONAL STUDY OF MATHEMATICS REQUIREMENTS FOR SCIENTISTS AND ENGINEERS (NSMRSE)

Statement of the Problem

Although there have been a number of studies on mathematics requirements for biologists, chemists, physicists, and engineers, none have been primarily concerned with specific mathematics requirements for specializations such as genetics, organic chemistry, solid state physics, and electrical engineering. Since there are obvious differences in the mathematics courses required by the organic chemist and the physical chemist, the mechanical engineer and the electrical engineer, the NSMRSE was designed to determine what these requirements should be. In addition, new fields such as biophysics and bioengineering have come into existence. Mathematics course recommendations for these new specializations would be of value.

This information was obtained by getting the consensus of outstanding authorities on mathematics course recommendations for each specialization. Such information is an aid in course selection to students and faculties in liberal arts colleges where electives in mathematics are limited. It will provide university professors with a national consensus of course requirements in mathematics for their specialization based on the recommendations of a large sample of experts in their area. Thus, in place of the advice, "Take as much mathematics as you can," the student can take the specific mathematics courses which will be of the most value for his specialization.

Procedure

The Board of Advisors for the Study was selected from a number of nationally-known scientists and engineers. They are as representative of the national population of scientists and engineers in university and non-university positions as possible. The suggestions of these members were used to determine the best selection of outstanding authorities in their areas of specialization. They also provided many suggestions for the improvement of the Study.

Approximately 10,000 scientists and engineers were selected for the Study. They were placed in one of the following categories:

1. Awards Group - those who were recommended by the Board of Advisors as being outstanding in their area of specialization or were the recipients of national awards or honors.

2. Abstracts Group - those who were exceptionally productive in their research based on the number of journal articles listed in the past five years in the Biological Abstracts, Chemical Abstracts, Engineering Index, Scientific and Technological Aerospace Reports, and Physics Abstracts.

The Course Recommendation Form and the Instruction and Course Content Sheet were constructed with the aid of consultants and the Board of Advisors. These forms were devised so that a minimum amount of time was needed to complete them. Editorial support for the Study was requested from some of the major professional journals.

Each scientist and engineer who was selected was given an IBM code number for use in later analysis. Each individual was sent the following:

(1) An individually typed short statement on letterhead stationery setting forth the need of the Study, (2) The Course Recommendation Form, and (3) The Instruction and Course Content Sheet, which contained instructions for the coding and a brief resume of the content of each of the forty courses.

Each respondent was asked to indicate his area of specialization, orientation of work, highest degree obtained, type of employment, administrative capacity, and age category in the first six sections of the Course Recommendation Form. In the seventh section he was asked to mark his form for the following: (1) Recommended time for a specific course (3, 6, 12, 18, or 36 weeks), (2) Grade level of the course (freshman-sophomore, undergraduate-graduate, graduate only), (3) Applied-theoretic orientation (five-point scale), (4) Actual knowledge of the course, (5) Use of course content in his work. He was asked to recommend courses for the Ph.D. in his specialized area only. Reminder letters were sent to those who did not return their completed forms.

Analysis of the Data

The data were analyzed on the computer at Tennessee Technological University. The results for each specialization were reported in quintiles (upper fifth to lower fifth). Comparisons within each specialization were made when there were two or more groups of ten. In the largest groups the following comparisons were made: the differences in age, academic or non-academic status, administrative-non-administrative capacity, applied or theoretic orientation, and place of employment. The report of the data was sent to the professional journals so that it would be available to the maximum number of people.

General Conclusions and Recommendations for All Specializations

1. Most respondents indicated a decided preference for mathematics courses to be approximately fifty per cent theory and fifty per cent application.
2. The mathematics courses most often recommended were the calculus sequence; vectors; elementary, intermediate, and advanced ordinary and partial differential equations; applied statistics; and machine computation.
3. There was little use for courses such as modern algebra, functional analysis, mathematical logic, and multilinear algebra. The one exception was a recognized need for group theory for certain specializations.
4. There were great differences in the number of course recommendations among the major areas of science and engineering. Mathematics recommendations increased in the following order: biology, chemistry, engineering, and physics. There were great differences in specializations within certain sciences such as between the organic chemist and the physical chemist.
5. There were many recommendations for the combining of parts of two or more mathematics courses into one course composed of material valuable for a specific specialization.
6. Those courses recommended were usually for the standard lengths of time.
7. Almost all courses beyond calculus were recommended for the undergraduate - graduate level.
8. There was much uniformity between groups for each specialization when checked on course recommendations. There was almost no difference between the Awards and Abstracts Groups, the administrative and non-administrative groups, and the academic and non-academic groups. However, there were minor differences among the applied, combination, and theoretical groups and among different age groups.

II. INTRODUCTION

A. The Problem

Although there have been a number of studies on mathematics requirements for biologists, chemists, physicists, and engineers, none has been primarily concerned with specific mathematics requirements for common specializations such as genetics, organic chemistry, solid state physics, and electrical engineering. Since there are obvious differences in the mathematics courses required by the organic chemist and the physical chemist, the mechanical engineer and the electrical engineer, a study was needed to determine what these requirements should be.

This information was obtained from the recommendations of a large number of outstanding authorities in each specialization. Such information will be an aid in the course selection of students in liberal arts colleges where electives in mathematics are limited. In addition, it will provide university professors with a national consensus of the course requirements in mathematics for their specialization. Thus, in place of the advice, "Take as much mathematics as you can," the undergraduate and graduate student will be able to take the specific course work which will be of the most value for his specialization.

The amount of applied or theoretical emphasis for each course varies with the area of specialization. In certain cases a maximum amount of applied material with a very minimum of theory is needed, and in other cases a maximum of theory is needed with a minimum of applied material. Since this is such an important question, and one which cannot be determined properly by one or two experts or a committee of experts due to the large number of specializations, it was necessary to obtain the objective viewpoints of a great many scientists and engineers for the most accurate analysis. In making this analysis, it was necessary to find out what the reactions of the authorities were after they had taken the course or had done reading on their own as compared with those who did not have this background.

Since there are a number of new areas of active scientific research, such as biophysics and bioengineering, it was desirable to find out what the mathematics requirements would be for them so that students preparing for these areas can be given the proper course work. Although these new areas may not have a large number of scientists or engineers working in them at the present time, it is possible that they will be the most extensive fields of specialization in the next decade or two. Thus, information on them is of great importance.

In making a study of this type, a number of additional important objectives were checked. For instance, it was possible to find out what differences in viewpoint existed between academicians and non-academicians in course work recommendations, what differences existed among different age levels, and what differences appeared in suggested lengths of time for a specific course.

Thus, a study of this type can provide a great amount of necessary material for the development of an improved curriculum program for graduates, as well as for undergraduates, in the sciences and engineering.

B. Objectives

1. To determine the best mathematics course selection for the potential and present Ph.D. candidates for each specialization at both the undergraduate and graduate levels. This information will also be of value to those in industry who wish to increase their mathematical competence in their specialization.
2. To determine the degree of applied and theoretical emphasis recommended for each course by specialization.
3. To determine the mathematics course requirements recommended for new areas such as biophysics and bioengineering for students planning to enter these potentially large areas of science.
4. To investigate other valuable factors such as age differences, academic - non-academic differences, and degree differences in course recommendations.

C. Review of Related Research

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

Until the past few years, the biological sciences have had the least amount of research done on 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 (6) did 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) (7) was formed to investigate the problem of overall improvement in 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.

The Bucknell Study (20) and the Advisory Council on College Chemistry of the American Chemical Society (ACS) (1) have done 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 has made suggestions for improvements involving recommendations 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 have more independent research on the undergraduate level. The BMSS Panel (6) was responsible for an analysis of the mathematical requirements of a number of institutions. They reported the per cent of institutions requiring specific mathematics courses for biochemistry majors.

A number of conferences have been held in the area of physics, such as the First and Second Ann Arbor Conferences (5, 9), the Princeton Conference (12), and the Denver Conference (10). These conferences studied

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 (8). 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 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 were considered (16, 19). The American Society for Engineering Education (ASEE) has had several articles devoted to the need for a course in computers for engineers (13). 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 go on for 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 Reactions with Industry Division of the ASEE (11) gave the choice of courses of over 7,000 people in industry. These courses were 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 1961 by the Engineering Council for Professional Development of the ASEE (3). 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 such courses were included in the study. The important question of applied-theoretic emphasis was only indirectly covered by this study. The results of this study have been analyzed. Some of the basic recommendations were: Change from the four-year college degree to the five-year college degree in engineering, improve the liberal arts background of engineers, cooperate with industry, and increase emphasis on research. The final report has recently been published in the ASEE Journal, January 1968 (3).

To sum up all the research to date, it is seen that no study has been primarily concerned with mathematics requirements for scientists in each area of specialization since most of the studies were very general. Thus, the NSMRSE will pinpoint the recommended course work in mathematics for each area of specialization for those seeking advanced degrees.

III. METHODS

The first step in the Study was to obtain a Board of Advisors (Appendix B). The members of the Board were selected from a number of nationally-known scientists and engineers who supported the basic idea of the Study. They are as representative as possible of the national population in the university, business, and government. In the case of the Board of Advisors for engineering, deans of engineering, executive secretaries of professional organizations, and vice-presidents of research in the larger industries were selected from different parts of the nation to give the wide representation needed for over one million engineers. These individuals served in an advisory capacity. Their assistance was obtained through individual meetings, telephone conversations, and correspondence.

The major problem of the selection of the best participants for the Study to assure valid recommendations was discussed in detail with the members of the Board, as well as with other scientists and engineers. Despite the difficulties involved in locating correct addresses and in preparing lists of individuals, the decision was made to select those who had received national recognition or who were active contributors to the professional journals. Based on this decision, approximately 10,000 scientists and engineers were selected for the Study. These individuals were placed in two categories: (1) The Awards Group - those individuals who were recipients of national honors or awards and those who were recommended by members of the Board as having national and international reputations in their area of specialization and (2) The Abstracts Group - those individuals who have been exceptionally productive in their research, based on the number of journal articles listed in the Biological Abstracts, Chemical Abstracts, Engineering Index, Physics Abstracts, and Scientific and Technological Aerospace Reports in the last five years.

Once the names were located, finding correct addresses became a problem. Most of the scientists were listed in American Men of Science, but it was not until the recent volumes were published that addresses could be verified.

Locating the correct addresses for the engineers selected for the Study was extremely time consuming. The major sources of names were the Engineering Index and Scientific and Technological Aerospace Reports (STAR). STAR had addresses that were recent, but it was difficult to determine whether these individuals were experienced engineers with advanced degrees or with no degrees. The Engineering Index had sufficient background information on names, but the problem there was locating correct addresses. This had to be done by the tedious process of referring to the original journal articles in cases where the engineers were not listed in American Men of Science or Who's Who in Engineering. Due to the high mobility of engineers, addresses obtained in this way resulted in a large number of incorrect ones. Also, there was a problem of similar names since the Engineering Index gives only the initials of the author. Thus, names like A. J. Smith are not easily identifiable (i.e., is it Arnold James Smith, Albert James Smith, or Alexander John Smith?).

Due to problems in address verification, over 1,000 engineers were removed from the final list. An additional 1,729 scientists and engineers

had to be eliminated from the original list because of insufficient background information, duplications, or wrong addresses.

The NSMRSE Course Recommendation Form (Appendix C) and the Instruction and Course Content Sheet (Appendix D) were constructed with the aid of the Board of Advisors and other consultants (Appendix B). The Course Recommendation Form was devised so that a minimum amount of time was needed to complete it and yet obtain the maximum amount of information. Forty courses were selected by the mathematical consultants for the Study. The Course Content and Instruction Sheet was devised so that all instructions were concise and yet as clear as possible. 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 forty courses was given.

The first letters (Appendix E) were sent out during the end of February 1967, and follow-up letters (Appendix F) were sent until October. In cases where a larger number of responses was needed for the analysis of certain specializations, additional letters were sent out after October. Each individual was sent (a) an individual letter stating the importance of the Study, (b) a NSMRSE Course Recommendation Form, (c) an Instruction and Course Content Sheet, and (d) a return stamped envelope. The respondent was asked to indicate his area of specialization, orientation of work, highest degree obtained, place of employment (academic, industry, government, non-profit organization), administrative capacity, and age category (five-year intervals) on the first six sections of the Course Recommendation Form. In the seventh section he was asked to mark his form for the following:

1. The recommended time for a specific course (3, 6, 12, 18, or 36 weeks)
2. The grade level of the course (freshman-sophomore, undergraduate-graduate, graduate only)
3. The applied-theoretic orientation (a five-point scale ranging from all application to all theory)
4. Actual knowledge of the course (took course, took part of course, read some, or read extensively)
5. Use of course content in his work (none, sometimes, often)

He was asked to recommend courses for the Ph.D. in his specialization only.

The data on the Course Recommendation Forms was transferred to IBM cards and analyzed on the computer at the Tennessee Technological University Computer Center. The results were reported in percentages for each course in each specialization with the breakdown of each of the categories in Section 7 involving course length, applied-theoretic orientation, course level, knowledge, and use of the course. In addition, differences in each specialization between different orientations of work, degrees, places of employment, administrative or non-administrative capacities, and age groups were investigated to note any significant trends. A criterion of at least ten respondents in a group was set up before any analysis was made. Since these recommendations are not precise, the reporting of course recommendations is done in the form of quintiles (upper fifth to lower fifth).

IV. FINDINGS

The results of the analysis of the specializations are reported in quintiles for each specialization. Due to the great variability in recommendations for a specific course, the percentage response was changed to quintiles to reflect the relative accuracy of the results. The tables are reported in numerical codes ranging from 1 through 6 based on the following designations:

1 - Very High Recommendation (80-100%)
2 - High Recommendation (60-79.9%)
3 - Moderate Recommendation (40-59.9%)
4 - **Low Recommendation (20-39.9%)**
5 - **Very Low Recommendation (0-19.9%)**
6 - No Recommendation (0%) Note that this rating is the lowest numerical result for quintile 5 and represents unanimous agreement on the lack of value of a specific course.

All specializations are listed alphabetically along the top of the tables. The forty courses are listed on the left-hand side, and the corresponding quintile for each course in each specialization is indicated by the code numbers 1 through 6. Specializations in which sixteen or more responses were received are reported in the five tables.

Table I deals with the biology specializations - anatomy, biophysics, botany, ecology, genetics, microbiology and virology, pathology, pharmacology, physiology, zoology, and medical biology. Table II deals with the five basic specializations of chemistry - analytical, biochemistry, inorganic, organic, and physical. Table III deals with the major engineering specializations - aeronautical, chemical, civil, electrical, engineering science, industrial, mechanical, metallurgical, mining, and nuclear. Table IV deals with most of the physics specializations - acoustics, atomic and molecular, electromagnetism, elementary particles, fluids, nuclear, optics, and solid state. Table V deals with miscellaneous specializations - agriculture, astronomy and astrophysics, bioengineering, electronics, general M. D., geology, and nutrition - and with specializations which received a smaller number of replies - thermal physics and mechanics.

The percentage breakdown of completed forms for the combined Abstracts and Awards Groups in each of the four major areas of science and engineering (biology, chemistry, physics, and engineering) are reported in the sections on Analysis of Respondents. The total number in the four basic areas will not equal the total number of the sums of the specializations in these areas since an individual selected from the Biological Abstracts may be in zoology, biochemistry, biophysics, or any number of different specializations. The number of forms received in each specialization is given in the following sections on Biology, Chemistry, Engineering, Physics, and General Analysis for All Specializations.

The reader should note that the course recommendations represent an upper bound of mathematics requirements for each specialization since the data is based on a very large sample of the most active research specialists in the nation today.

Table I. Course Recommendations for Biology Specializations

	Anatomy	Biophysics	Botany	Ecology	Genetics	Microbiology and Virology	Microbiology and Vir.,M.D.	Pathology	Pharmacology	Pharmacol.,M.D.	Physiology-Aw	Physiology-Abs	Physiology,M.D.	Zoology
1. 1st Yr. College Math.	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2. 1st Yr. Calculus	2	1	1	1	1	1	1	1	1	1	1	1	1	2
3. 3rd Sem. Calculus	4	2	4	4	3	3	3	3	3	3	3	3	2	4
4. Vectors	5	2	5	5	5	5	5	5	5	5	4	5	4	5
5. Tensor Analysis	5	4	5	5	6	5	6	6	6	5	5	5	5	6
6. Elem. Diff. Eq.	3	2	4	3	4	3	4	4	4	3	2	3	2	5
7. Interm. Ord. D. E.	5	3	5	5	5	5	5	6	5	4	4	5	5	5
8. Adv. Ord. D. E.	6	4	5	5	5	5	5	5	6	5	5	5	5	6
9. 1st Cr. Part. D. E.	5	2	5	5	5	5	6	5	5	4	4	5	4	6
10. Adv. Part. D. E.	6	4	6	5	5	6	6	6	6	5	5	5	5	6
11. Num. Sol. of D. E.	5	4	5	5	5	5	5	6	5	5	5	5	5	5
12. Advanced Calculus	5	3	5	5	5	5	5	6	5	5	5	5	4	5
13. 1st Cr. Real Var.	6	5	6	5	5	5	6	6	6	6	6	5	5	6
14. Real Variables	6	5	6	5	5	5	6	6	6	5	6	5	5	6
15. Functional Analysis	6	5	6	5	5	5	6	6	6	5	6	5	5	6
16. Calc. of Variations	6	5	6	5	5	6	6	6	6	6	6	5	5	5
17. Elem. Complex Var.	6	4	6	5	6	5	5	6	6	5	5	5	5	5
18. Complex Variables	5	5	6	5	6	5	5	6	6	5	6	6	5	6
19. Survey Modern Algebra	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20. Group Theory	6	4	6	5	5	5	5	6	5	5	5	5	5	6
21. Group Representations	6	5	6	6	6	6	6	6	6	5	6	6	5	6
22. Lie Algebras, Groups	6	5	6	6	6	6	6	6	6	6	6	6	5	6
23. Matrix Theory	5	4	6	4	4	5	5	6	5	5	5	5	5	5
24. Multilinear Algebra	6	5	6	6	6	6	6	6	6	6	6	6	6	5
25. Elem. Probability	3	3	4	3	2	4	4	5	5	4	3	3	4	4
26. Adv. Probability	5	4	5	4	4	5	5	5	5	5	5	5	5	5
27. Applied Statistics	2	3	2	2	2	2	2	2	1	1	2	1	3	2
28. 1st Cr. Math. Stat.	4	4	4	3	3	4	4	4	4	3	4	3	4	4
29. Adv. Math. Stat.	5	5	5	4	4	5	5	5	5	5	5	5	5	5
30. Machine Computation	4	3	4	3	4	4	4	4	4	3	4	4	4	4
31. 1st Cr. Num. Analysis	5	4	5	5	5	5	6	5	5	6	5	5	5	5
32. Mathematical Logic	5	5	5	5	5	5	5	5	6	5	5	5	5	5
33. Linear Programming	5	5	5	4	5	5	5	5	5	5	5	5	5	5
34. Game Theory	6	5	6	5	5	5	6	6	6	6	5	6	5	6
35. Special Functions	6	5	6	5	6	5	6	6	6	5	6	6	5	6
36. Integral Equations	6	5	6	5	6	5	5	6	5	6	6	5	5	5
37. Approx. Theory	5	5	6	6	6	5	6	6	6	6	6	5	5	6
38. Analytic Mechanics	6	5	6	6	6	6	6	6	6	6	6	5	5	6
39. Integral Transforms	5	5	6	5	6	5	6	6	6	6	5	5	5	6
40. Geometric Algebra	6	5	6	6	6	6	6	6	5	6	6	5	5	6

Table II. Course Recommendations for Chemistry Specializations

	Analytical-Aw	Analytical-Abs	Biochem.-Aw	Biochem.-Abs	Inorganic-Aw	Inorganic-Abs	Organic-Aw	Organic-Abs	Physical-Aw	Physical-Abs				
1. 1st Yr. College Math.	1	1	1	1	1	1	1	1	1	1				
2. 1st Yr. Calculus	1	1	1	1	1	1	1	1	1	1				
3. 3rd Sem. Calculus	2	1	2	2	1	2	2	2	1	1				
4. Vectors	4	3	4	5	2	3	4	4	1	2				
5. Tensor Analysis	5	5	5	5	4	5	5	5	4	3				
6. Elem. Diff. Eq.	1	1	2	2	1	1	1	2	1	1				
7. Interm. Ord. D. E.	3	4	4	4	3	3	4	4	2	3				
8. Adv. Ord. D. E.	5	5	5	5	5	5	5	5	4	4				
9. 1st Cr. Part. D. E.	3	4	4	5	2	3	4	4	2	2				
10. Adv. Part. D. E.	5	5	5	5	5	5	5	5	4	4				
11. Num. Sol. of D. E.	5	5	5	5	4	4	5	5	4	4				
12. Advanced Calculus	4	4	5	5	2	3	4	4	2	2				
13. 1st Cr. Real Var.	5	5	5	5	5	5	6	5	5	5				
14. Real Variables	5	6	6	5	5	5	6	5	5	5				
15. Functional Analysis	6	6	6	5	6	5	6	5	5	5				
16. Calc. of Variations	5	5	6	5	6	5	6	5	5	4				
17. Elem. Complex Var.	5	5	5	5	4	5	6	5	3	3				
18. Complex Variables	5	5	6	5	5	5	5	5	4	4				
19. Survey Modern Algebra	5	5	5	5	5	4	5	5	4	4				
20. Group Theory	5	5	5	5	2	4	5	4	2	3				
21. Group Representations	5	6	6	6	4	5	5	5	4	4				
22. Lie Algebras, Groups	6	6	6	6	6	5	6	5	5	5				
23. Matrix Theory	5	5	5	5	3	4	4	5	2	3				
24. Multilinear Algebra	6	6	6	6	5	5	6	5	5	5				
25. Elem. Probability	5	4	4	4	5	4	5	4	3	3				
26. Adv. Probability	5	5	5	5	5	5	5	5	5	5				
27. Applied Statistics	3	3	4	3	5	4	5	4	4	4				
28. 1st Cr. Math. Stat.	5	4	5	4	5	4	5	5	5	4				
29. Adv. Math. Stat.	5	5	6	5	5	5	5	5	5	5				
30. Machine Computation	2	4	4	4	3	3	4	4	3	3				
31. 1st Cr. Num. Analysis	5	5	5	5	6	5	5	5	4	4				
32. Mathematical Logic	5	6	5	5	6	5	5	5	5	5				
33. Linear Programming	5	5	5	5	5	5	6	5	5	5				
34. Game Theory	6	5	5	5	6	5	6	5	5	5				
35. Special Functions	5	6	6	6	5	5	6	5	5	5				
36. Integral Equations	5	5	5	5	5	5	6	5	4	5				
37. Approx. Theory	5	5	6	6	6	5	6	5	5	5				
38. Analytic Mechanics	6	6	6	5	5	5	6	5	5	5				
39. Integral Transforms	5	5	5	5	5	5	6	5	5	5				
40. Geometric Algebra	6	6	6	6	6	5	6	5	5	5				

Table III. Course Recommendations for Engineering Specializations

	Aeronautical	Chemical-Aw	Chemical-Abs	Civil-Aw	Civil-Abs	Electr.-Aw	Electr.-Abs	Eng. Sci.-Aw	Eng. Sci.-Abs	Industrial	Mechanical-Aw	Mechanical-Abs	Metallurgical	Mining	Nuclear
1. 1st Yr. College Math.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2. 1st Yr. Calculus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3. 3rd Sem. Calculus	1	2	1	2	1	1	1	2	1	1	1	1	1	1	1
4. Vectors	1	2	2	2	2	2	1	2	1	3	1	1	1	3	2
5. Tensor Analysis	2	2	2	3	2	3	3	2	1	5	2	2	2	4	3
6. Elem. Diff. Eq.	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1
7. Interm. Ord. D. E.	1	2	2	3	2	2	2	2	2	3	2	2	3	3	2
8. Adv. Ord. D. E.	3	4	3	4	4	3	3	3	3	4	2	3	4	5	3
9. 1st Cr. Part. D. E.	1	1	1	2	2	2	1	2	1	4	1	1	2	3	1
10. Adv. Part. D. E.	2	4	3	4	3	3	3	3	3	5	3	3	4	5	4
11. Num. Sol. of D. E.	2	2	2	2	2	2	2	3	2	4	2	3	3	4	3
12. Advanced Calculus	1	2	2	2	2	1	2	1	2	3	1	2	2	3	1
13. 1st Cr. Real Var.	4	5	5	5	3	4	4	3	4	4	5	5	5	5	5
14. Real Variables	5	5	5	5	5	4	4	4	4	5	5	5	5	5	5
15. Functional Analysis	5	5	5	5	5	4	4	4	4	5	5	5	5	5	5
16. Calc. of Variations	2	4	4	4	2	3	3	2	2	4	4	3	4	5	4
17. Elem. Complex Var.	2	3	2	2	2	2	2	2	2	5	2	2	4	5	3
18. Complex Variables	2	4	4	5	4	2	3	2	2	5	4	4	5	5	4
19. Survey Modern Algebra	6	5	5	5	5	4	4	4	4	4	5	5	5	5	5
20. Group Theory	6	5	5	5	5	4	4	4	4	5	5	6	5	5	5
21. Group Representations	6	5	5	5	6	5	5	5	5	6	6	6	5	5	6
22. Lie Algebras, Groups	6	5	5	5	6	5	5	5	5	6	6	6	5	6	6
23. Matrix Theory	3	2	3	3	2	2	2	2	2	1	3	3	4	4	3
24. Multilinear Algebra	5	5	5	5	5	5	5	5	5	5	6	6	5	5	5
25. Elem. Probability	3	2	2	3	3	1	2	2	2	1	4	4	3	3	4
26. Adv. Probability	5	5	5	4	4	3	4	3	3	2	5	5	5	4	5
27. Applied Statistics	5	3	3	4	3	4	4	4	4	2	2	4	2	2	4
28. 1st Cr. Math. Stat.	5	4	4	4	4	4	3	3	3	1	4	4	4	4	5
29. Adv. Math. Stat.	6	4	5	5	4	4	5	4	4	2	5	5	5	4	5
30. Machine Computation	3	2	2	3	3	3	3	3	3	2	2	3	3	2	2
31. 1st Cr. Num. Analysis	2	3	3	3	2	3	3	2	3	3	2	3	4	4	4
32. Mathematical Logic	5	5	5	5	6	5	4	4	5	4	5	5	5	5	5
33. Linear Programming	6	4	4	4	4	4	5	4	5	1	5	5	5	3	4
34. Game Theory	6	5	5	5	4	4	5	4	5	2	5	5	5	4	5
35. Special Functions	4	5	5	5	5	4	4	4	4	5	5	5	5	5	4
36. Integral Equations	4	5	4	5	5	4	3	3	3	5	4	4	5	5	4
37. Approx. Theory	5	5	5	5	5	4	4	4	5	5	6	5	6	5	5
38. Analytic Mechanics	2	5	5	5	4	4	4	3	3	5	4	4	5	5	5
39. Integral Transforms	3	4	4	5	4	3	3	3	3	5	4	4	5	5	4
40. Geometric Algebra	6	5	5	5	6	5	5	5	5	5	6	6	5	5	5

Table IV. Course Recommendations for Physics Specializations

	Acoustics	Atom. and Molec. Awards	Atom. and Molec. Abstracts	Electromag.-Aw	Electromag.-Abs	Elem. Part.-Aw	Elem. Part.-Abs	Fluids	Nuclear - Aw	Nuclear - Abs	Optics - Aw	Optics - Abs	Solid State - Aw	Solid State - Abs
1. 1st Yr. College Math.	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2. 1st Yr. Calculus	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3. 3rd Sem. Calculus	2	1	1	1	1	2	1	1	1	1	1	2	2	2
4. Vectors	1	1	1	1	1	2	2	1	1	1	1	2	1	1
5. Tensor Analysis	2	2	2	2	1	2	2	2	2	2	1	3	2	2
6. Elem. Diff. Eq.	1	1	1	1	1	2	1	1	1	1	1	2	1	1
7. Interm. Ord. D. E.	1	2	2	2	1	2	1	2	1	2	1	3	2	2
8. Adv. Ord. D. E.	2	4	3	4	2	3	3	4	3	3	2	3	4	3
9. 1st Cr. Part. D. E.	1	1	1	1	1	2	1	1	1	2	1	2	1	1
10. Adv. Part. D. E.	2	3	3	4	2	3	3	3	4	3	3	4	3	3
11. Num. Sol. of D. E.	4	4	3	5	2	4	4	4	4	3	2	4	4	3
12. Advanced Calculus	1	1	1	2	1	2	1	1	1	2	2	1	1	1
13. 1st Cr. Real Var.	4	4	4	4	4	4	3	5	4	4	4	4	4	4
14. Real Variables	4	5	4	5	4	4	4	5	5	4	4	4	5	4
15. Functional Analysis	5	5	4	5	4	4	4	5	5	5	5	5	5	5
16. Calc. of Variations	4	4	3	4	3	4	3	3	3	3	2	4	4	3
17. Elem. Complex Var.	2	2	2	2	1	2	1	2	2	2	2	3	2	2
18. Complex Variables	3	3	3	3	2	3	3	2	2	3	3	3	3	3
19. Survey Modern Algebra	5	4	3	4	4	3	3	5	4	4	4	5	4	4
20. Group Theory	4	3	3	4	4	3	1	5	3	3	3	4	3	2
21. Group Representations	5	4	4	5	5	3	3	5	4	4	4	6	4	4
22. Lie Algebras, Groups	5	4	5	5	5	3	2	5	4	5	5	5	5	5
23. Matrix Theory	4	3	2	2	3	2	2	3	3	3	3	3	3	3
24. Multilinear Algebra	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25. Elem. Probability	2	3	4	4	3	3	3	3	3	2	2	4	3	3
26. Adv. Probability	4	5	5	4	5	5	4	4	5	5	4	5	5	5
27. Applied Statistics	4	5	5	4	4	4	4	5	5	4	4	5	4	5
28. 1st Cr. Math. Stat.	4	4	4	4	3	5	4	5	4	4	4	4	4	4
29. Adv. Math. Stat.	5	5	5	5	5	6	5	5	5	5	5	5	5	5
30. Machine Computation	4	3	3	2	3	3	3	3	3	3	3	4	3	3
31. 1st Cr. Num. Analysis	4	4	4	5	4	5	4	3	5	4	4	4	4	4
32. Mathematical Logic	5	5	5	5	5	6	5	5	6	5	5	5	5	5
33. Linear Programming	4	6	5	5	5	5	5	5	5	5	4	5	5	5
34. Game Theory	5	5	5	5	5	6	5	5	6	5	5	5	5	5
35. Special Functions	4	4	4	4	4	3	3	3	4	4	4	5	4	4
36. Integral Equations	3	4	4	3	4	3	3	3	4	4	4	4	4	4
37. Approx. Theory	5	5	5	5	4	6	5	5	5	5	5	5	5	5
38. Analytic Mechanics	3	3	4	3	3	4	3	2	3	4	4	4	3	4
39. Integral Transforms	3	4	3	3	3	4	4	3	5	4	3	4	4	4
40. Geometric Algebra	5	5	5	5	5	6	5	6	5	5	5	6	5	5

Table V. Course Recommendations for Miscellaneous Specializations

	Agriculture	Astronomy and Astrophysics	Bioengineering	Electronics	General M.D.	Geology	Mechanics	Nutrition	Thermal Physics					
1. 1st Yr. College Math.	1	1	1	1	1	1	1	1	1					
2. 1st Yr. Calculus	1	1	1	1	1	1	1	1	1					
3. 3rd Sem. Calculus	1	2	2	2	2	1	2	3	1					
4. Vectors	3	1	3	1	3	2	3	5	2					
5. Tensor Analysis	4	2	3	3	5	3	1	6	3					
6. Elem. Diff. Eq.	1	1	2	1	1	1	1	5	1					
7. Interm. Ord. D. E.	4	2	2	3	4	3	2	6	3					
8. Adv. Ord. D. E.	5	3	5	4	4	5	2	5	4					
9. 1st Cr. Part. D. E.	2	1	2	2	4	2	1	5	2					
10. Adv. Part. D. E.	5	3	4	4	5	4	3	6	5					
11. Num. Sol. of D. E.	4	3	4	4	5	3	3	6	5					
12. Advanced Calculus	3	2	2	1	4	3	2	6	2					
13. 1st Cr. Real Var.	6	4	5	4	5	5	4	6	4					
14. Real Variables	6	5	5	5	5	5	4	6	5					
15. Functional Analysis	6	4	5	5	5	6	5	6	5					
16. Calc. of Variations	5	4	4	4	5	5	2	6	4					
17. Elem. Complex Var.	4	2	3	1	5	3	2	6	2					
18. Complex Variables	5	4	4	4	5	4	2	6	4					
19. Survey Modern Algebra	5	5	4	4	4	5	4	6	4					
20. Group Theory	6	5	5	4	5	5	5	6	4					
21. Group Representations	6	5	6	5	5	6	5	6	5					
22. Lie Algebras, Groups	6	6	6	5	5	6	5	6	6					
23. Matrix Theory	4	3	2	3	5	3	2	5	3					
24. Multilinear Algebra	6	6	6	5	5	6	5	6	6					
25. Elem. Probability	3	3	2	3	4	4	3	3	3					
26. Adv. Probability	6	4	4	5	5	5	4	5	5					
27. Applied Statistics	1	4	2	4	2	3	3	2	5					
28. 1st Cr. Math. Stat.	3	3	3	4	4	3	4	4	5					
29. Adv. Math. Stat.	5	5	4	5	5	5	6	5	5					
30. Machine Computation	2	2	2	3	4	3	3	4	4					
31. 1st Cr. Num. Analysis	3	3	4	5	5	4	3	5	4					
32. Mathematical Logic	6	5	5	6	4	5	5	6	5					
33. Linear Programming	4	5	5	5	5	5	4	5	5					
34. Game Theory	6	5	5	6	5	5	5	5	5					
35. Special Functions	6	4	5	5	5	5	4	5	5					
36. Integral Equations	6	3	5	5	5	5	4	5	4					
37. Approx. Theory	5	5	5	5	5	5	4	5	6					
38. Analytic Mechanics	4	3	4	4	5	4	2	5	4					
39. Integral Transforms	5	4	4	4	5	5	3	5	4					
40. Geometric Algebra	6	5	6	6	5	6	6	5	6					

V. CONCLUSIONS AND RECOMMENDATIONS

A. Biology

1. Analysis of Respondents

The analysis of the biology respondents showed that a 77% reply was received in both the Awards and Abstracts Groups. Approximately 60% of the two groups completed the Course Recommendation Form or sent in an opinion. Due to inactivity during retirement, foreign training, or not being familiar enough with the mathematics courses, 15% disqualified themselves. Of the 1.5% who indicated that they were too busy, many expressed their regret in not being able to cooperate at the time. There were .5% who did not fill out the form. Along with the completed questionnaires, there were 68 comments. Also, many significant comments were given by 66 respondents who did not send in the completed questionnaire. The total number of biologists, including biophysicists, who sent in forms was 857.

The following number of completed forms were received in each specialization of biology: anatomy - 30, biophysics - 74, botany - 31, ecology - 58, genetics - 131, microbiology and virology - 113, microbiology and virology, M. D. - 26, pathology - 76, pharmacology - 49, pharmacology, M. D. - 27, physiology, Awards - 30, physiology, Abstracts - 88, physiology, M. D. - 69, and zoology - 55. Refer to Table I.

2. Conclusions and Recommendations

a. Biology students who plan to be active research specialists should take all mathematics courses which are very highly recommended or highly recommended in their area of specialization provided they have the mathematical aptitude. Those courses which are very highly recommended are the one-year calculus sequence and applied statistics. Courses which are moderately recommended are third-semester calculus, elementary differential equations, and elementary probability. Machine computation and the first course in mathematical statistics are of moderate value for those in ecology and genetics. All courses should be selected with the aid of consultants or advisors where they are available.

b. The great majority of the biologists indicated that they prefer a mathematics course which is approximately fifty per cent theory and fifty per cent application. A number of the scientists in the specializations of anatomy, botany, genetics, physiology, microbiology, and zoology indicated that the course in machine computation should be either all application or mostly application with little theory.

c. The mathematics courses recommended were to be given for the standard lengths of time such as one or two semesters.

d. There was considerable uniformity in the recommendations of the biologists despite their different specializations. In general, those in anatomy, botany, microbiology, and zoology used the least amount of mathematics. Those in ecology, genetics, physiology, and biophysics used the greatest amount of mathematics. The number of mathematics courses given a moderate or higher recommendation ranged from a low of three courses for those in

botany and zoology to a high of ten courses for those in biophysics and for a selected sample in ecology.

e. An interesting result of the Study was a realization by biologists in the specializations of anatomy, ecology, genetics, physiology, and biophysics of the need for courses such as elementary probability, applied statistics, and machine computation. It was recommended that these courses be mostly applied in content.

f. Due to the few awards given by the professional biological organizations, it was not always possible to obtain separate results for an Awards Group and an Abstracts Group for the purpose of comparison. However, in the few specializations which had large samples for both groups, it was observed that most of the results were within one quintile of each other with the Abstracts Group recommending slightly more mathematics than the Awards Group.

g. A very large portion of the comments were devoted to the fact that they did not use much mathematics in their work. Most of those who disqualified themselves did so for this reason. There were a number of biologists in anatomy, botany, and zoology who have made very significant contributions to their profession without the use of much mathematics. A number of respondents indicated a definite need for biologists in these specializations who have excellent research potential but may not have good mathematical ability. Thus, mathematical requirements should not be so rigid that these potential biologists are eliminated from the field of their choice.

h. It would appear that advanced applied mathematics in courses such as intermediate ordinary differential equations and the first course in partial differential equations and the newer courses in mathematics such as group theory, functional analysis, game theory, and multilinear algebra are of little use to the biologists at the present time. Thus, these courses should be given a low priority for the biology student.

i. An analysis of the differences within each specialization showed uniform recommendations among applied, combination, and theoretical groups, between academic and non-academic groups, administrative and non-administrative groups, and among age groups. Most of the differences within specializations were concerned with the following courses: third-semester calculus, elementary ordinary differential equations, applied statistics, elementary probability, the first course in mathematical statistics, and machine computation.

B. Chemistry

1. Analysis of Respondents

The analysis of the chemistry respondents showed that we received a 76% reply. Approximately 62% of those in the two groups completed the Course Recommendation Form or sent in an opinion. Due to inactivity during retirement, foreign training, or not being familiar enough with the mathematics courses, 11% disqualified themselves. Of the 1.5% who indicated that they were too busy, a high portion expressed their regrets in not being able to cooperate at the time. There were .5% who did not fill out the form. There were 69 comments which came along with the completed questionnaires. Many significant comments were also given by 62 respondents who did not send in the completed questionnaire. The total number of chemists who sent in forms was 1310.

The following number of completed forms were received in each specialization of chemistry: analytic, Awards - 46, analytic, Abstracts - 59, biochemistry, Awards - 109, biochemistry, Abstracts - 275, inorganic, Awards - 20, inorganic, Abstracts - 79, organic, Awards - 47, organic, Abstracts - 327, physical, Awards - 81, and physical, Abstracts - 267. Refer to Table II.

2. Conclusions and Recommendations

a. Chemistry students who plan to be active research specialists should take all mathematics courses which are very highly recommended or highly recommended, provided they have the mathematical aptitude. All research chemists recommended that students take the full calculus sequence, including third-semester calculus and elementary differential equations. In addition, the Awards group of the inorganic chemists recommended a first course in partial differential equations, vectors, advanced calculus, and group theory. The physical chemists recommended all of the above plus intermediate ordinary differential equations, the first course in partial differential equations, and matrix theory. All courses should be selected with the aid of consultants or advisors where they are available.

b. The great majority of chemists indicated that they prefer a course which is approximately fifty per cent theory and fifty per cent application. Very few marked their responses for all theory.

c. Most of the mathematics courses were recommended for the standard lengths of time. However, on certain advanced topics a number of chemists recommended only a few weeks' preparation in place of a complete course.

d. According to a number of comments, there is a definite need for organic chemists and biochemists who do not have outstanding mathematical ability but do have excellent research potential. Thus, mathematics requirements should not be made so rigid that these potential chemists are eliminated from the fields of their choice.

e. It appears that courses such as functional analysis, Lie algebras, multilinear algebra, mathematical logic, game theory, approximation theory, analytic mechanics, and geometric algebra are not valuable at the

present time for the research worker in chemistry and thus would not be of value to the chemistry student. Therefore, a low priority should be given to the mathematics courses in the chemists' curricula.

f. As expected, biochemists and organic chemists recommended the least amount of mathematics. The inorganic and analytical chemists recommended a moderate amount of mathematics, and the physical chemists recommended a very large amount. Physical chemists use the most mathematics in their work,but at the same time they have the most disagreement on the value of specific mathematics courses.

g. One interesting fact brought out is the awareness of the importance of group theory by the physical, inorganic, and analytical chemists. Even though they recommended group theory, they did not give as high a recommendation to a survey of modern algebra, which is recommended by the mathematicians as a background course for group theory. What seems to be needed is material in group theory which will provide the basic fundamentals and at the same time give all the necessary applications which will be of value to the chemist.

h. Observation of the recommendations by the Awards group and the Abstracts group showed that all courses were within one quintile of each other. Thus, these recommendations remain approximately the same for both groups of chemists.

i. There were a number of opinions and some general discussion on the fact that there has been too much emphasis on mathematics for chemists, especially in regard to the amount of theory which many mathematics courses contain. A number of chemists think that the standard recommended courses, such as first-year college mathematics and calculus, are all that are needed.

j. A number of respondents recommended that chemistry students come to college prepared to take calculus. This comment was noted most often in the responses of the physical chemists.

k. A comparison within specializations showed little differences between administrative and non-administrative chemists and between academic and non-academic chemists.

l. There were minor differences between age groups and applied, combination, and theoretical groups. In general,the younger the age group, the more mathematics they recommended. However, there was a very noticeable uniformity of responses in the 35-59 age groups. The more theoretical the orientation, the more mathematics was recommended. Differences in recommendations varied greatest with the physical chemists who took the most mathematics. Most of the differences within specializationswere concerned with the following courses: matrix theory, group theory, and machine computation.

C. Engineering

1. Analysis of Respondents

The analysis of the respondents showed that we received a 79% reply from engineers in both the Awards Group and the Abstracts Group. Approximately 61% of those in the two groups completed the Course Recommendation Form or sent in an opinion. Due to inactivity during retirement, foreign training, or to not being familiar enough with the mathematics courses, 16% disqualified themselves. Of the 1.5% who indicated that they were too busy, many expressed their regret in not being able to cooperate at the time. There were .5% who did not fill out the form. Along with the completed questionnaires, there were 52 comments. Many significant comments were also given by 32 respondents who did not send in the completed questionnaire. The total number of engineers who sent in forms was 700. An additional 50% of the non-respondents were found to lack the Ph.D. However, since most of the 113 engineers who disqualified themselves did so on the basis of not having the qualifications for the Ph.D., it is highly likely that these non-respondents felt unqualified to make recommendations even though they were excellent research specialists.

The following number of completed forms were received in each specialization of engineering: aeronautical - 36, chemical, Awards - 41, chemical, Abstracts - 65, civil, Awards - 25, civil, Abstracts - 18, electrical, Awards - 83, electrical, Abstracts - 50, engineering science, Awards - 43, engineering science, Abstracts - 37, industrial - 67, mechanical, Awards - 27, mechanical, Abstracts - 36, metallurgical - 99, mining - 44, and nuclear - 29. Refer to Table III.

2. Conclusions and Recommendations

a. Engineering students who plan to be active research specialists should take all those courses which are very highly recommended and highly recommended in their area of specialization. Those courses in the upper two quintiles and recommended by most engineers are the calculus sequence, vectors, tensor analysis, elementary and intermediate ordinary differential equations, partial differential equations, numerical solutions of differential equations, and advanced calculus. Courses of moderate recommendation are matrix theory, elementary probability, machine computation, and the first course in numerical analysis.

b. The great majority of engineers indicated that they prefer a course which is approximately fifty per cent theory and fifty per cent application. In a number of specializations, the recommendation was for mostly application in courses such as applied statistics, machine computation, the first course in numerical analysis, numerical solutions of differential equations, and the advanced courses in differential equations. Those in engineering science and electrical engineering made less use of applications than those in the other specializations.

c. Recommendations in general were for courses to be given for the standard lengths of time such as one to two semesters.

d. Since a number of highly qualified research engineers in certain specializations such as chemical, civil, and mechanical engineering do not make much use of the higher level courses, it would be best that mathematics requirements not be so rigid that potential engineers cannot continue in the field of their choice.

e. Since there were a number of recommendations for short three to six-week courses in many topics, it would seem desirable to combine these related courses into a one or two-semester course so that the student could acquire this important mathematics at an early date and be better prepared to do his research.

f. There was considerable uniformity in the recommendations of the engineers, although there were rather noticeable differences between engineers in certain specializations. Those in electrical engineering and engineering science recommended the most mathematics, and those in chemical, metallurgical, mining, and nuclear engineering recommended the least amount of mathematics.

g. The same general pattern of recommendations was made by both the Awards Group and the Abstracts Group with almost all recommendations being within one quintile of each other.

h. Many of those who disqualified themselves mentioned that their work made very little use of mathematics beyond the calculus level. This type of answer was received most often from those in civil engineering. It seems apparent that there are a number of excellent contributing engineers who do not use much mathematics beyond differential equations.

i. There was little use for courses such as the real variables-functional analysis sequence. In addition, there were uniformly very low recommendations for multilinear algebra, advanced probability, advanced mathematical statistics, mathematical logic, linear programming, game theory, special functions, approximation theory, and geometric algebra. Therefore, these courses should be given a low priority for the engineering student.

j. The comparison of differences between groups (i.e., administrative-non-administrative, academic - non-academic) within specializations of engineers showed a number of variations. These variations, however, showed no basic trends among the different specializations. The reader is referred to the appropriate professional journals in engineering for more detailed information on his specialization.

D. Physics

1. Analysis of Respondents

The analysis of the respondents showed that we received an 80% reply from physicists in both the Awards and Abstracts Groups. Approximately 60% of those in the two groups completed the Course Recommendation Form or sent in an opinion. Due to inactivity during retirement, foreign training, or to not being familiar enough with the mathematics courses, 18% disqualified themselves. Of the 1% who indicated that they were too busy, many expressed their regret in not being able to cooperate at the time. There were 1% who did not fill out the form. Along with the completed questionnaires, there were 84 comments. Many significant comments were also given by 55 respondents who did not send in the completed questionnaire. The total number of physicists who sent in forms was 874. The highest response of completed questionnaires in the Study was that of the physicists in the Abstracts Group who had a 69% response.

The following number of completed forms were received in each specialization of physics: acoustics - 34, atomic and molecular, Awards - 37, atomic and molecular, Abstracts - 92, electromagnetism, Awards - 23, electromagnetism, Abstracts - 32, elementary particles, Awards - 38, elementary particles, Abstracts - 74, fluids - 58, nuclear, Awards - 58, nuclear, Abstracts - 81, optics, Awards - 29, optics, Abstracts - 26, solid state, Awards - 79, and solid state, Abstracts - 213. Refer to Table IV.

2. Conclusions and Recommendations

a. Physics students who plan to be active research specialists and physicists in industry who plan to work on advanced degrees should take all the mathematics courses which are very highly recommended and highly recommended. These courses are as follows: first-year calculus, third-semester calculus, vectors, tensor analysis, elementary and intermediate ordinary differential equations, the first course in partial differential equations, advanced calculus, and elementary complex variables. In addition, the potential Ph.D. in physics might want to consider taking additional mathematics courses which are moderately recommended provided he has sufficient time. These courses are as follows: advanced ordinary differential equations, advanced partial differential equations, complex variables, matrix theory, elementary probability, machine computation, analytic mechanics and integral transforms. All course work should be selected with the aid of advisors when they are available.

b. The great majority of physicists indicated that they prefer a course which is approximately fifty per cent theory and fifty per cent application. There were some recommendations for mostly theory, but they were for courses that are primarily theoretical, such as functional analysis and a survey of modern algebra. On the other hand, there were a number of recommendations for mostly applications in courses such as machine computation, linear programming, and analytic mechanics.

c. Recommendations were for courses to be given for the standard lengths of time such as one or two semesters. However, only certain topics from some of the more advanced courses were considered necessary since recommendations were for only a few weeks' instruction in place of the usual semester's or quarter's designation.

d. There was considerable uniformity among the recommendations of the physicists despite their different specializations. However, there was some disagreement between specializations on the following courses: numerical solutions of differential equations, the first course in real variables, survey of modern algebra, group theory, group representations, Lie algebras and Lie groups, applied statistics, the first course in mathematical statistics, the first course in numerical analysis, and integral transforms. The most mathematics was used by those in elementary particles and mechanics, and the least amount of mathematics was used by those in thermal physics. Those in elementary particles seemed to place much emphasis on group representations and Lie algebras and Lie groups in marked comparison with those in other specializations. Those in fluids and mechanics made much use of the first course in numerical analysis compared with those in other specializations. The only physicists who thought that the first course in real variables was of moderate value were those in elementary particles.

e. One interesting fact that was brought out is the awareness on the part of a number of specialists in atomic and molecular physics, elementary particles, nuclear physics, optics, and solid state physics of the usefulness of a course in group theory. Even though they recommended the course in group theory, they did not give as high a recommendation to a survey of modern algebra, which is a prerequisite course for group theory. What seems to be needed is material in group theory which will provide the basic fundamentals and at the same time give all the necessary applications which will be of value to the physicist.

f. Observations of the recommendations by the Awards Group and the Abstracts Group showed the same relative position for all courses within one quintile with the exception of a few differences which existed in optics. Thus, in general the recommendations were about the same for both groups although the Abstracts Group used a little more mathematics than the Awards Group.

g. A number of respondents recommended that those who will be physics majors should come to college prepared to take the calculus sequence. This trend was noted for all specializations in physics.

h. There was considerable agreement among most specializations as to what mathematics courses were the least valuable. They were as follows: real variables, functional analysis, group representations, multilinear algebra, advanced probability, applied statistics, advanced mathematical statistics, mathematical logic, linear programming, game theory, approximation theory, and geometric algebra. These courses should be given low priority.

i. There was little difference in course recommendations between physicists in the Awards or Abstracts groups, administrative or non-administrative groups, and academic or non-academic groups. There was a slight difference in increased mathematics requirements as one goes from the applied group to the combination group to the theoretical group. In addition, the trend was observed that physicists in the age groups from 35 through 60 agreed on most of the course work. Those over 60 recommended less mathematics than any other age group.

E. General Analysis for All Specializations

1. Analysis of Respondents

The analysis of the respondents showed a 78% reply from scientists and engineers in both the Awards and Abstracts Groups. Approximately 61% of those in the two groups completed the Course Recommendation Form or sent in an opinion. Due to inactivity during retirement, foreign training, or to not being familiar enough with the mathematics courses, 15% disqualified themselves. Of the 1% who indicated that they were too busy, many expressed their regret in not being able to cooperate at the time. There were 1% who did not fill out the form. Along with the completed questionnaires, there were 273 comments. Many significant comments were also given by 215 respondents who did not send in the completed questionnaire. The total number who sent in completed forms was 4035. The total number of scientists and engineers which remained in the Study after eliminating those with wrong addresses, insufficient background information, and duplications was 6914. The highest response in the Study came from the physicists in the Abstracts Group who had 69% completed questionnaires.

The breakdowns for the miscellaneous specializations in Table V are as follows: agriculture and related specializations - 16, astronomy and astrophysics - 24, bioengineering - 16, electronics - 22, general M. D. - 37, geology and geophysics - 31, mechanics - 18, nutrition - 25, thermal physics - 22. In addition, there were minor specializations - 11, non-scientific fields - 21, and forms too late for analysis - 51.

2. Conclusions and General Recommendations for All Specializations

a. All scientists and engineers who wish to be research specialists should take all those courses which are very highly and highly recommended for their area of specialization. Course selections should be made with the assistance of an advisor when available.

b. The great majority of scientists and engineers indicated that they desired a course which is fifty per cent theory and fifty per cent application. A number of recommendations for "mostly application" were in courses such as applied statistics and machine computation. Thus, mathematics departments which instruct courses for scientists and engineers providing 50 per cent theory and 50 per cent application follow the recommendations of the top research scientists and engineers in the nation.

c. Courses were usually recommended for the standard lengths of time such as one or two semesters. However, there were a number of requests for the combining of the useful topics in two or more courses in mathematics into one course so that the individual can have sufficient mathematical training to solve the problems which he encounters in his specialization.

d. Scientists and engineers found little use for courses such as the functional analysis sequence, the modern algebra sequence, and the advanced group theory sequence. In addition, there were uniformly low recommendations for complex variables, multilinear algebra, advanced mathematical statistics, mathematical statistics, linear programming, game theory, approximation theory, and geometric algebra. Thus, these courses should be given low priority.

e. The one exception to the above statement was the awareness of the value of group theory for certain specializations such as analytical, inorganic, and physical chemistry; most physics specializations; and electrical engineering and engineering science. However, in these cases there seemed to be the need for a course which would provide the basic fundamentals of theory and at the same time give all the necessary applications which would be of value for their specializations.

f. The recommendations of those in the specializations were most consistent. There were few differences in recommendations between the Awards Group and the Abstracts Group. There were few differences between the academic and non-academic groups, as well as between the administrative and non-administrative groups. However, it was noted that those in the academic and non-administrative groups recommended slightly more mathematics than those in non-academic and administrative groups. Those in the combination-theoretical group used more mathematics than those in the applied group. In most instances the recommendations of the combination and theoretical groupswere closely related. Due to the low number of theoretical scientists, comparisons with the theoretical group above could not always be made. The analysis of the specializations for age groups showed that the recommendations of those from 35 to 60 were very similar; but in general, the lower the age group, the more mathematics was recommended. Those above 60 usually recommended the least amount of mathematics. In some cases those below 35 recommended less mathematics than the older age groups. Also, the under 35 group had a tendency to recommend more of the newer courses.

g. In the specializations of botany, zoology, organic chemistry, and biochemistry, there were a number of scientists who quite clearly indicated that a good mathematical background was not necessary to make contributions in their area. They indicated that rather good research could be done without much mathematics. In addition, there were a number of engineers who indicated that there was too much emphasis on mathematics. Thus, one should be cautious in making requirements in mathematics so rigid that potential research specialists are eliminated from their chosen fields.

h. There were great differences in course recommendations among specializations within the same area of science. The most differences were in chemistry, and the least differences were in physics. The difference between the organic chemist who recommended three courses and the physical chemist who recommended twelve courses is most significant. There was also a great difference when botany and zoology were compared with genetics and ecology and when civil engineering was compared with engineering science. Due to these great differences in recommendations, one must be sure that he chooses the best mathematics courses for his own specialization.

Appendix A

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Appendix B

Board of Advisors and Consultants

Board of Advisors

Biological Sciences

1. Dr. Const. J. Alexopoulos
   Prof., University of Texas
2. Dr. Earl L. Green, Director
   The Jackson Laboratory
3. Dr. H. O. Halvorson
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4. Dr. Cadet H. Hand, Jr.
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7. Dr. Wm. A. Nierenberg, Director
   Scripps Inst. of Oceanography
8. Dr. John R. Olive
   Executive Director, A.I.B.S.
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   Oak Ridge N.L. - Univ. of Tenn.
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    Prof., University of Illinois

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5. Dr. Robt. S. Mulliken, Univ.
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   American Chemical Society
9. Dr. E. L. Tatum, Professor
   Rockefeller University
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    Stanford University

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3. Dr. E. U. Condon, Prof.
   University of Colorado
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   General Motors Corporation
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6. Dr. E. R. Piore, Vice Pres.
   IBM Corporation
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   American Inst. of Physics
8. Dr. W. D. Walker, Professor
   University of Wisconsin
9. Dr. C. Zener, Dean
   Texas A and M University
10. Dr. V. K. Zworykin, Hon. V. P.
    RCA Laboratories

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   Dean of Engineering, MIT
2. Dr. A. M. Bueche, Vice Pres.
   General Electric Corporation
3. Mr. Donald G. Fink
   General Manager, IEEE
4. Mr. Carl Frey, Secretary
   Eng. Joint Council
5. Dr. George A. Hawkins
   Dean, Purdue University
6. Mr. Edward H. Heinemann, V.P.
   General Dynamics Corporation
7. Dr. George E. Holbrook, V.P.
   E.I. du Pont de Nemours and Co.
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   of Eng., Univ. of So. Calif.
9. Dr. Charles H. Norris, Dean
   University of Washington
10. Mr. Robert L. Wells, V. P.
    Westinghouse Elec. Corp.

Mathematical Consultants

Dr. Edward Cannon, Director of Applied Mathematics
U. S. Bureau of Standards, Washington, D. C.

Dr. Charles W. Curtiss, Department of Mathematics
University of Oregon

Dr. H. H. Goldstine
IBM Corporation, New York

Dr. Wolfgang R. Wasow, Professor of Mathematics
University of Wisconsin

Educational Consultants

Dr. John W. M. Rothney, Professor of Education
University of Wisconsin

Dr. D. Welty Lefever, Professor Emeritus of Educational Psychology
University of Southern California

Mr. Robert E. Roseen, Systems Engineer
IBM Corporation, Madison, Wisconsin

Appendix C

NSMRSE

COURSE RECOMMENDATION FORM

PRINTED IN U.S.A. IBM H95312

IDENTIFICATION NUMBER

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
0 1 2 3 4 5 6 7 8 9

MAXIMUM RECOMMENDED HOURS OF MATHEMATICS _____ HRS

SECT. 1 — BIOLOGY

ANATOMY BOTANY ECOLOGY GENETICS MICROBIOLOGY PATHOLOGY PHARMACOLOGY PHYSIOLOGY VIROLOGY ZOOLOGY

CHEMISTRY

ANALYTICAL BIOCHEMISTRY INORGANIC ORGANIC PHYSICAL

PHYSICS

ACOUSTICS ATOMIC & MOLECULAR ELECTRO-MAGNETISM ELEMENTARY PARTICLES FLUIDS MECHANICS NUCLEAR OPTICS SOLID STATE THERMAL

ENGINEERING

AERONAUTICAL CHEMICAL CIVIL ELECTRICAL ENGINEERING SCIENCE INDUSTRIAL MECHANICAL METAL-LURGICAL MINING NUCLEAR

OTHER SPECIALIZATION (WRITE IN) _____

INTERDISCIPLINARY

BIOPHYSICS BIOENGINEERING ELECTRONICS

SECT. 2

APPLIED COMBINATION THEORETICAL

SECT. 3

B.A. M.A. PH.D. OTHER (WRITE IN) _____

SECT. 4

ACADEMIC INDUSTRY OR BUSINESS GOVT. NON-PROFIT

SECT. 5

ADMIN. NON-ADMIN.

SECT. 6

UNDER 30 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-70 OVER 70

SECT. 7 — I. COURSE LENGTH — II. APPLIED THEORETIC — III. COURSE LEVEL — IV. KNOWLEDGE — V. USE

	I. COURSE LENGTH	II. APPLIED THEORETIC	III. COURSE LEVEL	IV. KNOWLEDGE	V. USE
First Year College Mathematics	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
First Year Calculus and Analytic Geometry	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Third Semester Calculus	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Vectors	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Tensor Analysis	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Elementary Differential Equations	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Intermediate Ordinary Differential Equations	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Advanced Ordinary Differential Equations	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
First Course In Partial Differential Equations	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Advanced Partial Differential Equations	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Numerical Solutions of Differential Equations	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Advanced Calculus	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
First Course in Real Variables	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Real Variables	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Functional Analysis	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Calculus of Variations	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	
Elementary Complex Variables	3W 6W 12 18 36	AA MA FF MT AT	F-S U-G GO TC PC	RS RE N S O	

(over)

PRINTED IN U.S.A. IBM H95313

IDENTIFICATION NUMBER

CT. 7 I. COURSE LENGTH II. APPLIED THEORETIC III. COURSE LEVEL IV. KNOWLEDGE V. USE

Complex Variables
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Survey of Modern Algebra
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Group Theory
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Group Representations
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Lie Algebras and Lie Groups
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Matrix Theory or Linear Algebra
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Multilinear Algebra
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Elementary Probability
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Advanced Probability
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Applied Statistics
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

First Course in Mathematical Statistics
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Advanced Mathematical Statistics
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Machine Computation
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

First Course in Numerical Analysis
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Mathematical Logic
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Linear Programming
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Game Theory
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Special Functions
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Integral Equations
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Approximation Theory
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Analytic Mechanics
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Integral Transforms
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Geometric Algebra
3W 6W 12 18 36 AA MA FF MT AT F-S U-G GO TC PC RS RE N S O

Appendix D

INSTRUCTIONS FOR COMPLETING THE NSMRSE RECOMMENDATION FORM

Please complete the Course Recommendation Form in the following manner.

Mark all responses by filling in between the double lines. Use pencil only. In Section 1 mark your present specialization as a scientist or an engineer. If you have several specializations, consider only the specialization in which you have had the most experience. If you feel qualified in other specializations, you may write your recommendations on a separate sheet and return it with the Course Recommendation Form. **In Section 2** mark whether your work is primarily applied, theoretical, or a combination. **In Section 3** mark your highest degree–i.e., Bachelor, Master, Ph.D., or other degree if it is not given. **In Section 4** mark your primary type of employment–Academic, Industry or Business, Government, or Non-profit Organization. **In Section 5** mark whether you are primarily an administrator or a non-administrator. **In Section 6** mark the category which contains your age.
Section 7 contains forty possible courses which students might take for their area of specialization. These courses have been recommended by a panel of well-known mathematicians and scientists. **Please mark only those courses with which you are familiar and which you would recommend for the Ph.D. in your area of specialization. If you are unfamiliar with a course and do not recommend it, make no mark whatever regarding that course. If you are familiar with the course but do not recommend it, please mark Section IV only.** For each course you do recommend, there are five parts to be considered. Please mark the most appropriate category for each part. The five parts are as follows.

I. Length of time of course (3 hours per week–assume one semester equivalent to 18 weeks and one quarter equivalent to 12 weeks)
   - 3W. 3 weeks
   - 6W. 6 weeks
   - 12. 12 weeks
   - 18. 18 weeks
   - 36. 36 weeks

II. Degree of applied-theoretic emphasis
   - AA. all applications (no proofs, only statements of important theorems)
   - MA. mostly applications with some work in proving a few major theorems
   - FF. fifty percent on applications and fifty percent on proving theorems
   - MT. development of all major and some minor theorems with some practical applications of the theorems
   - AT. all theoretical (only mention of possible applications)

III. Undergraduate or graduate level
   - FS. freshman or sophomore
   - UG. undergraduate or graduate
   - GO. graduate only

IV. Your knowledge of the course work
   - TC. took the complete course
   - PC. covered some of the topics in part of another course
   - RS. read some material in this area
   - RE. read extensively in this area

V. Your use of the course topics in your specialization
   - N. none
   - S. sometimes
   - O. often

After completing your selections, please check to make sure that these courses represent the best selection of required courses that a student can take for your area of specialization. **Please be sure that the courses which you do recommend are realistic from the standpoint of the usual time required to obtain the Ph.D. in your area of specialization.** When the form has been completed, please send it to the NSMRSE Center. If you would like to make additional comments, enclose them with the Course Recommendation Form.

Before marking the form, please fill in the box in Section 1. to indicate the maximum number of semester or quarter hours, credits or units in mathematics you would recommend for the Ph.D. in your area of specialization. Include both undergraduate and graduate work.

(over)

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 simplectic groups. Pre: 19, 23

N S M R S E

National Study Of Mathematics Requirements For Scientists And Engineers

Dr. G. H. Miller, Director - Tennessee Technological University, Cookeville, 38501

The NSMRSE has been initiated to determine the most realistic mathematics requirements for the areas of specialization in the biological sciences, chemistry, engineering, and physics. Since you are an outstanding authority in your specialization, your viewpoint is being sought to establish realistic mathematics requirements for the Ph.D. candidate that will prepare him for the future in your specialization.

This study has been designed so that you can make your recommendations in a very short period of time and yet provide significant information. The Course Recommendation Form and the Instruction and Course Content Sheet have been developed with the assistance of the members of the Board of Advisors and with consultants in the appropriate areas. The data that you provide will be of invaluable aid in advising undergraduate and graduate students and in forming realistic curricula based on the consensus of a large number of national authorities in their specialization.

Your cooperation in promptly filling out the course recommendation sheet will be greatly appreciated. As soon as the data are complete, you will receive a resume of the results. Thank you for your assistance.

Sincerely,

G. H. Miller
Professor of Mathematics

GHM/mm
Enclosures 3

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Appendix F

N S M R S E

National Study Of Mathematics Requirements For Scientists And Engineers

Dr. G. H. Miller, Director - Tennessee Technological University, Cookeville, 38501

Several weeks ago you were sent a course recommendation form to be completed for our study. At present our records indicate that we did not receive your completed form.

The information from this study will be of great benefit to many students in colleges and universities and to those in industry who plan to continue their work on advanced degrees. A great amount of work was done in identifying you as an authority in your specialization, as indicated by the professional journals. Therefore your viewpoint of realistic mathematics requirements in your specialization, whether you recommend less or more mathematics, is vital to the validity of our study. We would appreciate your completing and returning this course recommendation form as soon as possible.

If you find it more convenient to write your recommendations than to complete the form, please do so. Also, if you find that you are unable to complete the form, please return the letter with a brief explanation so that our records may reflect your response.

You will receive a copy of the results as soon as the data are analyzed.

Sincerely,

G. H. Miller
Professor of Mathematics

GHM:jm
Enclosures (3)

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