The Phoenix—A Challenge to Engineering Education*

W. L. EVERITT†, FELLOW, I.R.E.

FOREWORD

WALTER CAMPBELL
UNITED STATES SIGNAL CORPS

"The Phoenix—a Challenge to Engineering Education," a paper by Dr. W. L. Everitt, Chairman of the I.R.E. Committee on Education, lights a torch for a campaign that may affect man's life and history down through the years to come. It is an opening gun, calling all members of the engineering fraternity to the colors; it opens a long-period program on which *every* engineer and engineering educator has a vital part to play.

We of the present, have benefitted from the efforts of our predecessors. We have dedicated our lives to the progress of mankind, for that is the *primary goal* of engineering. It is our privilege and duty to consolidate our experience and education and apply these as a guide to the training and education of those members of our profession yet unborn. We must accept "The Challenge to Engineering Education" and unitedly assure "The Rising of the Phoenix."

Engineering is based on economy; economy of manpower, economy of resources, economy of time. We usually evaluate these factors in terms of money but the paramount criterion remains the value in terms of progress and benefits to mankind.

With an active unity of all engineers and engineering educators, we can establish a modernized and well-designed plan for engineering education. We can provide the future engineers with tools, by means of which they can achieve better and more extensive results.

The future curricula of our technical schools must be designed and developed with the same care and thought as goes into well-engineered equipment. The schools providing these curricula must be adequately directed by competent educators. A resulting level of experience and education must be appreciated by all, both the public and existing engineers if the profession is to be respected and supported.

The aims and results of the program to modernize and redesign the plan for engineering education will require much work and involve the consummation of many details. For example, it is anticipated that a *code of ethics* will be developed and established. This code will pertain not to a statement of benefits to be derived by the engineer but rather to his performance, his loyalty, his reliability, and his paramount objective in assisting the progress of mankind. It is also anticipated that the engineer at the time of graduation will take an oath, much as a medical student undertakes, by which he dedicates his life and abilities to the progress of mankind.

Summary—**Engineering education is presented with a unique opportunity for improvement due to the interruption caused by the war. This improvement can only be obtained by a clear determination of the fundamental goals of engineering education and the application to its curricula of the engineering design processes it claims to teach. A distinction should be drawn between the problems of Science, which are those of analysis, and the problems of engineering which are those of Synthesis. Engineering and nonengineering students both should be taught what engineering really is, its philosophy and what it can do. The importance of its humanistic aspect should be stressed. A program is proposed for participation in the discussion and design of engineering curricula by the Institute sections.**

ENGINEERING education is at a crossroads. In this critical period, when the manpower requirements of industry and the Armed Forces are, of necessity, draining current and potential students from our schools, we are presented with an opportunity never before available.

The development of engineering education has been an evolutionary process. To a large degree, it began to expand after the Morrill Land Grant Act of 1862. This Act provided for the foundation and maintenance of colleges "where the leading object was, without excluding other scientific and classical studies, to teach such branches of learning as are related to agriculture and the mechanic arts." Those who have followed the history of the beginning of the Land Grant colleges know that the conception of engineering as a profession was practically unknown at that time and there was much groping and experimentation in the teaching of the "Mechanical Arts."

While education in this field has been modified and

---

* Decimal classification: R070. Original manuscript received by the Institute, April 14, 1944.

† Chief, Operational Research Branch, Office Chief Signal Officer, United States Army, Washington, D. C.; on leave as Professor of Electrical Engineering, The Ohio State University, Columbus, Ohio.

expanded since that time, it is quite generally admitted that it has, in many cases, grown like Topsy, and has not itself been the subject of the engineering design processes which it claims to teach.

Many of our plans and procedures of Engineering Education are haphazard, without broad but definite objectives, and inadequate in scope and detail. Redefinition and modernization are required if mankind is to reap the tremendous benefits of sound engineering.

We find an inspiring concept in "the Phoenix" of Egyptian mythology, a bird consumed in fire by its own act, but which arose from the ashes in youthful freshness, more vigorous than ever. This concept implies that an essence of immortality is the ability to begin anew, combining the wisdom of age with the dynamic drive of youth.

Engineering education is now being burned by the fires of a technological war. Will it arise from the ashes, like the Phoenix of old, with a rejuvenation shown by its awareness of its opportunities, and the vigor to attack and solve its problems? Or will it simply continue on the path laid out by the old curricula and methods after a temporary recess? The choice is plain, and must be made by engineers and educators now, if a "Phoenix" is to be ready when the war is over.

The present interim is a golden opportunity for a real study of the basic problems of engineering education, and for the *design* of curricula. In peaceful years, there has been a resistance to marked change because of the difficulties of disturbing a going concern, and at times even because of the vested interests of departments and individuals who were teaching subjects in ways which they did not wish to see questioned. Furthermore changes in individual curricula would have reduced flexibility in the arranging of schedules of irregular students and transfers from institution to institution. But these and many other objections to a basic study of the problem and action thereon do not apply today. Most of the upper-class engineering students in school at the time of Pearl Harbor were allowed to complete their college courses. After the war, a new crop of freshmen will enter and be carried forward. Now is the time for the engineering design of curricula in the several branches of professional engineering. In fact, if this opportunity is passed by, we may never in our lifetime have another.

In order to carry on discussions on any problem, it is important that an agreement be reached among those concerned on the subject of their discussion. Definitions are needed. Unfortunately definitions are frequently given which require such elaboration that they confuse rather than clarify. The words Science and Engineering have so frequently been confused that it is believed essential that they should be distinguished, at least for the purpose of this discussion. Of late, there has been a particular tendency to imply that scientific and engineering education are one and the same thing. If this be so, then the engineering colleges have no justification for their existence and their duties should be absorbed by the appropriate basic-science departments. The writer believes there is a definite and important difference, and furthermore this difference has not been taken into account in the *evolutionary* development of engineering curricula.

Webster defines Science as "knowledge of principles or facts," or more specifically "accumulated and accepted knowledge which has been systematized and formulated with reference to the discovery of general truths or the operation of general laws."

Webster defines Engineering as the "art by which the properties of matter are made useful to man in structures and machines."

The most fundamental difference between Science and Engineering is the difference between Analysis and Synthesis. Science is interested primarily in learning what effects follow causes, in learning why and how nature, both physical and biological, behaves as it does, in other words in analyzing everything and finding out what to expect under a given set of conditions. Engineering, on the other hand, goes far beyond this. It is interested in assembling a combination of men and materials to produce a desired result or a reasonable facsimile thereof. This is the process of synthesis, of putting things together to accomplish a definite end.

The processes of synthesis can be accomplished only after a thorough grounding in the processes of analysis. One must know what results will follow from definite causes, both when they occur singly and in combinations. But the methods of synthesis go beyond those of analysis and must be learned as such. Certain of these methods can be taught, others involve judgment, the willingness to try, recognize failures, and try again repeatedly, and some involve intuition which inevitably differs among individuals. But their importance in engineering should be recognized and taken into account in the training of the engineer.

Synthesis inevitably requires more mature judgment than analysis. Childhood is the time for taking clocks apart to find what makes them tick, only the mentality of the adult can design an assembly of springs, cogs, etc., to keep time within acceptable limits.

In particular, engineering synthesis requires the use of a knowledge of more related elements while analysis can be broken down into isolated areas. The performance of a radio set can be analyzed without attention to economic factors; but the design of such a set without considering economics, or the human use to which the set is to be put, is no design at all.

It is not intended to imply that the work of the pure physicist is less important or less mature than that of the engineer. The pure physicist in his research designs many ingenious devices to assist him in his work of analyzing nature. The cyclotron is itself a monumental work of synthesis. As such, it is essentially an engineering product, designed by physicists. But it is important to realize that the synthetic processes which physicists pply in research are not, in general, taught in the science classes. Applied physics is a form of engineering upon which the comments of this paper bear fully.

In our engineering curricula, we have taught the student almost exclusively the methods of analysis and very little of the methods of synthesis. He attends classes and laboratories and learns what happens when certain forces and materials are brought together. Very seldom does he have the opportunity to assemble, either on paper or in physical being, from out of all the world of nature at his disposal, a combination to produce a desired result. In other words, engineering curricula have omitted instruction in "Engineering." As a result of this, our students go out as graduates, obtain a job, and then ask "Why wasn't I told about this thing called engineering before?" We have, it is true, trained enginneers but we have not taught engineering. We have taught the engineer how his tools are put together, but we have not generally shown him how to use them.

Engineering is a way of life for those who pursue it, much more than a way of making a living. An engineer cannot be made by academic procedures alone, but these procedures should point the way from the beginning. Clear thinking should be an essential in an engineering education and yet we have not even been clear in explaining to him what engineering is. Engineering is a dynamic force, it requires *doing* in order to exist, it cannot be learned solely by passively studying what is already known. It never consists in working the problems in the book, or ones like them with only changed constants. An engineering problem always contains new elements, requires the production of a new result or device, or else it is not an engineering problem. It cannot be solved by routine application of rule-of-thumb methods. Although he depends greatly upon experience for his results, the engineer seldom repeats the work of the day before without modification.

A way of life must be inspired and cannot be taught by rote. Engineers, as a group, are generally recognized as having high ethical principles. However, we lose a golden opportunity in the engineering college if we do not point out to the student the need for high moral principles, and the inspiration which can be drawn in working both with people and the laws of nature. We need also to point out the danger of a Frankenstein which can result from the improper application of scientific principles. We must be more articulate in the expression of the engineer's creed. We should have the equivalent of the Hippocratic oath which has inspired medical students for centuries.

Many people who merely operate instruments or turn dials or do other repetitive work are called engineers. But such people are not engineers, even though they may have engineering degrees, and every effort should be made to make this clear to the public. In fact, engineering education should unfit a man for repetitive tasks, even though such tasks may require their performer to *know* a greal deal.

The definition of engineering given by Webster included the phrase "made useful to man." This is extremely important, as the engineer has not produced an engineering product unless it *is* useful to man. Consequently, the engineer should understand man as well as matter. He must learn how to recognize the needs of men, and how to interpret his material products to men so that men will use them. Therefore, the curricula should include instruction which will help the young engineer to speak and write fluently and clearly. He must be able to convey his ideas to others. He should also be taught open-mindedness and a survey of other fields of knowledge, present and past, so that he can understand and evaluate the thoughts of others. And he should be required to use these principles throughout his course in his class recitations and in his written reports. The motto should be "learn and apply," not "study and forget."

It has frequently been assumed that courses in an engineering curricula should be set up to teach *all* that the engineer should know about a given subject. But such an aim is futile, both because of lack of time and because the instructor himself does not know everything. Furthermore, at the time he is a student, the art itself does not possess what the engineer will need to know ten years later. Therefore, the fundamental problem is to make the student Literate in the subject. By the word "literate" is meant not only the *ability* to read and understand the literature and other available material on the subject, but also the *desire* to continue his reading or education in the field. Any educational course has *completely failed* if it does not so relate the material to the man's life that he will be stimulated to continue to acquire knowledge in the subject and in turn relate it to his actions and decisions. The mental impressions received in a course where the student has the feeling at the end "Well, thank God that's over," will fade so rapidly that the course might better have been omitted. These remarks, of course, simply mean that engineering education should produce an educated man. Attainment of these objectives require not only good teaching but also a definite recognition of the goal and the integration of the whole educational program.

The processes of engineering, and synthesis in general, normally require the use of approximations. It is very seldom that an engineering product can be made to fit perfectly all the desirable criteria. If we try to make it fit too perfectly the most desirable objective, it may cost too much or be too difficult to run or maintain. Therefore, one of the most important decisions to be made is "how good is good enough." The engineering graduate too frequently does not realize this. The design of a $15 radio will, in general, require better engineering than that of a $500 one because it requires more judgment in eliminating the nonessential and making the most of the essential elements. And the design of the $15 radio may also be more "useful to man" because of its greater distribution. The engineer must be taught the utility of the imperfect, and the importance of the attainable and practical. Someone has said that an engineer is a man who can draw correct conclusions from incomplete and frequently incorrect premises. Above all, he should be thoroughly indoctrinated in the economics of everyday life, and how it affects the work of the engineer.

In learning the importance of the practical, the engineer should be taught not to waste his efforts or those of his associates. If he is going to use resistors which are manufactured to tolerances ±5 per cent, he should not make calculations to a large number of significant figures. On the other hand, if his answer depends upon the difference between two large numbers which are nearly equal, the calculations of the individual numbers must be very accurate in order to get a reasonable accuracy in their difference and he should recognize when this is necessary. In the curricula, a studied effort should be made to introduce repeatedly situations where judgment is needed, and the student should be graded on his performance and given advice.

Special situations should be given where the student can use the principles of synthesis, starting with simple cases and proceeding to the more difficult. He should be taught how in a particular problem he can select from the complete world of data which is at his disposal, those elements of importance to the problem. He should then be shown that synthesis in general uses the principle of educated guessing and checking of the results of the guess by analytical methods. The problem is somewhat similar to the mathematical one of integration, where the answer must be guessed (unless an old problem is recognized) and the analytical method of differentiation is available to find out whether the guess is correct.

Engineering schools should consider a greater use of the "case method" which has been adopted so widely for legal training. Certain types of problems can be used to illustrate the synthetic process. The author has found the design of an attenuation equalizer a good example. In this problem, a network is desired whose attenuation characteristic fits a particular curve. A table is consulted to find combinations of resistances, inductances, and capacitances which have the general type of curve desired. Several may be available. The more complicated will, in general, cost more, both in time to design and money to manufacture. So we may try the simplest first. It may have two independent variables. We therefore select two points we shall try to fit exactly. This may be done by setting up two simultaneous equations. After we have fitted these two points, we then *analyze* the resulting network by computing its curve over the frequency range of interest. It will not fit the desired curve exactly but will be an approximation thereof. The designer must decide whether it is good enough. If it isn't, he must try again, either by using two new points to fit or by selecting a more complicated network which has more independent variables and so can be fitted at more points. In the end, he may have several solutions of different degrees of approximation and complexity (cost) and a decision must be made whether the better article is worth the extra cost. The complete plan of operation has most of the elements of engineering synthesis.

The purpose and conduct of laboratory courses should be examined carefully. To a large extent, the apparent aim of most laboratory experiments has been to verify that all the important statements in the book are really so. The same techniques are applied first on one piece of apparatus and then another to obtain curves which are already published. It is true that we should instill in our students a questioning mind that will not always accept the printed word as the gospel, but it is believed that repetition in the methods of test may not always make the best use of the student's time. At least in the senior year, an opportunity should be given the student to design his own experiments, with only some general instruction such as "Find what the important characteristics of this machine are." Then he should be given some opportunity to design and assemble a working piece of apparatus to produce a desired result. Such a laboratory program would necessarily mean that he would not have the time to verify as many principles which have been taught but it would give him some experience in the engineering method of making tests and producing designs.

Training in the combination of analysis and synthesis required by the engineer necessarily takes an extended time. The completed education of the engineer involves both the period spent in the college and in industry. Certain things can be taught best in the college, other things can be learned best in industry. Inevitably the job of the college will tend more toward the analysis which must be taught and the synthesis will be learned in industry. However, it would be surprising if the distribution of time decided on for the engineering curricula seventy or more years ago were the ideal today. Frequent suggestions have been made that the engineering curricula should be extended beyond four years. These suggestions have not been adopted because the *burden of proof* has been upon the colleges to show that more than four years would be advantageous to the individual and to industry in the completed training of the engineer, and this proof has *never been given* except in the case of men who intend to enter research or teaching in certain fields. Proper design procedure in the development of the curricula, and a realistic recognition of aims and possibilities should lead to a more definite answer.

It may be felt that, because our existing curricula have trained men who have become good engineers, no change should be considered. But this is the philosophy of "what was good enough for father is good enough for me", which is the very antithesis of the engineer's creed. As a matter of fact, we had engineers long before we had engineering education and we shall have engineering even though we do not teach it, because men will work out their own problems if the schools do not assist them

But, unless the educational process itself is considered a failure, it seems evident that a properly designed curriculum will produce a better product.

The cultural value of the engineering way of thinking should not be overlooked in our postwar educational planning. The engineer has a way of life, a mental directness and vigor, which is useful in the solution of many of mankind's problems. The social scientist, the physician, the lawyer, the politician, the preacher, and many others can learn from him as well as teach him. But when the nonengineering student of arts has asked what course or courses he might take to learn about engineers and engineering, we have offered him Elementary Surveying 301 or Direct-Current Machinery 426. Such courses can never convey any idea of what engineers are or what they can do. Is it any wonder our profession is misunderstood? We should give serious consideration to providing some such course as the "Philosophy and Methods of Engineering" for the cultural education of nonengineers. If our methods were known, workers in other fields could frequently frame their problems so they could be brought to engineers for solution and great additional good would result.

The design of proper engineering curricula should not be the job of educators alone, but should be participated in by practicing engineers of experience. In order to obtain such participation, an orderly procedure is desirable. It is proposed that the individual sections of The Institute of Radio Engineers devote one meeting in the near future to a discussion of these problems. The representatives of the Institute at the educational institutions in the immediate vicinity of each section might act as a nucleus or committee to open the discussions. A secretary should be appointed for each section to record the significant comments and these should then be sent to the Institute's Committee on Education for compilation. Then these assembled comments, the opinions of a representative group of engineers, could be made available to educators for consideration of any action which might be recommended.

The design of new curricula may require changes in methods of teaching, without which the desired results cannot be obtained. Serious study must be given to this problem as well as to the curricula content itself.

CONCLUSION

The design of individual curricula for civil, electrical, radio, and other engineering branches will differ and this article is not intended to suggest particular collections of courses. What is suggested is that engineering curricula should be *designed*. The engineering method of synthesis to produce the most desirable result from all the available material should be applied. It is further emphasized that this is a golden opportunity for educators and engineers to get together to discuss their mutual problems. It is suggested that during a time when the flow of scientific knowledge is restricted for security reasons, many Sections of engineering societies could profitably devote meetings to the methods and aims of engineering education, so that following its resurrection after the war, we may find it indeed a new and better agency for promoting the welfare of the profession and of mankind in general. Simultaneously, the educators should make use of the time available to consider the possibility of modifications in curricula which will more nearly approach the possibilities latent in a true engineering education, taking into account the comments of practicing engineers who are the ones who make use of their product.

The Amplidyne System of Control*

E. F. W. ALEXANDERSON†, FELLOW, I.R.E., M. A. EDWARDS†, NONMEMBER, I.R.E.
K. K. BOWMAN†, NONMEMBER, I.R.E.

***Summary*—Some typical forms of amplidyne control are described and a method of analyzing their functional characteristics is given. It is shown how it is possible to predict the speed and accuracy of response of a follow-up control and how to avoid self-sustained oscillations. The problem is approached by the method of resolving irregular control functions into their equivalent sine-wave components. Several methods are described for suppressing oscillations due to feedback in follow-up controls and it is shown how anti-hunting systems may be worked out so as to result in a minimum impairment of the speed and accuracy of the control.**

THE amplidyne is an amplifier used for power control. It has found extensive use both in industry and in other places, and it has proved to be a very successful alternative to the electronic amplifier in those cases where it can be used. The best way to explain briefly how the amplidyne functions is to indicate some of the typical applications.

VOLTAGE CONTROL

The amplidyne is used to regulate the field of a generator. The advantage over an ordinary exciter is that it forces the changes in field strength to take place in much shorter time and therefore it smoothly and swiftly corrects either wide load swings or small deviations. Fig. 1 shows diagrammatically the application of amplidyne induction control to an induction furnace.

---

* Decimal classification: 621.313.23. Original manuscript received by the Institute, January 26, 1944. Presented, Winter Technical Meeting, New York, N. Y., January 28, 1944.

† General Electric Company, Schenectady, N. Y.