The Role of Physics in Engineering Education

The Report of a Committee of the American Institute of Physics

The Report in Brief:

The role of physics in engineering education is not a static one. It must respond and evolve with the momentous changes in both engineering and physics which are occurring continually. The predominent reliance of early engineering upon art is giving way to a modern technology based squarely upon the physical sciences. Since the beginning of this century we have seen as much progress in physics as had been obtained in the whole previous history of mankind. Yet the obvious and enormous increase in subject matter of modern physics is not the most significant factor relating to the aim of instruction in physics in the education of engineers. On the contrary, the cardinal aim should be that of imparting to the student a point of view, an attitude of mind, and a capacity to deal with the principles and methods of analysis of contemporary physics, for, without training and experience in these modes of thought, neither physicist nor engineer will prove competent to deal with the emerging problems of science and technology.

In the interest of instilling this point of view with respect to basic principles and to the mastery of methods of approach, the Committee makes the following recommendations which are discussed in detail in the report:

1. Improved communication between engineers and physicists at the institutional level to discuss objectives and determine mutual needs.
2. Early contact of engineering undergraduates with physics.
3. Increased participation of research-minded professors in undergraduate teaching.
4. Introduction of more challenging experiments in laboratory instruction.
5. Greater emphasis, particularly in textbooks of general physics, on ideas, principles, and methods.
6. More appropriate use of mathematics in general physics teaching.
7. Greater encouragement of experimentation in teaching.

Foreword

PRESENTED herein is the final report of a committee established in December 1954 by the American Institute of Physics to study the role of physics in engineering education and to recommend ways of making the teaching of physics in engineering as effective as possible. This committee had its genesis in a request made to the American Association of Physics Teachers (AAPT) by the Committee on the Evaluation of Engineering Education of the American Society for Engineering Education (ASEE), which was appointed in 1952. The ASEE committee has been studying the patterns needed in engineering education to keep pace with the recent rapid developments in science and technology. In this study, the Committee on Evaluation recognized that physics deserves special attention and made a request of the AAPT to appoint a committee for this purpose. In considering this problem, the AAPT concluded that the problem was so broad and of such importance that the American Institute of Physics, representing all physics in America, should be asked to set up the proposed committee. It was expected that the Institute's committee would study and make full use of the results of the joint conferences between engineers and physicists, which had been or were being held on nuclear and solid-state physics, mechanics, thermodynamics, and electrodynamics under the sponsorship of individual universities, the ASEE, and the National Science Foundation. The present Committee was appointed and asked by the Institute to evaluate the teaching of physics in engineering education and to recommend means by which physics teachers could make the maximum possible contribution toward developing the kind of engineers that are needed in the complex civilization in which we find ourselves.

To obtain first-hand information in carrying out its work, members of the Committee in pairs visited 26 representative colleges offering engineering programs and discussed the physics courses within these programs with members of the staffs of both the engineering and physics departments. In addition, questionnaires were sent to the physics departments of essentially all engineering colleges asking for detailed information on the physics courses offered in these schools. Reports of these visits and the replies to the questionnaire, as well as reports of the joint conferences mentioned above, were studied by the members of the Committee. The present report has resulted from two extended meetings of the Committee and from critical discussions on the part of interested engineers.

The Committee takes this opportunity of expressing its deep appreciation to the National Science Foundation for its interest and financial support and to the many engineers and physicists who have given so much of their time in assisting the Committee in obtaining the factual information upon which the recommendations included in this report are based.

The members of the American Institute of Physics Committee on the Role of Physics in Engineering Education are the following:

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I. *The Changing Scene in Physics and Engineering*

PHYSICS and engineering have undergone revolutionary changes during the past century both in their individual development and in their interaction one with the other. The ability of man to profit by and to build on the experiences of the past and to join together in organized cooperative groups has permitted a great expansion of our knowledge and understanding of Nature and also the development and construction of complex machines and structures far beyond anything which would be possible through the ability of any one individual.

The early physicist worked with relatively simple equipment and with concepts based primarily upon his mechanical experience. As a rule he worked with no or few assistants in a small laboratory or at a desk. With such simple resources he discovered the electron, x-rays, and radioactivity and thus opened the door to a flood of new discoveries which are still being announced at an ever-increasing rate in this twentieth century. These new discoveries have been the foundation of entire new industries. The physics of electron flow utilized in the vacuum tube brought forth the vast electronics industry with applications to radio, television, automatic control, and radar. Nuclear fission has resulted not only in new weapons of destruction but in a new power industry as well. These new industries in turn have provided the physicist with powerful new tools, not only to explore the atom, but through improved instrumentation to revive and to accelerate advances in such classical fields of physics as mechanics, thermodynamics, acoustics, electrodynamics, and optics.

Today, although still depending greatly on individuals with deep insight, much of the progress of physics occurs through the strength of organized effort. The physicist draws on the immense resources of other branches of science and of engineering to do his part in advancing understanding and knowledge which at an ever-increasing rate provide new opportunities for engineering application.

The early engineer practiced his profession of building roads, bridges, buildings, as well as "engines" of war, on the basis of empirical knowledge and experience, passed down from generation to generation. Engineering was chiefly an art with little relation to the science of the time. The ingenuity and talent of these early engineers are evidenced by the great cathedrals, water systems, bridges, and many other structures which are still standing.

Gradually the projects taken on by the engineer widened in scope and complexity and gave rise to an important change in man's way of life, known as the industrial revolution. The engineer built machines to convert the stored-up energy of fuels into useful mechanical energy. Again, much empirical knowledge was gained, but the engineer began to utilize new scientific discoveries and scientific methods of investigation, seeking to establish a rational basis for engineering decisions. New and difficult engineering problems were analyzed into their component scientific problems; the solution thus obtained expanded many-fold the engineer's ability to cope with the increasingly complex requirements of our civilization for machines and structures.

What of the future? In what direction will engineering advance and what kind of emphasis is needed in engineering education to prepare young men to take full advantage of new knowledge being uncovered? These are difficult questions but there are a few guide posts. We do know, for example, that man's power requirements are at least doubling every decade. There is every evidence that this growth in demand will continue and that the engineer will be faced with the necessity for exploiting every possible source of energy to take care of the world's insatiable demand for power. He will need not only to find ways of converting energy from one form to another more efficiently, but will also have to be able to develop new sources of energy such as that from the nucleus, the sun, and possibly even from the waves or the wind.

As a second general guide, it seems inevitable also that man will be demanding continually more delicate and more rapid methods of controlling power. Automatic methods will pervade all branches of engineering. The civil engineer will use automatic methods in tasks ranging from surveying to the great movements of earth and steel that are needed in modern construction. To a greater and greater extent, factories will be automatically operated. The high-speed electronic calculator will supersede the slide rule and, in many cases, elements of the human thought process itself. Inevitably the sanitary, chemical, and metallurgical engineer and all other engineers will rely more heavily on science. The pace of scientific and engineering achievement is now such that obsolescence is a major consideration. Often, the engineer must embark on a long-range project which may be rendered obsolete by ideas or devices now only in the earliest stages of discovery or development. He will make the best decisions who can best evaluate the possible scientific competition.

The physicist in his quest for knowledge often may confine his study to one problem at a time, but the engineer must solve all problems in one integrated design synthesized from his knowledge of many disciplines. The engineer may be called upon to complete a task for which existing knowledge is incomplete or inexact; here he must rely upon judgment based upon long experience. But as knowledge increases and engineering becomes based more squarely upon physical science, the greater the scientific grounding of the engineer, the better his engineering achievement.

Teachers of physics and of engineering, in turn, must adjust their teaching to these continuing changes in physics and engineering. The engineer dedicates his life to improving man's physical well-being and health. His is a creative profession and requires men of ingenuity, resourcefulness, and imagination. The engineer needs a broad understanding of the fundamentals of physics and other sciences whether they have immediate application or not. He must be able to grasp the implication of new discoveries and the developing concepts of nature and be able to respond to the enthusiasm and stimulation of the creative scientist. Also, he must have knowledge of the course of history and be well trained in the art of receiving, interpreting, and communicating ideas to others. Yet, he must be taught that the engineer is a man of action, a doer, and a builder. To assist in training young men who can carry on these important tasks, the physicist and the engineer must work continually as partners in engineering education.

II. *Physics as it is Now Taught*

AS WAS mentioned in the foreword, the members of the Committee are convinced that a report of this kind to be meaningful must be based upon first-hand information gathered through actual visits to engineering institutions and on-the-spot discussions. The following paragraphs summarize the information obtained from such visits and give a reasonably complete picture of physics as it is now taught in engineering colleges throughout the country. Numerical statistics are given in the Appendix.

The time devoted to physics in the engineering curriculum varies over wide margins. In several strong institutions two years are devoted to a general physics course amounting to as much as 17 to 20 semester hours. In many cases the time assigned to physics has been substantially increased over the past decade and there is an apparent trend in this direction. Nevertheless, the program of physics most commonly found in engineering colleges is a course of 8, 10, or 12 semester hours. The courses with the smaller numbers of credit hours often start in the sophomore year. Three-fourths of the colleges visited or those who replied to the questionnaire fall into this category (see Appendix A).

Mathematical prerequisites for physics vary from none except those required for admission (usually not less than higher algebra in high school) to one or two semesters of calculus. Simultaneous registration in calculus is required in about one-half of the schools from which data were obtained.

Atomic physics or so-called "modern physics" included in the general course averages about 10 percent of the course. However, there is some evidence that if the numerous up-to-date examples of first principles cited in the several main divisions of physics, but not set apart as modern physics were included, the quoted percentages would be increased. In a few cases the time definitely devoted to modern physics is as much as 25 to 30 percent.

Two or three hours per week are generally devoted to laboratory work throughout the physics course. Deviations from this pattern are in the direction of less laboratory. Laboratory sections are taught in nearly all schools by graduate assistants under supervision of senior staff members. Lectures are always given by senior staff. Recitations are generally under the direction of mature staff members and are taught both by experienced teachers and advanced graduate assistants. In a number of institutions, a critical study of laboratory instruction is taking place and already several basic changes have occurred which will greatly improve the effectiveness of laboratory instruction.

The objectives of the elementary course as described by the majority of the physics departments are, with only a few exceptions, the teaching of the most general basic physical laws and conservation principles. A fraction (approximately 20 percent of those visited) emphasized problem-solving and the preparation of students for later engineering courses. The historical development of science, the presentation of the scientific method, the coordination of mathematics, understanding of physical laws and engineering applications were also mentioned. Unfortunately, too often, the objectives had not been clearly thought through and there had not been enough discussion of these objectives with engineering staff members.

Generally, the engineering departments, when asked, agreed with the first of the above objectives. They wish the elementary physics course to be taught as a self-sufficient scientific discipline without special emphasis on engineering applications except possibly as these are used pedagogically as motivation devices.

An interesting trend is noted in a number of institutions. In some this is represented by new courses under a distinctly new curriculum called Science-Engineering (or Engineering Science) which does not carry the designation of one of the usual engineering divisions. In others, the student is permitted to substitute physics courses for technical engineering courses, thus qualifying him for a science major under one of the usual engineering degrees. In contrast to this trend, in one institution, most of the work in general physics is taught by engineering departments.

III. *A Brief Appraisal of Present Courses*

IN THE preceding section we have a brief factual view of the physics courses being taught. The important question is, of course, "Are they being well taught?" As with many questions the answer must be both "Yes" and "No." In some institutions physics is very well taught; in others it certainly borders on the inadequate. Also there are parts of some courses which are very well taught and other parts which certainly could be improved. This section of the report attempts to appraise frankly the good features as well as some of the shortcomings of physics courses now being given.

There is widespread dissatisfaction among both physics and engineering faculties with the encyclopedic coverage of the general physics course. This characteristic is often attributed to the extensive coverage of texts even though the teacher could, if he chose to do so, delete large sections from most texts. The desire is frequently expressed for a text with inclusion of basic principles and a minimum number of relevant but unnecessary materials and illustrations. A widespread opinion exists also that the physics program for the engineers should include more atomic, nuclear and solid state physics and that to an increasing extent examples from modern developments in physics be used in the general course. It must be recognized, however, that the amount that can be introduced into the general course will not be sufficient for the engineer whose professional life will extend over the next half century. To include more of the modern developments, there is a growing approval of an additional course, at least one term or semester in length, at approximately the junior level and suitable for the engineer who has completed the general physics course and the parallel mathematics.

In many institutions it is felt that the physics program is not assigned a sufficient fraction of the student's time. It was stressed that the one-year course which is often given is not sufficient for inclusion of the subject matter *all* engineering students should have. The newer topics, particularly, cannot be presented adequately within a one-year course. It is recognized that a reduction in the number of topics covered in the first year will help. But most physics teachers and even many engineers are convinced that the gain will not be adequate to allow time for the inclusion of many present-day developments. At best the student will be left ill-prepared to comprehend these newer topics.

Unfortunately, the role of laboratory work in physics is often not clearly defined. It is interesting to note that sometimes engineers rated it more highly than the physicists did. If the objectives sought in the laboratory instruction are the development of techniques and the use of measuring instruments, the laboratory is generally considered to be successful. But if, as most teachers believe, it is to be an effective means of teaching principles, then improvement must be attained. The forward-looking experimentation now taking place will be watched with much interest.

Engineers and physicists alike deplore the poor mathematical preparation often obtained by the student in the secondary school. This situation necessarily lowers the mathematical level of basic freshman courses. In some schools an appreciable fraction of the students must take remedial mathematics, thus spending time that should be utilized for other purposes. In any case, it is recognized that the appreciation of mathematics as a physical tool must be supplied or at least be enhanced by the physicist.

In many institutions the members of the Committee found a great interest in, and really first-rate teaching of, physics for engineers. In others there is certainly room for improvement. Interestingly enough, improvements which the Committee would suggest and which form the basis for the recommendations in this report are not those which are sometimes mentioned in discussions between engineers and physicists. For example, there is no evidence of less interest today in expounding both the classical as well as the newer physics than existed decades ago. The great expansion of research in new fields has not caused the physicist to overlook the classical areas of physics in his teaching. In fact, this very expansion makes it imperative that from time to time we re-examine our teaching in terms of our present-day objectives. Only thus can we fulfill adequately our obligation to engineering education.

A large majority of engineering departments visited preferred to have the physics taught by the physics staff. In this way the student can best be exposed to the points of view and the methods characteristic of a basic science with its primary goal of understanding nature.

In a number of schools the engineers complain about the inadequacy of the preparation of the student who enters the first course in engineering mechanics, electricity, or thermodynamics. This may be an example of the almost universal complaint which is made at all levels that the previous training of the student is inadequate. Surely it can be helped by those teaching the advanced courses if they will take the necessary pains to assist the student in transferring to later courses the knowledge and understanding which he has gained from previous courses. However, to the extent that it is justified with respect to physics and engineering it may be due to uninspired teaching, poor organization, inappropriate texts, insufficient time, deficient preparation of the student, or a combination of all of these. If any of these are at fault then, indeed, do we have a common problem to be discussed between engineers and physicists and to be solved in a sympathetic and effective manner.

Communication between the various engineering departments and the physics department often is not adequate. It is generally agreed that both formal and informal meetings of all those staff members who are doing the teaching will provide an invaluable exchange of information of the course content and of the level of the performance of the students which is sought, expected, or actually attained. Such meetings are highly desirable and will yield returns in a better curriculum and understanding of mutual objectives and problems. Such meetings do not presume a dictation of content of course material, nor of a method of teaching by one group for the other. Each department should be the final arbiter in its own realm but the increased knowledge and the comments of the others may give a better background for a decision. The appreciation by the physicist of his contribution to engineering would be enhanced by the exchange of points of view with engineers but it is not suggested that this lead to the teaching of engineering in the physics classes or to the teaching of physics in the engineering departments.

IV. *A Set of Goals for Physics in Engineering Education*

PERHAPS the most important contribution that physics can make to the training of engineers is to provide a knowledge and appreciation for (1) the methods that have been found effective in describing the way nature behaves and (2) the concepts that have been derived therefrom. The body of physics as we know it today, which is considered essential to an understanding of these principles and concepts, represents the distillation and unification of knowledge gained over the past. The point of view of many physicsts has been, and now is, that one should acquire an understanding of natural phenomena irrespective of any practical application. Such a viewpoint has been eminently worthwhile since most modern technological developments are direct applications of many of these principles that were once considered academic and without practical use.

It is our belief that an increasing segment of the population and particularly those trained in technical fields should have an appreciation for the science of physics and the mode of thought which to such a large degree has been responsible for the phenomenal development of physics over the past decades. Specific contributions which the physicist can, by virtue of his training, make to the education of an engineer are:

(1) The physicist is, almost by definition, curious about the physical world in which he finds himself. It is hoped that some of this curiosity, and some of the satisfaction and enthusiasm resulting from increased understanding, will be imparted to his students.

(2) Along with understanding, the physicist also learns the limitation and scope of his descriptions and interpretations. These often are of a different character from those which the student meets in the solution of classroom problems in engineering and yet an appreciation of them is an essential part of an engineer's education.

(3) He has learned that there are underlying, unifying principles that can be rigorously expressed in mathematical terms and which are very general in their application. He has found these to be powerful tools in the expression and solution of important problems in nature. Examples of such principles are the laws of the conservation of energy and momentum which he teaches to his students with emphasis on where they apply and on their limitations.

(4) He knows that to appreciate fully the physics of today the student must know something of the historical development of underlying ideas, of the struggles of the past and the great strides that were taken by a few individuals in enunciating these broadly applicable unifying principles. We are firm in our conviction that all engineering students should know something of the origin of the knowledge which they will use so continuously.

(5) The physicist has often pioneered in the development of precise methods of measurement. This he has done to understand nature better and to place his concepts on as firm a base as possible. Thus he, more than other men, has been interested in determining the fundamental constants of nature with the highest possible precision.

(6) The physicist believes that through a proper understanding of the laws of nature, people can arrive at more objective judgments and, it is hoped, keep free of many of the popular fears and superstitions involving science itself today. The history of physics has given ample proof that this can be done and certainly should be one of the objectives of a physics course.

(7) Lastly, a precise understanding of the basic concepts of physics is perhaps the best guarantee that the presently trained engineer will be able to contribute to the technology of tomorrow and herein lies one of the most important contributions the physics teacher can make in engineering education.

Only a partial achievement of the above goals can be expected in any single physics course under the best teacher. Certainly, a one-year course in general physics from a modern viewpoint, utilizing calculus as an essential aid, is hardly adequate. The trend away from too great a dependence upon the practical arts and toward the sciences in engineering practice makes it highly desirable to consider a two-year general physics course for all engineers. To teach properly the principles discussed above, the content of the general physics course must be carefully screened to eliminate much of the material of an engineering or applied nature. Furthermore, to achieve an understanding of and a feeling for the way nature behaves, a challenging set of laboratory experiments should accompany this general physics course. Routine "cook-book" experiments should be kept to a minimum.

We also recognize that one of the goals of physics instruction should be an introduction to the basic principles underlying atomic and nuclear physics and the solid state. The one- or preferably two-year general course must be regarded only as a preparation for introductory modern physics courses which may be given at the junior-senior level. A thorough understanding of nuclear and solid-state physics is achieved only through years of intensive study at the graduate level.

V. *Recommendations—a Program for Achieving the Goals Set*

IN RECOMMENDING a program aimed at more effective physics teaching in engineering education, the Committee recognizes that primary effort must occur at the local level and stem from within the colleges themselves. It is incumbent upon physicists to recognize the changing character and needs of engineering. The predominant reliance upon art is giving way to a modern technology based squarely upon the physical sciences, and this is reflected in the growing demands of the engineering profession for both a deeper understanding of fundamental principles and a broader introduction into recent advances. Physicists would do well to view these demands with sympathy and understanding and to accept them as a challenge to wider influence rather than as an invasion of vested interests.

It is no less important that the engineering profession and, indeed, physicists themselves take account of the evolving character of physics. The obvious and enormous increase in subject matter of modern physics is in our judgment not the most significant factor relating to the aim of the physics instruction in the education of engineers. On the contrary, we believe the cardinal aim to be that of imparting to the student a point of view, an attitude of mind, and a capacity to deal with the principles and methods of analysis of contemporary physics, for without training and experience in these modes of thought, neither physicist nor engineer will prove competent to deal with the emerging problems of science and technology.

In the light of these comments we make specific recommendations under the several headings listed below:

1. Improved Communication

In each local institution members of the departments of physics and engineering should meet frequently together for free discussion in order that they may come to understand and appreciate more clearly their common interests and mutual needs. In some of the leading engineering schools it has been demonstrated that the contribution of physics, together with chemistry and mathematics, to the education of the engineering student can be greatly enhanced when the student clearly sees for himself that subsequent engineering courses draw upon the basic principles of the sciences and make use of the power of analysis developed from the point of view of the physicist. In these cases there is very little trouble with the problem of motivation. On the other hand, it is deadly from the standpoint of a student's motivation and morale if the engineering teacher assumes "a priori" that he must completely reteach his subject from the beginning even though it has been covered to a certain point in the basic sciences. It is urged, therefore, that teachers of engineering, wherever possible, provide an opportunity in their courses for the students to deal with engineering situations as best they can, using the understanding and methods obtained from the basic sciences. This cannot be done unless there is free exchange of information and views between the teachers of basic science and engineering; consequently, this constitutes one of many reasons why it becomes imperative to cultivate this close association.

2. Early Contact with Physics

We attach the utmost importance to instilling the point of view expressed earlier with respect to basic principles and to the mastery of methods of approach, and it is for this reason rather than any question of course content that we urge strongly that engineering students at an early point in their undergraduate careers be brought into an association with those who have made physics their life work.

3. Research-Minded Teachers for Undergraduates

Traditionally the home of research in the physical sciences has been the science departments of our colleges and universities. Much of the research that has led to the changing concepts and expanding scope of physics has been the work of members of the staff of such departments. Their research is essential to the continuing advance of science. The challenge of research promotes continuing vitality in those who engage in it and thus contributes to the development of science.

In recent years, however, there has been a growing tendency among some staff members engaged in research to neglect a basic responsibility which they share with the other members of their department, namely, the teaching of undergraduate students. This leads, we believe, to several undesirable effects.

Firstly, the high degree of motivation and inspiration which the successful research man can give is denied the undergraduate student.

Secondly, the undergraduate student is not provided with the high level of instruction which the research-minded professor is capable of giving.

Finally, such a professor, no longer required to refresh his understanding of the broad developments in physics, may tend to become increasingly narrow in his point of view.

In view of these facts we urge that consideration be given this problem to the end that all members of the staff, including those engaged in research, be encouraged to give instruction in physics to the undergraduate student. We firmly believe that in this way not only will the department provide the highest type of instruction in physics, but also the department will maintain its highest proficiency in research.

4. Laboratory Instruction

Since the fundamental laws and principles of physics provide the means of understanding many basic phenomena of nature, it is important that the student of science and engineering become acquainted first-hand with these basic phenomena in the laboratory and by means of well-chosen demonstration lectures. It is in the laboratory that the student comes into actual contact with phenomena in a basic way and, indeed, has the closest association with his teacher. Consequently, it is here that the teacher is presented with a great opportunity to aid the student in obtaining a clear and realistic understanding of basic physical principles. This opportunity should not be wasted by requiring the student to do unchallenging, stereotyped, and superficial experiments. "Efficient" operation in the sense of obtaining maximum data from standardized equipment should not be the goal of laboratory instruction. Rather, great effort should be expended to provide a type of laboratory instruction which will lead the student partially to discover a particular law or principle by his own efforts. This presents a challenge and allows the student to contribute to his own learning process. A law or principle arrived at in this way will not easily be forgotten and the more able student will appreciate its deeper significance. In this way the laboratory experience can contribute most forcefully to the student's assimilation of basic physical principles. It is, therefore, recommended that teachers of physics continue to give serious thought to the improvement of laboratory instruction in basic physics. In a few schools very significant results have already been achieved.

5. Textbook for General Physics

Since the educational arrangement of one teacher for each student which many consider ideal is rarely feasible, and since students cannot usually be trusted to take adequate notes on lectures, no matter how carefully delivered, the textbook will long continue to be the primary medium in the education of students, particularly in a science like physics, which demands close and repeated attention.

Examination discloses that though the number of general physics texts available for students of engineering is relatively large, some of them tend to be marred by numerous shortcomings which undoubtedly lower the efficiency of the educational process. Among these are the following:

(1) There is a tendency to put too much stress on facts and too little on fundamental *ideas, principles,* and *methods*. Some textbooks pay too little attention to the methodology of physics and hence give the student little idea of the manner in which physics progresses or even of the limits of present knowledge.

(2) As a corollary to (1), some texts provide too little encouragement for the student to reason things out for himself and to test his understanding of principles and methods. There are, in general, too many problems of the simplest substitutional variety that may be used by teachers to the exclusion of the more thoughtful items.

(3) There is often too little care and imagination in the *selection* of material from the standpoint of fundamental significance and hence the books tend to be far too long and encyclopedic in character. Moreover, they appear to be growing longer. Books of 800–900 pages seem too long for the general physics course unless the assignments by the teacher are very skillfully made to eliminate certain sections.

(4) In too many cases recent developments in physics are tacked on at the end instead of being thoroughly integrated into the general development. In particular there is frequently little consideration of the fundamental role of the theory of relativity and quantum theory in the *evolution* of classical physical ideas.

(5) The mathematical methods used in texts often underestimate the intellectual capacity and interest of the student. Elementary differential and integral calculus, vector analysis, and modern mathematical concepts should be used whenever they aid in the concise rigorous formulation of principles or problems; thus the student will become accustomed to such methods and gain confidence in their use.

It is very likely that no single physics text will satisfy all teachers or any one teacher for all time. The fact that a few of the existing texts have been adopted by a large number of teachers gives evidence of the high regard with which these texts are held. Nevertheless, some members of the Committee are still seeking the "perfect" text that would be free from the objections listed above. The text for general physics that they visualize would be considerably shorter than most existing texts. It would preferably be written by a teacher who has a strong research interest, or by a group of such persons; but if by one person, he should be one who has thought a good deal about the methodology of physics and is willing to develop the subject in unconventional fashion. Such texts in special fields are now actually being written at one large institution.

6. Mathematics in General Physics Teaching

Since mathematics in the form of the calculus is the natural language of physics, it is desirable that the student should get acquainted with it early in his college career and that the general physics text should use it freely. In many institutions an introduction to the calculus is given simultaneously with general physics. In others, beginning physics is delayed so that preliminary work in calculus may precede the first semester of physics. It is obviously very important that the physics teacher should continually stress the use of mathematics in expressing the ideas of physics. At the same time it is essential that he emphasize the physical meaning of all results obtained by mathematical analysis so that the student will not get the mistaken idea that physics is merely a collection of mathematical symbols.

The above recommendation in many instances raises problems in the teaching of elementary college mathematics. The mathematics teacher quite reasonably desires to develop in his students an *understanding* of mathematics and its meaning as a form of human activity and looks with justifiable suspicion on the teaching of mere manipulation. The physics teacher, therefore, has the responsibility to effect a gradual transition from mathematical philosophy as taught in the mathematics department to the use of mathematics as a tool as required in physics, just as the engineering teacher has the responsibility to effect a similar transition from physics as a basic science to the use of the principles of physics in solving engineering problems. To provide these transitions in a sympathetic and effective manner requires the utmost cooperation between the mathematicians, physicists, and engineers.

7. *Encouragement of Experimentation*

An impartial appraisal of the quality of instruction in American colleges and universities in both the sciences and engineering will reveal a distressing amount of teaching of a completely pedestrian sort. The prevalence of such mediocre efforts should not, however, conceal the fact that there are also many gifted and effective teachers and that interesting and rewarding experiments for the improvement of laboratory and classroom instruction are taking place in many institutions. It is our impression that a wider knowledge of such experiments and innovations would encourage similar efforts and that an exchange of views would be beneficial to all concerned. Consequently, we urge that the appropriate journals of the American Institute of Physics and also the *Journal of Engineering Education* take steps to give wider publicity to experimentation in teaching, to "case histories" of new approaches to laboratory instruction, and to similar endeavors.

The various conferences encouraged and supported in recent months by the National Science Foundation for the discussion of such topics as mechanics, thermodynamics, electrodynamics, solid state, and nuclear physics in engineering education have served a highly useful purpose by affording opportunities for the exchange of views among leaders of specialized fields. We believe that the organization of similar conferences from time to time in the future will be profitable to both engineers and physicists.

Recent meetings of the AAPT and of the Physics Division of the ASEE have had sessions devoted entirely to the teaching of general physics to engineers. We urge that meetings of this kind be continued and that whenever possible further joint meetings be held. Such meetings, by bringing together researchers and teachers, physicists, and engineers to share their experiences, their faiths and their hopes, will do much to stimulate further interest and understanding of the role of physics in engineering education.

APPENDIX

Summary of Information Obtained from Questionnaires

AS STATED previously, early this year there were sent to the physics departments of some 180 colleges, offering programs in engineering, questionnaires concerning the physics courses taken by the engineering students. To date replies have been received from about 120 colleges and the following summarizes the answers to questions on the general courses, the advanced courses, emphasis on research in classical physics, and changes in courses now being planned.

A. General Physics Course

Physics instruction to engineering students is limited to the general physics course only, in 46% of the colleges. This course is required by almost all engineering schools as an integral part of the curriculum. Data derived from the questionnaires in regard to some details of the General Courses are given in the paragraphs below.

1. *The number of semester hours and the distribution of time devoted to lecture, recitation, and laboratory vary with the school.* Fig. 1 shows graphically the number of semester hours devoted to general physics as related to the number of colleges. It may be noted that the one-year sophomore physics course of 10 semester hours is most popular. In many schools a two-year general course requiring up to 20 semester hours is taken by all or most engineers.

2. *Prerequisites for the general physics course for engineers.* Fig. 2 shows graphically that calculus is usually required as a co-requisite for this course and that

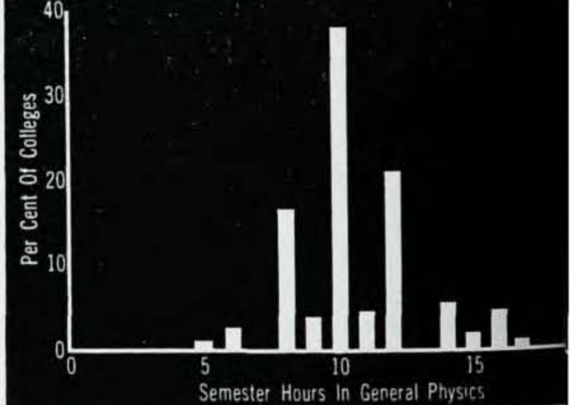

Figure 1

at least algebra and trigonometry are required prerequisites in almost all instances.

3. *Percentage of time in general physics devoted to "modern physics."* Fig. 3 shows roughly the stated amounts of "modern physics" included in the general course. Although contemporary physics is concerned with fluid dynamics, thermodynamics, microwaves, and many other modern topics, the term "modern" as used here refers to atomic, nuclear, and solid-state physics. It is, of course, difficult to define just what is modern and just what is classical so that the answers can be considered only as qualitative judgments. The answers given range from very little in a few instances to more than 30% at Princeton University. In most cases this treatment of modern topics is distributed throughout the course but in about one-third of the colleges it is concentrated, usually, at the end of the course.

4. *Texts used in general physics.* Five texts predominate and are used by 75% of the colleges. Some fifteen different texts are used by the remaining quarter of the colleges, many in only one college each.

B. Advanced Courses

In more than 50% of the colleges reporting, additional physics is taken by some of the engineering students, usually as an elective. The most common additional course is one in modern or atomic physics which is taken in about 35% of the colleges. As many as 325 engineering students take this course at Pennsylvania State University. The average engineering registration in advanced courses is about 30 students. Three or four different texts are popular, but a dozen others are used in one or more schools.

C. Research Interest in Classical Physics

There has been much discussion of the present-day interest of physicists in research on problems in classical physics in comparison with the widely publicized research in "modern" physics. Actually this comparison has no direct relation to the teaching effectiveness in general physics since the same critical understanding of fundamental concepts required in classical physics is basic to competent research in "modern" physics as well. Furthermore, the same point of view and attitude of mind so important to good physics teaching is present no matter in what particular branch of physics a man's research is being done. Unfortunately, there are no simple means by which research can be reliably measured so that, although a question on this matter was included, the reader must recognize the limited reliability of such a survey. The replies indicated that 58% of the colleges, all of which offer engineering education, reported research completed recently or in progress by their physics departments in mechanics, acoustics, heat or thermodynamics, electricity and magnetism, or optics. These research projects are divided as follows:

Table I

Field	*Number of Research Projects*	*Number of Published Papers*
Mechanics	32	24
Acoustics	23	14
Heat and Thermodynamics	30	23
Electricity and Magnetism	41	32
Optics	40	34
Totals	166	127

Table II

	Projects
17 colleges report research in one classical field only	17
14 colleges report research in two fields	28
15 colleges report research in three fields	45
14 colleges report research in four fields	56
4 colleges report research in five fields	20
64 Total	166

D. Changes in Physics Courses

About one-half of the physics departments specifically state that changes are being considered or planned. The most common change is the inclusion of more atomic, nuclear, and solid-state physics in the general physics course, frequently in the time provided by a reduction of engineering examples or applications. About 10% of the colleges are adding a course in modern physics, including atomic, nuclear, and solid-state physics, as a junior-senior elective for engineers.

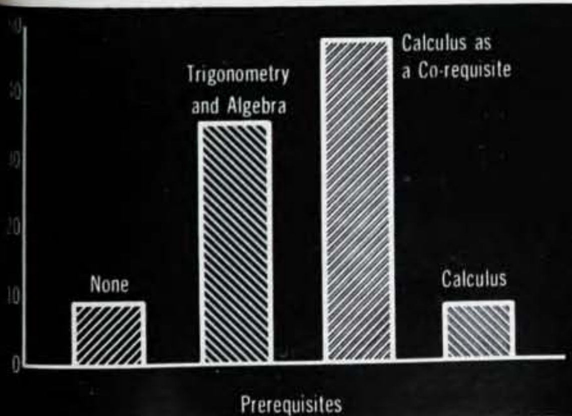

Figure 2

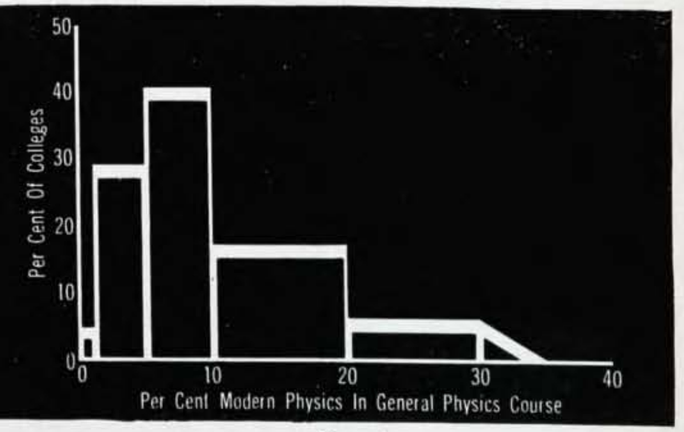

Figure 3