Mathematics for Biologists, Chemists, and Physicists

Results of National Study of Mathematics Requirements for Scientists and Engineers are presented.

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Because of the recent advances in science and technology and the accompanying increased use of mathematics, the selection of the best mathematics courses for a science curriculum is of major importance. The many studies of these requirements (*1*) have not been concerned with specific mathematics requirements for each specialization; nor have they concentrated on requirements for graduate degrees.

The value of courses in modern mathematics for students with higher degrees and for active research workers needs to be determined. The increased number of mathematics courses makes it necessary for the scientist studying for an advanced degree to know which mathematics courses will do him the most good. The National Study of Mathematics Requirements for Scientists and Engineers (NSMRSE) (*2*) was designed to make this information available.

The Study

The NSMRSE began with the selection of a board of advisers. The members of the board were nationally known scientists and engineers who supported the basic idea of the study. The selection of the best participants for the study was discussed with the members of the board, as well as with other scientists and engineers. Approximately 10,000 scientists and engineers were selected for the study and were placed in two categories. The Awards group were recipients of national honors or awards or were recommended by members of the board for their national and international reputations. The Abstracts group were individuals exceptionally productive in research, as based on the number of journal articles listed in the last 5 years 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 advisers and other consultants. The course recommendation form was devised so that a minimum of time was needed to complete it and yet obtain the maximum amount of information. The mathematical consultants selected 40 courses for the study. The course content and instruction sheet was made up with clear, concise instructions. A brief résumé of each of the 40 courses was given.

The first letters were sent out during the end of February 1967, and follow-up letters were sent until October. Each individual was sent (i) a letter stating the importance of the study, (ii) a coded IBM form, (iii) an instruction and course content sheet, and (iv) a return stamped envelope. The respondent was asked to indicate his area of specialization, orientation of work, highest degree obtained, category of employment (academic, industry, government, nonprofit organization), administrative capacity, and age category (5-year intervals) on the first six sections of the course recommendation form. In the seventh section he was asked to mark his coded IBM form for: (i) recommended time for a specific course (3 weeks, 6 weeks, 12 weeks, 18 weeks, 36 weeks); (ii) grade level of the course (freshman-sophomore, undergraduate-graduate, graduate only); (iii) applied-theoretic orientation (a five-point scale ranging from all application to all theory); (iv) his actual knowledge of the course (took course, took part of course, read some, or read extensively); and (v) his use of the course content in his work (none, sometimes, often). The respondent was asked to recommend courses for the Ph.D. only in his own specialization. Advance notice of the study was given in *Science* (7 April 1967, p. 47). This notification aided in obtaining an increased number of responses.

The analysis of the respondents in the Awards and Abstracts groups showed a reply of 77 percent for biology, 76 percent for chemistry, and 79 percent for physics. The breakdown of the replies for the combined groups gave the following results: 61 percent completed a form or sent in an opinion, 15 percent disqualified themselves, and 2 percent did not complete the form. This percentage is based on the total number of responses after those with wrong addresses, insufficient background information, and those which were duplications were eliminated from the original lists. There were 221 personal comments that came along with the completed questionnaires. Of those who did not complete the questionnaires, 183 respondents sent in personal comments. A total of 3229 scientists representing 34 specializations sent in completed forms.

The forms were analyzed at the Tennessee Technological University computer center. The résumé of the recommended courses is reported in quintiles (the upper fifth to the lower fifth), since recommendations of this kind are not precise. Because the results of the study are based on recommendations of the scientists most active in the United States today, they represent an upper bound of mathematics requirements for the Ph.D. in both undergraduate and graduate work.

Conclusions

Only the general observations for biologists, chemists, and physicists are reported here. More detailed information on each specialization will be found in the professional journals and in the final report to the U.S. Office of Education. For information on engi-

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neering, refer to the engineering journals.

All scientists in biology, chemistry, and physics recommended that mathematics courses be approximately 50 percent theory and fifty percent application. Many biologists and chemists advised that there be more applications and less theory in courses like applied statistics and machine computation.

In general, all scientists recommended that courses be given for the standard lengths of time (one or two semesters). There was uniformity of course recommendations for all scientists despite their different specializations. The course recommendations for each basic area are as follows:

Biology. First-year college mathematics (preparation for calculus), first-year calculus, and applied statistics.

Chemistry. First-year college mathematics, first-year calculus, third-semester calculus, and differential equations.

Physics. First-year college mathematics (if not taken in high school), the calculus sequence, vector and tensor analysis, elementary differential equations, intermediate ordinary differential equations, first course in partial differential equations, advanced calculus, and elementary complex variables.

There was wide variability in course recommendations in certain basic areas. In biology, a number of ecologists and geneticists strongly suggested elementary probability. The physiologists preferred elementary differential equations. In chemistry, the inorganic and physical chemists indicated a preference for a first course in partial differential equations, vectors, advanced calculus, and group theory. The physical chemists gave high recommendations to intermediate ordinary differential equations and matrix theory.

There were few recommendations for courses in modern mathematics such as abstract algebra, functional analysis, and mathematical logic with the exception of group theory. All results between the Abstracts and Awards groups were similar—usually within one quintile of each other. Thus, the recommendations show a fair degree of consistency.

Many scientists in specializations such as zoology, microbiology, and organic chemistry commented that valuable research could be done by those whose training in mathematics was minimum. The analysis of those who disqualified themselves indicated that even though they were outstanding research specialists, they did not use much mathematics in their work. Thus, the NSMRSE showed that there are many excellent research specialists whose work does not require much mathematics. In physical chemistry and in all branches of physics, many scientists stressed the need for the student to come to college ready to take calculus.

Recommendations

Most courses should be a combination of 50 percent theory and 50 percent application. In courses such as statistics and machine computation, most scientists recommended a greater emphasis on applications than on theory.

All courses which are highly recommended should be taken by all students working for the advanced degree. All course work should be selected on the advice of advisers when available.

Many scientists indicated that certain mathematics courses should be shortened. For example, many chemists and physicists have to take some group theory; however, a full course in group theory, plus its mathematics department requirements (abstract algebra and linear algebra), are too time-consuming and should be reduced to a one-semester course giving all the basic concepts, theorems, and applications of group theory to the scientist's particular specialization. Many scientists suggest combining one or more necessary mathematics topics into one- or two-semester courses.

Analysis of the data shows that scientists and engineers have little use for courses in modern mathematics such as functional analysis, abstract algebra, and algebraic geometry. Therefore, these courses should be given low priority. Group theory is the exception.

In specializations such as organic chemistry and zoology where there is less need for advanced mathematics, it is important not to make mathematics requirements so rigid that students capable of doing excellent nonmathematical research or research which requires little mathematics are eliminated from their field of choice.

More details on the precise content of each of the recommended mathematics courses for the scientists need to be obtained. This information can be gathered through personal interviewing and by working with the major professional organizations in science.

References and Notes

1. Advisory Council on College Chemistry of the American Chemical Society, Bulletins; C. B. Clark, *Amer. J. Phys.* **29**, 219 (1961); Committee of the Second Ann Arbor Conference, *ibid.* **31**, 328 (1963); Committee on the Undergraduate Program in Mathematics, *Amer. Math. Mon.* **69**, 339 515 (1962); Commission on Undergraduate Education in the Biological Sciences, CUEBS Publication Series (George Washington Univ., Washington, D.C., 1963–1968); H. R. Crane, *A Report of the First Ann Arbor Conference* (Univ. of Michigan, Ann Arbor, 1962); Denver Conference Report Committee, *Amer. J. Phys.* **30**, 153 (1962); E. L. Jossem, *ibid.* **32**, 491 (1964); B. R. Willeford, Jr., and L. B. Clapp, *J. Chem. Educ.* **38**, 251 (1961).

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