# IRE Transactions

## ON EDUCATION

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# IRE Transactions

## on EDUCATION

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**CONTRIBUTIONS**



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# Looking Forward

OCCASIONALLY one must turn around and look back in order to see ahead. Possibly PGE TRANSACTIONS has had such a short life that no depth may be obtained from a look back. For the Editor, the existence of PGE has been long but the time scale has been compressed into putting together six issues of these TRANSACTIONS. Deadlines seem to creep up on one faster than speaking engagements set one year away. The Editor looks both backward and forward at this time. (Please don't say what you're thinking when you read that last sentence.)

Most of the charter members of PGE felt that here was a youthful approach to engineering education problems. Nearly all believed that the growth of PGE would be slow. It has been slow. It will continue to be slow because its very existence is based on a dedicated love to do something for students and teachers. The monetary returns on love are indeed very low. Often these returns are expressed only in some deed, some kind action which industry, the students, or the teacher performs. (That's the best kind of pay anyway.) What has PGE done?

Through the pages of TRANSACTIONS and through its committee action PGE has planned for and executed several sessions on education. One of these was at the NEC, the other at MAECON. A summary of the panel discussion on laboratories is in this issue. PGE TRANSACTIONS is presenting as much evidence as it can on the budding application of the fruits of its own efforts—the application of electronic instrumentation to teaching. It has set forth a number of views concerning the changes needed in our educational system to prepare the student better for his future in a very rapidly changing technology. Industrial leaders and educational leaders have teamed up to try and lead the way.

As an immediate action, PGE, through Dr. E. W. Herold, a member of its administrative committee and a member of its Board of Editors, has set up the program described below for the IRE National Convention.

Here indeed is the youthful IRE's forward look at the Teaching-Learning system. Be there and be refreshed. Leave your pet gripes at home. Progress is faster than you think.

### Symposium: Psychology and Electronics in the Teaching-Learning System

Our Professional Group is sponsoring a Symposium at the March Convention in New York, which we believe will be of unusual interest to all our members. The official summary of our session is as follows.

"A teaching and learning system, when it involves a tutor and a single student, comprises an information source followed by imperfect transmission and reception. A delayed feedback system reduces the distortion. With large classes (or absentee teachers), the feedback compensates for an average distortion, and the time delay in correction is long, sometimes many days. Recent psychological studies have greatly increased our understanding of such systems, and the electronic scientist can assist in effecting great improvement. A distinguished psychologist (Professor B. F. Skinner), and a science educator (Professor H. E. White), each explain their experiments; two creative scientists discuss present possibilities and future solutions (Dr. R. F. Mager and Professor C. R. Carpenter)."

The session also includes a panel discussion, and will be in the Grand Ballroom of the Waldorf-Astoria Hotel, on Wednesday, March 25, 1959, from 10 A.M. until NOON. The Chairman will be Dr. F. E. Terman, former IRE President.

PGE and its TRANSACTIONS can only be as good as people dedicated to better education wish to make it. Let us shed our apathy and be a truly forward-looking force within IRE, Industry, and Education. Be at the proposed conference. It will be stimulating, provocative, and progressive.

—*The Editor.*

# The Time Is Now*

ERIC A. WALKER†

*Summary*—To supply our economy with the professional manpower it must have to meet the political, economic, and military challenges of the Soviet Union and to harvest for the benefit of all people the tremendous potential of the scientific age, America must provide an education that will permit all young people to realize their full potential for mental and intellectual development. These are challenges to man's capacity to know and to understand and to his capacity for disciplined and responsible intelligence. To meet these challenges, America must 1) devise a diverse, multilevel collegiate structure aimed at the development of individual talents and abilities rather than at the inculcation of a fixed body of knowledge; 2) conduct basic research into the educative process to find ways of improving our instruction while increasing its efficiency; 3) re-examine our methods of teaching to find means of emphasizing the development of creativity; 4) establish systematic methods of identifying our talented youth early in their school programs; 5) effect a change in general attitude toward scholarship in our country; and 6) find an equitable and satisfactory means of financing education in proportion to its value for America.

IN recent years, the education of scientists and engineers in the United States has twice been seriously buffeted by grave events of nation-wide importance. And, in each instance, our colleges and universities have been charged with failure to measure up to the challenge of the event.

The first of these was the shortage of engineers and scientists that threatened to imperil our economy and endanger our security. This shortage, which evidently reached its height of intensity early last year, triggered insistent demands for increasing the number of young people being trained in technical fields. Even before this problem was resolved, Russia launched the first of her sputniks, shocking the American people into a belated realization of Russia's phenomenal advances in science and technology. This realization led to charges that America had been caught napping and touched off comparisons between the American and the Russian systems for training scientists and engineers.

All of you, I am sure, are familiar with the debate that followed—a debate that is still being contested, often with considerable heat, in the nation's press, over its air lanes, and across its conference tables. To the extent to which this debate has dissipated America's smug complacency and has forced us to take a new look at the system by which we attempt to educate our young people, it has been good for us.

Unfortunately, however, the debate has often centered around charges and countercharges dictated, it would seem, by narrow vested interests. Further, the debate has been shaped by a dangerously inadequate assessment of the real challenge we face and has been based upon insufficient knowledge and data both about what we are trying to accomplish and about the mechanisms we use to try to achieve our goals.

It is vitally important, of course, to satisfy our internal economic and industrial needs for professional manpower. It is even more important, if we are to protect our ideals of democracy, free enterprise, and the dignity of man, for us to meet the Russian challenge—a challenge that has long since surpassed the relatively simple threat of military aggression to include the more complicated and more dangerous threats of economic, political, and ideological aggression. If we do not meet these challenges, we shall certainly be reduced to the status of a colony in the community of nations in the years to come.

But these challenges, as important as they are, are only part of a larger, even more vital challenge facing us. The real challenge is not to be measured by the number of inches of want-ads for engineers and scientists carried by the metropolitan newspapers on Sunday morning. Nor is it to be measured solely, nor even basically, by the threat to our leadership imposed by Russia's upsurgent technological and scientific competence. Rather, it is to be measured in terms of our ability to exploit and to extend for the benefit of all mankind the scientific frontier discovered in just the last few years.

This new world promises rewards that stagger the imagination. It has already given us the ability to change, rather than merely to adapt, nature to suit our needs. It has already given us a source of energy that will probably solve for all foreseeable time our power needs. It has already given us cures or preventions for some of man's most persistent and most deadly ills. It has already given us the ability, if only on a small scale, to explore the space seas lying about our island world. It has already given us automation, which promises at long last to free man from manual labor. It has already changed, to a significant extent, the kind of work we do and the kind of lives we live. And it has already shown us that the discoveries made so far are like the visible part of an iceberg: that which lies hidden beneath the surface bulks larger than that which is now known.

This is our real challenge—the extension and exploitation of this vast frontier. It is basically a challenge to man's capacity to know and to understand, to his capacity for mental and intellectual development. The frontier itself is infinite, and our explorations into it are limited only by man's innate potential for disciplined and responsible intelligence and by the degree to which we are able to realize that potential.

Perhaps an analogy will help. Each major scientific

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breakthrough is like opening a door into a room—a room whose use had been denied to man up to the opening of the door. Many other doors open from this room—doors we did not even know existed before the opening of the first one. And behind each of these doors lie other rooms from which open other doors.

These doors can seldom be forced. They are usually impervious to the sheer weight of numbers or even to the slow erosion of time. Rather, they can be opened only by a man of unusual talents—a man equipped with enough insight and genius to discover the combination of the lock on the door and with the proper tools for manipulating it.

Our stake in the scientific age, then, depends on our ability to find these rare geniuses—these men who can open the doors to the unknown for us—and on our ability to cultivate their rare talents, to provide them with the proper tools, and to encourage them in their work. The demand is for both quality *and* quantity: quality simply because the locks cannot be opened by ill-prepared, shoddily equipped workmen; quantity because, since each opened door discovers new ones to be opened, there will always be more doors than there are people to open them.

This demand for an ever increasing realization of man's full potential to know and to understand is not limited to our scientific pioneers. Bertrand Russell recently warned, "The discoveries of modern science have put into the hands of governments unprecedented powers both for good and for evil. Unless the statesmen who wield these powers have at least an elementary understanding of their nature, it is scarcely likely that they will use them wisely. And, in democratic countries, it is not only statesmen, but the general public, to whom some degree of scientific understanding is necessary."

Actually, the need is even greater than that indicated by Mr. Russell. We are not concerned solely with the governmental and political uses of the results of the scientific age but with their uses for the benefit of all mankind at all levels in all activities. And the price we must pay for these advantages is a general raising of the intellectual level of all people in all walks of life. A central characteristic of the scientific age is that it replaces, at the level of routine chores, human labor with machines that do the work faster, more accurately, and at less cost. And everyone, all along the line, must operate on a correspondingly higher human level of mental activity. We replace muscle power with brainpower. The unskilled laborers must then become craftsmen, the craftsmen technicians, the technicians engineers and professional people, and the professionals must become scientists and philosophers.

Our educational system, then, is faced with a tremendous responsibility. We must provide the best possible education for all young men and women at the highest level at which each boy and girl can profit. We must have both quality *and* quantity. The challenge gives us no other choice.

To meet this challenge, we shall have to effect something approaching an educational revolution in just the next few years. We must remember, however, that revolutions often destroy without producing anything to fill the void. If the sweeping changes that are going to take place are going to produce a sounder, better system of education in America, we must frankly recognize the problems we face; work out sane, logical solutions to them; and then proceed systematically and courageously to carry them out.

Where are we to start in this effort? I should like to discuss a few of the more pressing problems, as I see them—problems that demand immediate attention, problems that have grave implications for our colleges and universities, our social units and organizations, our political and governmental divisions, and our people generally.

1) In the first place, we need to take a long, hard look at the way in which our collegiate education is structured.

A little over a century ago, it became clear that our educational needs had outgrown the fixed-curriculum, required-course programs offered at the time by almost all American colleges. These colleges, committed to the ideal of tutorial, textbook instruction in classical languages and general culture, provided no mechanism for furnishing a dynamic and growing young country with either the type of person or the type of information it needed to feed its growth.

To fill this gap, pioneering institutions such as Harvard among the private colleges and Michigan among the newly created public ones established a new kind of higher education. This education, patterned generally after the German university ideal, emphasized research and scholarship as a means of providing specialized and professional training especially in the previously ignored fields of the natural and applied sciences and social studies. To carry out this program, these institutions evolved the multiple-major, Bachelor's-degree system almost universally followed by American universities today.

This system has served us well. But no significant changes have been made in it since it achieved its final form perhaps 75 years ago. In the meantime, our social, political, economic, and industrial structures and the arts and sciences upon which they are based have undergone revolutionary changes. Is it not possible that our educational needs have again outgrown our educational structure?

Actually, they have, if it is true that we need to educate all our young people to the highest level from which they can profit. Our multiple-major sytem offers our young people a wide choice of professional and academic fields in which to specialize—wide enough, surely, to provide almost any young man or woman with a major subject that closely matches his interest pattern. At the ability level, however, it provides almost no choice: a student can succeed or he can fail in a cast-in-concrete educational program leading to a Bachelor of Art or a Bachelor of Science degree.

This system seems to insist that the only proper training for useful work in this whole bewildering variety of professional and academic fields is somehow inherently tied to a four-year, 130-semester-hour program. This assumption is, of course, just not true; and our one-tier educational program is extremely wasteful of brainpower. Not all young people have the same capacity for education, just as not all people have the capacity for playing the piano. By forcing all of those who come to our schools into the same educational mold, we fail to provide the most gifted ones with challenges sufficiently vigorous to develop their full potential. In fact, we are more apt to implant habits of mental laziness by offering such students courses in which they can make good grades and perhaps even win honors without "cracking a book." Further, we lose the less gifted ones altogether by forcing them into courses beyond their mental capacities.

Industry today, for instance, desperately needs technicians. Further, it is estimated that about four times as many young men are qualified to become technicians as are qualified to become engineers. Yet we are graduating about twice as many engineers as we are technicians. We need to reverse the ratio, both from a standpoint of need and from a standpoint of making the best possible use of our available manpower. The question here is not one of quality vs quantity: we need good engineers, and we need good technicians. In fact, we need as many as we can get of both. And you get a good technician through quality technical-institute training and not through poor engineering training.

Our colleges and universities must recognize that, to educate all students to the highest possible level, they must devise graduated, flexible educational programs that permit the artisans to be trained at one level, the engineering and scientific aides at another, the ordinary engineers and scientists at still another, and the most creative of our students at the highest of all, the doctoral level. Only through such a system will we make it possible for each student to work at his proper level: the highest level attainable by him.

2) In the second place, we must conduct some bold, basic research into the nature of the educative process to determine ways in which superior teaching can be extended to greater numbers of qualified students. There have been no significant "breakthroughs" in educational methods during this century, nothing that can compare even faintly with the technological breakthroughs that have revolutionized our industrial complex. Yet nothing we now know indicates that such advances are impossible.

Are the courses we offer the best we can devise to prepare a young man for proefssional work in today's complex technological society? Can we meet the instructional loads that will be required of us with the faculty we shall be able to get in the next few years through traditional methods of teaching? In fact, are the traditional methods the best methods? Are we making the best possible use of the new techniques and equipment designed, for the most part, by products of our colleges and universities?

And how about class size? Are small classes good in themselves? There is no convincing research data supporting this popular belief. Is a low student-to-teacher ratio necessary for quality instruction? We do not really know. What, after all, are the best possible classroom conditions for most effective instruction? We do not know, but we need to find out.

And how about teaching methods? Is it not possible that we should do some research to improve our traditional methods? How about the possibility of putting closed-circuit television in dormitory rooms? Experiments carried out on a limited scale show that certain kinds of courses can be taught by television as well as, if not better than, by older direct-contact methods. And should we not consider putting our brighter students more on their own, giving them more responsibility for their own education? One of the criticisms of American higher education is that we spoon-feed far too much. How about the possibility of using teaching aides to help our better teachers to teach more students effectively? The method has worked in industry.

These are not proposals. They are not even suggestions. I ask these questions simply to illustrate the need for research into what we teach and how we teach it. The "state of the art" in education simply has not kept pace with the professions for which they attempt to prepare young people. To correct this inequity, we need to direct some of our research talent and effort toward a new and unfamiliar problem—the educative process itself.

3) We need also to re-examine our aims and the methods we use to achieve them. I am afraid we do most of our teaching by analysis. We give our students a situation and ask them to analyze it, to dissect it, to break it down into its component parts and classify them. Given a bridge, we ask our students to determine the stresses in the various members. Given an electric circuit, we ask them to calculate the voltages and currents in the different loops and nodes. The engineer is asked to analyze the design of a generator that is already made and proved. The chemist is asked to classify salts that are already classified. The architect is asked to trace Greco-Roman influence in American public buildings.

This is an excellent method for producing cultural and scientific caretakers, the men who will maintain the rooms after they have been opened for us by others. But it will not produce innovators, the ones whose genius is needed for opening the doors to the rooms in the first place. It will not prepare young men to invent machines, to develop new systems, to formulate new theories. For it teaches them to do that which has already been done. It teaches only analysis.

But analysis is not creative. The creative process is a synthetic one. Synthesis and creativity are inseparably tied together, but we do not teach synthesis. I think this is even more true in the sciences than it is in the humanities and the arts. In the arts we do try to give creative people a chance to express themselves. In the sciences, we almost never do. If we are to make the most of this brilliant new age, we shall have to learn to recognize the spark of creativity in our young people and to fan it into a full-blown but disciplined blaze.

Further, we must look closely at our programs to make certain that the major system has not led us into too much narrow specialization in all our colleges and departments, the humanities as well as the sciences, the social sciences as well as engineering. Our engineering curricula have been charged with being too narrowly specialized for a long time, but I rather suspect that the same charge can be proved against many of our programs in the arts and humanities. Is the history major concentrating in seventeenth-century middle European history any less specialized than the engineering major concentrating on the physics of acoustics? I doubt it.

The simple truth is that the humanities major today needs to know something of the impact of science on our total culture, just as the budding scientist needs to know something about our cultural heritage. We need specialists, but we need them broadly oriented and broadly trained so that they can transcend their specialty to make their maximum contribution to our total civilization. To this end, we need more courses for the non-major—courses not designed to provide a superficial "survey" but to lay a solid groundwork for broad interdisciplinary exploration.

4) We must establish a systematic method of identifying talent early enough to permit us to direct it into the proper channels. In a study published in 1954, the Commission on Human Resources and Advanced Training found that only six out of 10 boys and girls in the upper five per cent of our high-school graduating classes continued their education at the collegiate level. We simply cannot afford this waste of talent.

To salvage any of these, we must know who they are. In addition, it now looks as though the colleges and universities are going to have to limit their enrollments even more severely in the future then they have in the past. If we must do this, we should make every effort to see that those who can profit most from our curricula get preferential treatment. To this end, I suggest that we establish a nation-wide system of qualifying examinations for testing all students twice during their pre-college training, once at the ninth-grade level and again at the twelfth. Such a system would provide an orderly and productive method of discovering potential talent to replace our present haphazard, unsystematic ones. It would also provide some hard data on which colleges and schools can base their counseling, the need for which will be greatly increased if we adopt a more flexible structure for higher education such as I suggested earlier in this discussion.

In any event, we cannot afford the loss of potential talent simply because we do not know where it is. To conserve or develop anything, you must first discover it.

5) We must have a change in our attitude toward scholarship. The whole broad area of motivations and values is important not only to who goes to college but also to what sort of work is done by our students at all levels. Our pupils and students, at any level, simply are not generally working at the level of their full intellectual capacity.

This is especially true of the boys, who obviously find greater personal rewards by competing in sports or engaging in social activities than they do in making good scholastic records. A recent study, for instance, of almost 13,000 graduates of Connecticut high schools showed that, although 13 per cent of the girls stood in the upper 10 per cent of their classes, only six per cent of the boys did so. Since, in a random sample this large, the intelligence of the boys must be assumed to equal that of the girls, this difference in performance must be related directly to effort. And effort is directly related to motivation.

All of you know that solving a difficult mathematical problem or discovering the perfect order of any interlocking subsystem of nature can be as exciting as scoring a winning touchdown or having your first date. But our young people do not seem to know it.

I believe this is an area in which the parents must assume primary responsibility. But there are implications for all of us. We cannot expect our young people to make any particularly significant sacrifices for, or to be strongly motivated toward, a life of scholarly activity when, as a society, we honor our professional football players and our ballad singers more than we honor our scientists and scholars. As long as our local newspapers devote more space to high-school and college athletic achievements than they do to scholarly achievements, we shall probably not make much progress. Even the newspaperman's response, when asked about this, "Who cares?" is symptomatic of society's anti-intellectualism.

We cannot afford to support this anti-intellectualism. But perhaps equally important, it stands between the student and the intrinsic appeal of science and scholarship; the feeling of awe before their universalized observations; and the satisfying "rightness" of their workmanship, order, and organization. It stands between our youth and their full development as mature, productive members of society.

6) Finally, we must find means for channeling a greater percentage of our national wealth into our schools, colleges, and universities. They must have more money, if they are to do the job expected of them: more money for buildings and equipment, for scholarships and loans, for research, and, most important, for raising the salaries of faculty and staff. We cannot meet the challenge we face by holding the line on admissions to create an educational elite selected on the basis of parental wealth.

This problem has been freely debated and well advertised. Consequently, I shall limit myself to just one observation as a conclusion to my discussion.

Although we have been adequately forewarned of the problems we face—perhaps even because we have been—we have failed and are failing to prepare ourselves for the educational Pearl Harbor toward which we are rushing. Instead of figuring out how the problem can be met, everyone is busy trying to fix the responsibility for its solution onto someone else. Business and industry warn that they cannot be expected to give more than one per cent of the five per cent allowed by the tax laws. State legislatures find that taxes are already high and that it is difficult or impossible to raise them further. Parents point to the steadily rising cost of a college education and maintain that further increases will restrict college-going to the sons and daughters of our wealthier people. The students themselves resist loans as a means of financing a college education, pointing out the difficulty of establishing a family and starting a career even without the additional handicap of a large debt. No one seems to favor Federal aid.

If we are to meet this challenge, *someone* is going to have to foot the bill. I have pointed out several ways in which the colleges and universities themselves can help by increasing the efficiency of their operation. But the colleges and universities cannot do the whole job by themselves. Somewhere the buck-passing *must* stop.

Through two world wars and a prolonged "cold" war, we have demonstrated our willingness and ability to protect ourselves *militarily* whatever the cost. We have yet to demonstrate our willingness to educate our youth to protect our way of life from ideological aggression; from professional, scientific, and cultural malnutrition; and from social and philosophical insufficiency.

Our most immediately pressing problems then are:

1) To devise a collegiate structure that will permit us to develop the intellectual potential of each boy and girl to its highest possible level.
2) To conduct basic research into the educative process to determine ways of "improving our instruction" while increasing the efficiency of our best professors.
3) To re-examine our methods of teaching to emphasize the development of creativity as opposed to craftsmanship, the development of synthesis rather than of analysis, the development of innovators rather than of caretakers.
4) To establish systematic methods of identifying our talented youth early enough to direct their energies toward their most useful social role.
5) To effect a general change in attitude in the United States toward scholarship in order to make it possible to develop our potential talent to its highest level.
6) To find an equitable and satisfactory means of financing education in proportion to its value for America.

How well we meet the challenge of the scientific age depends squarely on how well we solve these problems, and how quickly.

If solutions to some of these problems, or even methods of attacking them effectively, grow from this conference, the conference will have provided a vital service to our country. It could well be that this conference will trigger reforms in education that will make it possible for man to enter an exciting higher plane of living. This is your personal challenge during this conference. Good luck and best wishes.

# A Senior-Year Semiconductor and Electron Device Course*

A. G. MILNES†

*Summary*—**Energy gap, minority carrier mobility, diffusion, and lifetime, and electron emission and space charge concepts present difficulties for many students. In the course described here, considerable emphasis is placed on student experiments to create sound understanding of these ideas.**

* Manuscript received by the PGE, November 11, 1958.
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## Introduction and Philosophy of the Course

In the last few years there has been a trend in the electrical engineering departments of most universities to provide increased emphasis on device physics, atomic physics, and theory of solids. Early in sophomore year, students may be encouraged to discover that simple concepts of resistance, inductance, and capacitance fail to fit many of the facts of life in modern electrical engineering. This can be accomplished by laboratory problems involving nonlinear circuit elements such as rectifiers, thermistors, square loop magnetic cores, and special devices such as Hall generators.

During junior year, students at Carnegie Institute of Technology receive Maxwell's field theory and two semesters of circuit theory as their main electrical courses. In addition they are required to take either two semesters of "Atomic Physics for Engineers" or a one-semester course on the "Science of Engineering Materials." Both courses review the structure of matter, quantum-mechanical concepts, Schrödinger's wave equation with particular reference to the hydrogen atom, binding forces in molecules and solids, Maxwell-Boltzmann and Fermi-Dirac statistics, energy band concepts, magnetism, and semiconductors. Experience shows that because of the highly mathematical presentation in these courses, students may easily lose grasp of the physical situation. Most students require frequent reference to simple physical models and analogies, and usually a mathematical presentation can be explained satisfactorily in such terms even though the models and analogies are incomplete and subject to modification as the subject is developed.

The "Semiconductor and Electron Device" course follows in the first semester of senior year. It involves 3 one-hour recitation or lecture periods, a morning or afternoon laboratory period and 8 hours of home preparation per week. The semester is 16 or 17 weeks long.

In teaching advanced courses, all of us have encountered massive misconceptions and lack of understanding on earlier important and basic matters. Introductory courses usually do not allow sufficient time for student appreciation of fundamental concepts. In this course, therefore, considerable emphasis is placed on student experiments and measurements in problem-solving situations which are related to basic concepts. Time expended in this way is usefully employed for its saves valuable lecture time later in the course. For instance, an elaborate analysis of the latest and most sophisticated semiconductor device loses its significance for students who have faulty concepts of properties such as energy levels, holes, diffusion, mobility and lifetime.

One consequence of this emphasis on root content is that normally the instructor has neither the time, nor the sense of compelling obligation, to survey the whole field of devices and device theory. However, if basic concepts are clearly developed, the student who successfully completes the course can subsequently study particular areas of device theory according to his own needs, and thus is better equipped to grow and develop in this field.

## Experiments on Semiconductor Concepts

The first six weeks of the semiconductor and electron device course are devoted to a study of semiconductor concepts and properties rather than devices. Since the measurements actually made by the students themselves are of key importance in the learning process, the main emphasis in this description of the course will be on the laboratory work performed.

Experiments or problems are proposed to the students about a week or ten days before they are begun in the laboratory. In the interval, student groups (of three) are required to produce plans, about 6 to 8 pages in length, detailing the theory of the experiment and the procedures to be followed. All component values, pulse rates, etc., must be specified with the reasons for their choices. After the instructor has inspected these plans a class period is spent discussing the problems involved. Formal lecture material, which is usually necessary to coordinate the work and discussion, is not allowed to anticipate the student's first studies of the problem. The experiment is concluded by the writing of a report by each group before proceeding to the next problem.

The three experiments that take up the first six weeks of the course are concerned with properties such as energy gap, carrier densities, resistivity, mobility, and lifetime.

*Experiment 1—Resistance and Hall Effect Measurements*

With specimens of germanium, silicon, and indium antimonide, resistance and Hall effect measurements are made to determine majority carrier densities and mobilities. The conductivity types determined by Hall polarities are compared with those given by hot-probe testers. Resistance measurements are checked against four-point probe test readings. Facilities are provided for resistivity measurements over the temperature range from 200°C to that of liquid nitrogen (−195°C). This provides a simple means of estimating the energy gap and of learning something of the change from extrinsic (doped) to intrinsic conductivity.

*Experiment 2—Minority Carrier Mobility and Diffusion Studies*

This is the classic Haynes-Shockley drift experiment in which a pulse of holes is injected into a bar and moved along the bar by an applied electric field. From the transit time and the dispersion of the pulse, the mobility and diffusion constant may be determined. Studies are carried out of the effects of field strength and pulse injection level on the measured values, and conductivity modulation usually shows in the results.

The test specimens, made in the E.E. Department, are thin bars about 2 mm wide and 1.5 cm long of $n$-type, 15–20 ohm-cm germanium with a minority carrier lifetime in excess of 300 μsec. At each end is an ohmic contact and adjacent to each ohmic contact is an indium alloyed, rectifying contact for injection and sensing of holes. For protection the bar is set in transparent epoxy-type resin.

These specimens may also be used for minority carrier lifetime measurements, for the study of diode characteristics, as filamentary transistors, and as negative resistance double-based diodes. Locally they have acquired the name "Experimistors."

*Experiment 3—Diffusion Length and Lifetime Measurements*

The experiment here is the Valdes or Morton-Haynes technique and involves the process of minority carrier injection by a thin-slit chopped-light source with micrometer movement of the specimen (usually an "experimistor") to determine the diffusion length and, hence, the lifetime. An independent check of minority carrier lifetime is then made by large area photoinjection and measurement of the time-constant of the decay of the induced resistance change.

A few specimens are also available with which groups can distinguish between bulk and surface lifetime effects, and observe photoelectromagnetic effects and trapping phenomena.

### Semiconductor Device Studies

By the time the third experiment is completed, the class lectures and discussions have advanced to the basic diode equation

$$J = q\left(\frac{D_p p_{n0}}{L_p} + \frac{D_n n_{p0}}{L_n}\right)(e^{qV/kT} - 1).$$

Further discussion on other diode properties such as differential resistance, diffusion capacitance, minority carrier storage, and voltage dependence of the reverse-biased depletion layer capacitance, continues while experiment 4 is in progress.

*Experiment 4—Semiconductor Diode Tests at Various Temperatures*

Alloy junction or diffused junction diodes are provided and studies proceed as follows.

1) Checks of the exponential form of the diode V-I relationship and evaluation of the $kT/q$ part are made. Effects due to bulk resistance and conductivity modulation are also considered.

2) With clear-resin encapsulated alloy junctions, as in the experimistor, it is possible to measure resistance, diffusion length, and junction area. Thus the expected reverse current can be calculated theoretically and compared with that observed. The shape of the reverse current knee as an avalanche condition is approached is also noted.

3) Minority carrier storage is then observed and used as a method of determining the effective lifetime immediately under the alloy junction. Usually this lifetime is appreciably less than that given by the Valdes method in 2) above, and the reduced value is used to bring the expected reverse current more into line with that observed experimentally.

4) Capacitance measurements as a function of reverse bias voltage are undertaken as a way of studying impurity distribution across the junction region.

5) Finally, an attempt is made to explain quantitatively the effects of temperature in terms of the generally recognized variations of parameters such as mobility and resistivity.

*Experiment 5—Study of Transistor Characteristics and Parameters*

Detailed transistor characteristics are plotted to provide the greatest possible familiarity with common-base and common-emitter curves, and regions of operation. Collector voltage ratings under common-base and common-emitter conditions are studied and a search is made for avalanche effects. Sets of curves are taken at room temperature and 100°C, and special quantities such as $I_{co}$ may be studied as a function of temperature.

The frequency characteristics are determined and the hybrid parameters are measured so that equivalent circuit concepts are understood. Inverted operation with the normal collector operating as emitter is also proposed for study. In conclusion, the groups open their transistors to measure emitter and collector areas; they may have time to section and etch units to measure the base widths which determine the frequency characteristics.

*Experiment 6—Test on a Special Semiconductor Device*

At this stage each year, a less common semiconductor device is selected to form a good study problem. It may be a filamentary transistor, a double-base diode, a four-layer trigger diode, a unipolar field-effect transistor or tecnetron, a Peltier-effect thermoelectric junction, a Suhl-effect junction Hall generator, or some electroluminescent device. In the Department, graduate research is underway, or has been completed recently, on all of these subjects and this facilitates the provision of specimens for undergraduate use.

Perhaps it should be stressed once again that when experiments are first proposed, they are not given in any detail; it is the function of the student groups to provide this information in their plans. Indeed, groups are encouraged to suggest all possible cross-checking of measurements and equations by proposing auxiliary experiments and tests. Such proposals are discussed in class so that other groups can adopt them if they see fit.

### Electron Tube Studies

The course, as described so far, occupies about ten weeks, and vacuum tube and gas tube devices have to be covered in the remaining six or seven weeks. At this stage, therefore, attention is directed to the physical basis of thermonic emission and the Richardson-Dushman equation

$$J = AT^2 e^{-q\phi/kT}$$

must next be studied.

*Experiment 7—Vacuum-Tube Diode Studies*

1) A diode with directly heated filament is provided and with it the Richardson-Dushman equation is checked and the work function $\phi$ and emission constant $A$ are determined. (The filament resistance provides the required measure of the temperature, and one tube is opened so that a typical measurement may be made of filament length and area.)

2) Observation is also made of the Schottky tunnel effect.

3) Finally a study is made of the Langmuir-Childs three-halves space-charge-limited law and its effect on diode impedance.

*Experiment 8—Triode, Tetrode, and Pentode Characteristics*

Triodes, tetrodes, and pentodes are taken and characteristics are plotted for comparison. The mutual conductance, amplification factor, and dynamic plate resistance are determined for typical quiescent points and their interrelationship is checked. External capacitances are added to clarify the role of the "unavoidable" internal capacitances. The pentode may be operated successively as a triode and tetrode, and careful account is required of the physical action responsible for the curve shapes observed.

*Experiment 9—Test on a Special Tube Type*

The concluding experiment of the course may be on any one of a variety of tubes, gas-discharge or hard vacuum. Thyratrons or photomultiplier tubes are possible choices for the former type. For a vacuum tube experiment it is possible to select from tubes of unusual form, perhaps built for special military functions now superseded. Many electrical engineering departments have acquired small quantities of such tubes at some time or another. Frequently such tubes can be used to illustrate some basic aspect of tube action in new disguise and to pose reasonable but instructive problems for the student. Some examples are described as follows:

1) U. S. Navy CKR 1636: a beam deflection mixer tube which is particularly useful for magnetic field sensing. The structure comprises an electron beam gun and a complex anode and dynode structure.
2) RCA 1630: a tube using secondary emission for amplification as in a photomultiplier.
3) Western Electric 101D: a planar triode useful for study of the influence of boundary edge effects.
4) Amperex C100: a experimental electrometer type tube with grid external to the glass envelope.

Electrolytic tank, or rubber membrane studies form the basis of other suitable problems where these facilities are available for the necessary number of student groups. Resonant cavity magnetrons and klystrons are regarded as rather outside the range of the present course as far as experimental work is concerned, although the physical action may be briefly considered in class work.

## Conclusion

Throughout the course the emphasis is on development of a good physical understanding of the subject by personal effort made in connection with the experiments. Basic experiments and instructive problem-solving situations are regarded as more important educationally than complete (therefore superficially understood) coverage of the whole field of electron devices. As courses develop further, some of the semiconductor studies and experiments described are expected to be transferred into the junior year, but this will not alter the philosophy propounded above.

Every second week, written tests are given and these are selected for continuity in the development of forthcoming recitation or lecture material. The questions are chosen to test physical understanding of the situation and ability to reason ahead, but normally they require specific numerical answers to prevent gradings reflecting problems of expression rather than lack of physical understanding. Points of similarity and difference between semiconductor and vacuum tube devices are stressed in tests and recitations.

Circuit functions for information processing (involving amplifier, oscillator, pulse shaping, gating, and storage problems) are considered in the final semester of senior year.

Student reaction to the course has been excellent, although a considerable amount of preparation on their part is necessary for success. Extensive use must be made of library facilities and numerous semiconductor, solid-state physics, transistor, and electron tube books are placed on reserve for this course. For additional information students are advised to consult PROCEEDINGS OF THE IRE, IRE TRANSACTIONS ON ELECTRON DEVICES, *Physical Review, Bell System Technical Journal,* and *Journal of Electronics.*

# College Recruiting—A Portfolio of Expectations*

*Summary*—**Each year America's industries and colleges join forces in an action aimed at converting the engineering student into an engineer employee. Principals in this operation are the company recruiter and the college placement director. Through the years each member of this unique alliance has come to learn the strength and weaknesses of his partner; each has profited and suffered through the other; each has developed his own ideas on how the other should operate.**

**IRE TRANSACTIONS ON EDUCATION recently asked a number of executives on company recruiting staffs and college placement offices for their opinions on the current state of college recruiting, and for suggestions on improving the operation in future years. This two-part article presents excerpts from some of the replies received.**

## What the Company Recruiter Expects of the College Placement Office

GROUP interviews in advance of individual interviews were a desideratum generally voiced by industry, though it was conceded that this practice might be impractical from the colleges' viewpoint. Industry's representatives on the whole emphasized the importance of the work accomplished by the placement office and commended the quality of the service the office provides. Other interesting opinions and recommendations will be found in the following comments.

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Our company, like most, has come to expect services such as the following from a placement office:

1) Notice to students of our campus visit.
2) An orderly interview schedule.
3) A private room for interviewing.
4) Special contacts with students previously interviewed or known.
5) A student achievement record, including grades, campus activities, etc.
6) An open channel to faculty members, for student references.
7) Students appropriately oriented for employment interviews.

The list of services provided by most placement offices goes further, but those mentioned concern services we have come to depend upon.

At the risk of riding a good horse too hard, there is an area of service on which I wish college placement officials would look more favorably. This concerns arrangements for group meetings in advance of interviews. For very understandable reasons most placement offices discourage or entirely preclude group meetings between company representatives and students. Recognizing that there are many difficulties in arranging space and scheduling students for such meetings, I believe there are some very concrete economies of time and effort obtainable through this procedure.

My thesis is to suggest a more positive appraisal of some of the benefits which can be derived by encouraging group meetings. I list a few such benefits and believe you could add to them, whether you represent student, school, or industry:

1) A company representative could tell his story or display his wares in a single presentation, instead of going over the same facts with each student he interviews. The possible economies are obvious. The thirty-minute interviews can be reduced a third or half. Interview time could be more fully utilized for appraising the student, making other important campus contacts or a quicker exit from the campus.
2) Many interviews are needless because there is no mutual interest between the two parties. A student could decide quickly from a well-planned group meeting whether he is qualified or interested in what a company has to offer. If done properly this could easily reduce the number of interviews in half, resulting in many economies to all three parties.
3) A group meeting by its nature would cause a company representative to prepare his story well. The student would understand a prospective employer much better and then decide whether it is worthwhile to spend this time in a personal interview.
4) A student could make a more objective evaluation of a company through a group meeting than under the stress of an individual interview. Certainly, lasting objectives of both company and student are reached only when both sides are honestly, accurately and objectively appraised.

Since the normal school day is used for campus interviews, group meetings should similarly occur sometime during the normal daily schedule. This is easier said than done; however, the possible good results make it worth a revived effort. (Worthwhile things seldom come easily.) It could be arranged at the beginning, or end of the school day, making sure it occurs in advance of private interviews. Thirty to forty-five minutes would be adequate. At the end of the meeting the company representative could quickly schedule interviews for persons interested. This small step would save the placement office much time in scheduling interview appointments. Obviously, many other problems would have to be worked out. I believe this approach will eventually be

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revived. If this thesis has credence, perhaps writing about it will speed the day of acceptance of the pre-interview group get-together by all interested parties.

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First I think, the company recruiter can expect that one or more personal discussions have taken place between the placement officer, or a competent member of his staff, and each student who is seeking employment. These discussions, supplemented by applicable tests, will have accomplished two things. They will have given the placement officer knowledge of the interests, dislikes and relative abilities of the students who are to be placed, and they will have given the students an insight into their respective attributes and shortcomings, and a qualified opinion regarding the types of work for which each seems best suited. This is certainly the first step if the placement office is to be anything more than a scheduling service.

In connection with the determination of the type of work for which the engineering student is best suited, it is hoped that research work for this purpose, which the Educational Testing Service, Princeton, N. J., started in 1954, will soon be proven successful. If so, placement officers and recruiters will have available to them tests which will remove much of the guesswork from these judgments.

Second, the placement officer must have an adequate knowledge of each company's work and job openings. Having this, he can provide proper guidance for students who come to sign up for interviews, so that none waste their time in an interview for a position in which they have no interest. This will also permit the recruiter to feel reasonably sure that his time will be spent in talking only with students who are interested in the positions he has open.

Third, it is important that the facilities which the college provides for placement of its students be suitable for the purpose. This means that 1) company literature, which is the best source of facts that the student has for his initial investigations, be systematically arranged for easy access, and 2) that interviews be held in an atmosphere of privacy and quiet. The size and decor of the interview room is not important, but the opportunity to talk freely, without interruptions and interferences, is very important.

Lastly, there are certain administrative details which must be handled well to contribute to the success of the process. For instance, it is very helpful to the recruiter, particularly those seeking engineering and scientific students, to receive from the college early in the academic year information on the number of graduating students in each field of study. This information can be useful to him in developing his recruitment plans for that year. Also, in lieu of group interviews in advance of the individual interviews (a device which is highly desirable but currently found to be impractical on most campuses), many companies rely on an advance distribution of literature to those students who have signed up for an interview. When this is the case, the value of the discussion to both participants is decreased if the student has not had the necessary material sufficiently in advance of the interview to prepare himself for it.

In summary, ideally the placement officer should know and counsel each student thoroughly and should be well informed on the companies that come to his campus and on the positions they seek to fill. Also, through his college he should provide suitable facilities and the various administrative services that are desirable.

Realizing full well the hazards and pitfalls that exist for anyone who attempts a generalization on a broad subject such as this, it still seems worthwhile to make an appraisal of present practices in college placement work as compared with the objectives set forth above.

The increasing number of students and the growing list of companies with their diversified requirements has placed a heavy load on the placement officers and their limited staffs, so that they do not have the time to learn as much about the students and the companies as they and the recruiters would like. However, the administrative services in most cases are good, and the interviewing facilities on many campuses have been greatly improved during the past several years. This, in view of the many demands for space that exist on most campuses today, is a clear and practical demonstration of the increasing recognition that is being given by college and university administrations to the placement office as an important college function.

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## WHAT THE COLLEGE PLACEMENT OFFICE EXPECTS OF THE COMPANY RECRUITER

College placement offices were chiefly critical of industry's past-year practices of 1) canceling scheduled college visits with little or no advance notice, and 2) withdrawing employment offices—in some instances after formal acceptance had been made. Two separate codes were cited as guides to professional and ethical standards of college recruiting—"Principles and Practices of College Recruiting," published by the College Placement Council and the Chamber of Commerce of the United States, and the code adopted in 1956 by the Midwest College Placement Association and later adopted with minor changes by the American Society of Engineering Education and several other organizations. Additional recommendations appear in the following excerpts.

Due to the recent demands and recruiting pressures, some of the practical and ethical aspects of college relations have been forgotten. The following observations have been made by our placement office during the last several years and particularly in 1958.

1) A recruiter visiting the college campus to interview students often forgets that he is the company to the student. His actions, attitudes and interpretations reflect the company's thinking and not just his own. The honest approach will build a good reputation with the placement office and students and increase the chance of employing outstanding graduates.
2) The campus interview should be nothing more than an opportunity for the company to evaluate the student and his particular qualifications for employment and the chance for the student to decide if the company has the type of opportunity and other things that he is looking for. It should not be a sales promotion show but an equal exchange of information.
3) During the recession of 1957–1958 some companies ignored the standards and professional status of college recruiting as outlined in the code of principles mentioned earlier. Because of the demands of top management, recruiting reservations at the college campuses were cancelled and often at the last minute. These cancellations caused not just confusion in the placement office but startled many members of the faculty and student body. It also eliminated the possibility of providing interviewing facilities for a company still looking for college graduates. Employers expect the colleges and universities to turn on the faucet of eligible employees when times are good and also expect the faucet to be turned off when business is poor. College graduates should be considered as investments for the future and not be expected to perform an immediate function. Every company should give serious thought to a better manpower planning and utilization program.
4) Some employers made their annual visits to the campus this year without current or even possible openings for college graduates. These "good will missions" actually created ill feelings among the students, faculty and placement officers. The idea in a number of the cases was to continue the valuable relationships with the colleges and placement offices but this could have been done in a different way and not involve the valuable time of students under the pretense of having openings.
5) The withdrawal of employment offers and acceptances has caused quite a problem for the colleges and employers, particularly people directly involved with college recruiting. In recent years the placement officers have been educating their students to honor any commitment and acceptance. It is very embarrassing for a placement director to talk with students and have them refer to a company that has resorted to withdrawing offers and, even worse, acceptances. We like to think that companies are more mature than college students and above such unethical practices.
6) The pressure for early commitments by recruiters was very noticeable in the last several years. Companies in planning their recruiting programs and establishing quotas have been very anxious to fill their needs and get their new employees off the market. It is very unfair to expect a student to make an intelligent decision on an offer without some time to evaluate other companies. In 1958 some employers made early offers and demanded an answer within two or three weeks. Other companies waited until the last minute during the spring semester to make their pitch and as a result the student was caught in the middle.
7) A few recuiters have, at times, attempted to solicit faculty members for possible employment within their organization. This is not only unethical, but a major crime, when good professors are needed to educate the college students.

Since I have been elaborating on some of the negative approaches to college recruiting I would like to list several ideas which attempt to approach the professional, ethical and successful side of employing college graduates.

1) The recruiter should discuss with the student during the interview his plans and explore with him the possible opportunities within the organization. If it appears that the student should continue with graduate work or if there is no employment in his field of interest, the recruiter should consider the well-being of the student and his company and not force employment.
2) The employers visiting the various campuses should find time to meet with faculty members and discuss projects, programs and research work being conducted on the campus and at the same time inform them of what the company is doing of mutual interest. This should be done with good judgment and not be just using up valuable time.
3) The "golden rule" should apply for all individuals involved in college relations including the recruiters, students, placement officers, and faculty.

There does not seem to be any one answer or formula to a successful college relations program. In spite of the lack of a formula, carefully planned visits and the use of common sense in dealing with human beings will help to bring better prospects into the various businesses and industries.

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Since the formation, about two years ago, of a working code of ethics,[1] to follow in interviews, for the industrial company, the college placement service, and the student, we have found only a very few minor unethical procedures in college recruiting. Industry has been most cooperative in carrying out its provisions.

A preliminary, but fundamental, provision of this code was that the employer should contact the college placement officie well in advance relative to interview dates, categories of employment, college degrees required and other pertinent facts. It stressed the necessity of notifying the placement office promptly of any changes in the original request.

It emphasized that no more than two interviewers, preferably only one, be sent on the interview date representing the company, and if more than two were deemed necessary, arrangements for them be made well in advance. It also emphasized that if both the parent company and a subsidiary or affiliated company were to have representatives present, each must make clear to the student interviewed, where and by which unit he was to be employed. It also called for clarification to the student of company employment policies and requirements.

In its final phases, the code listed such stipulations for the company employer as notifying the student within two weeks of the result of the interview, banning use of pressure to influence the student's decision, and emphasizing that if the student declined the offer, his decision was to be accepted as final. It bound the employer to engage every student accepting a job offer except when failure to do so stemmed from a contingency explained fully to the student prior to his acceptance of the offer.

The code provided several obligations on the college placement office. Among them are notifying interviewer if insufficient number of students are available for interviews in the various curricula; announce date of interviews well in advance to the students; no restrictions on the number of interviews per student except when necessary to discourage indiscriminate "shopping"; provide adequate facilities for private interviews; and wherever feasible, arrange for interviewer to meet faculty members most qualified to provide information about student's work and qualifications.

It placed on the student the responsibility of preparing for an interview by reading all available company literature, of being punctual and business-like in the interview, and to notify the company as soon as possible of his decision to accept or decline the job offer.

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When companies feel that it is necessary to renege on accepted offers, they damage their position on campus for several years, as the "grapevine" spreads such news just as effectively as if it were published in the campus newspaper.

There is a difference of opinion among college placement people concerning the practice of employers interviewing on campus when they feel that they will not be in a position to make any offers of employment. It would seem desirable to encourage any employer to conduct campus interviews if there is any chance that he might have openings. Once an interview has been canceled, it is still possible to establish another date with a school, but it is unlikely that interview space will be available on a desirable interview date.

Recommendations:

1) Every effort should be made to avoid the cancellation of campus recruiting trips.
2) In the event that the cancellation of a campus interview trip is mandatory, the cancellation should be made as early as possible and in any event at least *two weeks* prior to the interview date.
3) The practice of withdrawing offers that neither have been accepted nor rejected should be avoided whenever possible.
4) Employers should honor all accepted offers of employment.
5) Whenever an employer's needs change, after a placement office has been given information to be used in scheduling interviews, the employer should immediately notify the placement office.
6) The employer should give the student reasonable time to accept or reject an offer.
7) Placement directors should encourage employers to interview if there is any chance that they may have openings for graduates.
8) Placement directors should book all employers on a first-come, first-served basis, and cancellations should not affect this policy.

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[1] F. L. Cason and W. Burton (Minnesota Mining and Mfg. Co.), were co-chairmen of the committee drafting this code for the Midwest College Placement Association.