bracketing of research with education is necessary for this statement to be tenable; for, among other things, the researchers and developers must have been previously educated and trained, and the utilization of new technical knowledge often requires degrees of dissemination and comprehension that cannot be attained without broad and general education.

If it should be possible to find statistical criteria for the identification of the specific contributions which "investment in knowledge" and investment in physical facilities have made to the increase in productivity, and thereby to obtain evidence for claiming "major credit" for the former, one would have to guard against the mistakes of regarding these findings as pertinent for other places, other times, and other allocations of resources. Particularly one would have to guard against the fallacy of confusing "total utility" and "average utility" with "incremental (marginal) utility." It is perfectly possible for technological research to deserve first prize in the distribution of merits for economic growth and, nevertheless, not to deserve first claim on additional resources.

Lest these remarks be understood as an attack on IRAD, or as a plea for drastic curtailments of IRAD expenditures, be it noted that such has not been my intention. I have intended to show that there *can* be too much IRAD work, not that there *has* been too much of it. Whether the present rate of IRAD expenditures is too high, too low, or just right, I do not know—though I am impressed with the present plight of education and cannot help looking askance at any so clearly identified rival bidder for potential teachers. In any case, a warning is in order against the position of the IRAD enthusiasts who champion the idea of "the more the better."

Note

1. This colorful expression was used by Abba P. Lerner [*Economics of Employment* (1951), pp. 141–150]. An "upside-down economy" is characterized by unemployment of all the productive resources that would be needed to produce increased amounts of goods and services. "Topsy-turvy economics is appropriate for an upside-down economy" (*ibid.*, p. 142). Such an economy is upside down because it would not be benefited by the things which contribute to the welfare of a normal economy—namely, economy, efficiency, and thrift—but, rather, would be benefited by their opposites—wastefulness, inefficiency, and prodigality (*ibid.*, p. 146). The prescription for upside-down economies is to print money and spend it. But when this prescription cannot lift the economy beyond a certain level of employment and activity, this level should be regarded as normal, and topsy-turvy economics should be shelved in favor of "ordinary economics," "concerned with the economical use" of scarce resources.

Literature in a Technological Age

Attitudes and values involved in a possible symbiosis between arts and science students are discussed.

T. R. Henn

This article is, of necessity, concerned with some problems in English education; but my experience of American and Canadian universities suggests that the problems may not be different there. For I have seen Plato issued as "mandatory" reading for the first-year students at the Royal Military Training College of Canada, and Sir Richard Livingstone was invited to lecture on that writer at Massachusetts Institute of Technology. I have listened to discussions of poetry at West Point, and by physicists and engineers at a dozen universities, and was struck in every instance by the eagerness, tact, good taste, and intolerance of nonsense that was apparent everywhere. Indeed, many of my best students of English have been trained in other disciplines—mathematics and natural sciences as well as classics or modern languages—and there is much to be said for these preludes to literary criticism.

But we are told that the gap between sciences and arts is steadily widening; that in a few years' time our society will be predominantly technological, and that this is because the whole cultural pattern of the world is changing. The study of literature and particularly of poetry thus becomes an interesting, perhaps pleasant, but wholly useless, anomaly, belonging (as Peacock saw it a hundred and fifty years ago) to a heroic age, and out of place in this age of iron. Our educators feel, vaguely, that this negation is "a bad thing." Here and in North America there have been countless experiments in "integrated courses." I have seen large classes of engineering students sprayed, as it were, with the warm Eau de Cologne of "Eng. Lit.," or dragged unwillingly through courses in "creative writing," their mentors hoping, rather despondently, that some of them would acquire a veneer of "culture." (Should not we still reach for our revolvers at that word?) We must examine the complaints a little more closely.

There is, in the first place, a fairly steady outcry against the relative illiteracy of many advanced students of science. Often this comes in the form of criticism of the shapelessness, inaccurate English, and lack of formal control in scientific writing, particularly at the postgraduate stage, with a consequent waste of time by those who direct such studies. Parallel to this, yet of quite another order, is the complaint, both from teachers and employers of scientists, of the lack of what Shelley called "the creative imagination." By that he meant, I think, no more than the ability of the mind that has been trained to think *synthetically*; to make, from time to time, "leaps in the dark"; to meditate profoundly on resemblances and analogies between things; and so to lead the way to creative thinking, which is apt—so I am told—to atrophy under the sheer weight of factual knowledge that the student of any of the great sciences must master today.

There are other complaints. Great in-

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dustrial firms appear to find that, while the supply of *competent* technologists is adequate for their purposes, the supply of men for the very top posts—men who know enough science to direct research, yet whose concern is mainly with wider issues and problems of the highest magnitude—is relatively poor. Many of these firms find it profitable to select arts men —preferably, and strangely, classicists— and train them for such posts. A world-famous electrical firm has just taken seven men with first-class degrees in classics and is converting them, by an intensive three-year course, into physicists and mathematicians. Cambridge University has before it a plan for a one-year course (as a tripos, part II) in physics (*1*) of such a nature that it could be taken by a man (necessarily of high intellectual caliber) who had spent the previous two years in one of the arts disciplines.

But the roots of the matter lie much deeper than this. The student who wishes to read science or mathematics at a British university today has, virtually, to spend his last three years at school—say, from the age of 16, more or less, to about 19—working intensively to obtain admission in his chosen subjects. He is confronted, by university requirements, with such a mass of knowledge that this specialization appears inevitable, though many university teachers deplore and lament it. For his ordinary level General Certificate of Education he will have taken five subjects, including one or two languages, to qualify him for university matriculation; but he will have little or no opportunity to keep up, and strengthen, his Latin, French, German, and English. Yet he has been faced, at the age of 15½ or 16, with the necessity for choosing one of the two roads, leading either to arts or to science; and here it is worth remarking that, while the school child who has chosen the science road can, and sometimes does, switch effectively to arts after a year or so, the reverse does not hold good. It is true, indeed, that one or two Cambridge colleges do offer entrance scholarships in classics for prospective medical students, and while such men often do brilliantly in the long run, they are faced with the need to spend one or two years in gaining the necessary preliminary qualifications in physics, chemistry, biology, zoology, before they can enter the university. Something of the sort applies to the new scholarships founded by Imperial Chemical Industries to enable the arts students to "convert" to sciences.

The schoolboy, then, is usually faced with the need for making this early choice. We may glance at the reasons on which his choice is based. Often it is a romantic one, disguised in various ways. The scientist is the supremely romantic figure of the present age, and much of the schoolboy's reading fosters this view. He is the controller of "push-button" power, always a satisfying fantasy. Science at his particular school may have a "snob-value" (these emotional factors are often significant), and the "best" people are going on that side. (Forty years ago the reverse was usually true.) The boy may even argue along lines somewhat similar to these:

"The scientist, and the scientist alone, is pursuing "truth" [that is, naively, "verifiable facts"]; he [and he alone] will find, preferably at an early stage, the *science*—not the art—of living."

The boy is profoundly impressed by the national demand for the scientist, by the scientist's high value in the labor markets, because of his scientific attainments. Therefore, in selecting science, he is in a sense one of the "chosen" who will help to diminish the disparity in numbers between the technologists of his own country and those of others.

The *values* which he holds, consciously or potentially, might be expressed thus: The two major ends to modern life are (i) a higher standard of living, (ii) more leisure. Both ends are subserved by the scientist-technologist, and by him alone. Therefore the scientist-technologist is the most important figure in the modern world. We may note that the boy appears to be encouraged in these views at every turn, by advertisements and by the daily press, and by those most important formative influences, the comic papers.

If this view is substantially correct, there may be certain corollaries which we might tentatively summarize as follows: (i) All "truth" is or should be susceptible to scientific evaluation. (It is worth noting that the schoolboy is seldom forced to clarify in his mind the nature of this term.) (ii) All "spiritual" values, which are not susceptible to such evaluation, are at best peripheral, at worst "false." (iii) All "art," being concerned with subjective values is—I use a selection of epithets—"effeminate," "sissy," "escapist," "unreal," "self-deluding." (We shall not get quite so far, as yet, as "the opium of the suburbs.")

Along with these corollaries we may find a tendency to rationalize an aversion to literature and art on the pretext that "there is no time for it"; that it is not worth "wasting time and trouble over" (this is encouraged by "potted" books, digests, strip cartoons, and so forth, which all suggest that literary processes can be short-circuited). And perhaps the compartmenting of college courses, which allows men to study *and forget* a particular subject, militates against the acquisition of reading habits that are likely to be carried into later life. Similarly, the enormous amount of typed matter—in business, politics, or warfare —which the duplicating machine has made possible is probably another factor which makes us all inclined to minimize the importance of the printed word, and to reject meditation upon it.

Minimum "Arts" Requirements for the Scientist

Before we go into the deeper questions of attitudes and values, we must consider the minimum requirements in "arts" for the scientist or technologist. These we might tentatively suggest to be as follows: (i) the ability to describe, in clear and correct English, *any* scientific process or event; (ii) the ability to construct, logically and with complete clarity, a scientific statement or paper of any length, using the normal resources of language to ensure efficiency of communication; (iii) the ability to present verbally, with clarity, cogency, and brevity, statements which aim to *persuade*; (iv) the ability to handle, in correspondence, not only matters which demand statements of "impersonal" business negotiations but also those involving, both directly and obliquely, complex human relationships; (v) the ability to draft agreements, contracts, concordats, and so forth, with both factual accuracy and sufficient constructive imagination to foresee (to use Aristotelian terms) "what might happen according to the laws of probability or necessity." (A simple instance is the work of a legal draftsman, who must envisage or imagine all the possible contingencies arising out of a set of provisions.)

In addition, we should probably demand a reasonable ability to read French —at the lowest level, for its scientific literature, or, more moderately, because we may hold that no one can be considered civilized without that knowledge. To this we should add a working or dictionary knowledge of German and of Russian, without which an enormous mass of scientific knowledge is sealed away. Ideally we should add Latin and Greek, to enlighten, and perhaps enliven, our scientists' vocabularies.

And if we accept some such objectives as these as desirable, how are we to achieve them?

Roads to Good Writing

At this point I think we must be ruthlessly dogmatic. There is no way to learn to write except by (i) reading good English prose of as many varieties as possible and (ii) practicing incessantly. Further, the practice in writing must begin early and must be built up and encouraged by individual correction of the thing written. No short cuts are possible, no lecture courses or mass classes in composition, however admirably planned, can ever replace individual training in prose writing, and in the clarity of thought that must accompany it. It is not difficult to lay down the qualities of an ideal prose in a technological society; they would probably be, by common agreement, roughly as follows: (i) clarity; (ii) adequacy (a full vocabulary); (iii) unity (the organization of the thought, the internal structure of sentence, relationship of sentence to paragraph, of paragraphs to the whole); (iv) *organic* quality (suitability of tone to intention); (v) avoidance of monotony (ability to interest, and consequent increased efficiency of communication); (vi) rhythm, supporting and enforcing meaning.

We should, of course, assume a full understanding of all the uses of punctuation, including its more subtle powers of presenting nuances of meaning. With regard to our scientific papers, it seems to me that confusion most often arises through a failure to recognize the basic *structure* of any piece of writing of this nature. For example, many of the theses that I have seen would have been better if the writers had in mind even a simple mnemonic such as this:

*O*bject: What exactly am I trying to do—prove, state, expound?
*R*eferences to previous work already done on the subject and up to the point at which the new work is being continued or projected.
*I*nformation about the facts now under enquiry.
*D*escription of those facts prior to the analysis of them.
*A*nalysis of the facts.
*S*ynthesis and deductions.
*C*onclusions in relation to the
*O*bject of the paper.

There is in this a suggestion of a circular structure, the whole being summed up under the mnemonic ORIDASCO.

Words and Meaning

I have suggested that there is no short and easy road, no substitute for practice and individual correction. But I believe that much might be done, concurrently, to arouse an interest in language as an instrument by showing, quite simply and, where possible, by means of scientific imagery, the uses and limitations of words as signals. Much of this will seem elementary; but too often it seems that the elements have not been given to students in the right way at the right point in their development. We might, for example, stress the difference between technical, defining language and emotive language, and the vast area that is common to both kinds, perhaps starting with a consideration of such words as *absolute, neutral, temper, sublimate.* We could indicate the multiple potential meanings of words by means of electrical or electronic images; the selection of meaning by qualification, position, stress, pitch, tone, accent; the instances in which several possible meanings are allowed to exist simultaneously, as often in poetry; the place of tradition and usage in modifying and establishing meaning.

And to do this we shall require sheets of carefully selected examples, starting always with prose statements which relate to one of the students' intimate spheres of scientific interest. (One source of failure is, I think, the habit of starting students on relatively complicated philosophic or literary examples, merely because these are traditional.)

It is not impossible to use mathematical formulas to show the determination of meaning in relation to the selector-mechanism of the mind, and the place of rhythm in this selection, and this would lead naturally to elementary semantics and phonetics. Thence we could consider the nature and functions of imagery, perhaps in terms of a thermionic valve (*2*); the fixing of a point of meaning in terms of coordinates (*3*); the possibility of penumbral meaning (*4*). And this would provide some valuable groundwork for a later—much later—discussion of the philosophy of poetic statement.

"Nonprofessional" English Teachers

At this point we may face up to certain difficulties. I have no doubt whatever that in many instances there are in the background strong emotional factors which are perpetually at work to widen the gap between the scientist and the arts man. One of them is the question of *beliefs,* at which I have hinted earlier. It is probable that the pattern is firmly established at 17 or so (much depends, of course, on the family background), and it is worse than useless to confront it directly. The intervention of the "professional" teacher of English at this stage often does far more harm than good. He is suspect, belonging to an alien world, claiming a *mystique* which is (in the eyes of the student) probably bogus, probably effeminate, and expounded by those who have no effective contact with the scientists' values and problems. (In certain societies he may be seen as a financial failure as well.) The English teacher is too often aware of a veiled or overt hostility, and this may lead, on his part, to the fatal assumption of a superior attitude. I am inclined to think that the teaching of English at this stage should be done wherever possible by the science teachers themselves. They and they alone can begin without being suspect. And if the science teacher himself can move naturally and gracefully among other arts (as many of the greatest do, finding analogies and examples from architecture, painting, history) in the course of their everyday work, it is surprising how readily and fully the students respond.

The Human Situation

At some point the science student may inquire, very properly: "I can now write correct and vigorous and clear English. I know enough to avoid emotive words, false analogies, disconnected thought. I can order and control my thought, speech, and writing. Why, then, do you urge me to read literature of any kind, and particularly poetry? I have no time for it, anyway; it is all I can do to master a part of the ever-widening field of my chosen science. All these other things—however desirable in a leisured age—are out of place in this. I except, of course, music, for I recognize its mathematical and scientific basis. I can enjoy, occasionally, an exhibition of paintings, and anyway it doesn't make demands on me, as books do."

These are serious and valid questions, and we must confront them. In the first place, the problem of time is a very real one. It is true that the excuse of "no time" is often, among all students, a convenient rationalization; equally, it is true that an enormous amount can and should be read in odd moments, by anyone who has acquired civilized reading

habits. If there are books readily available, as part of the normal household necessities, and if there is a desire to read, the time will be found somehow, in spite of the commercial interest in presenting new forms of simplified and compressed literature.

To the second question we should, I suppose, reply in some such terms as these:

"Whatever your studies, whatever your standing as a scientist, you are committed at every stage to the human situation, and to the relationships on which it depends. This is true of every social unit, from the family to the councils of nations, and you cannot escape it. And these relationships depend, in turn, on your own sense of values, which (whatever your 'philosophy') you must shape and consider throughout this life, and particularly through 'that toil of growing up.'

"The art of living can never become a 'science.' Even on the lowest terms of the human situation this is a truism. A 'universal psychology' is a contradiction in terms. It is futile to attempt the delegation of responsibility in the psychologist's consulting room. Nor is there any short-circuiting of the natural process that is possible. What *is* available is the vast storehouse of human knowledge, which is yours for the asking, *and* for the effort that you must put into every skill or experience that you have to master. This literature is, first and foremost, the study of the human being and the human situation. Only if you master what it has to give, reading selectively and critically, can you provide yourself with the 'armor against fate' which is essential to the individual in all civilized communities. Only if you possess a sense of history can you control political and social forces. Only if your imagination is trained can you perceive in the experience of the past the seeds of the future and of the world to which you are committed."

Something like this we should say, slowly and no doubt less heavily, but making the approach always from the point of psychology and sociology, and avoiding carefully any suggestion (at this stage) of metaphysical or esthetic content. It would be important to stress the nature of "experience," the balance between the physical and the mental, the need to recreate, imaginatively and historically, the setting of a work, if we are to consider it successfully as a potential fund of experience. A reasonable example might be found in the approach to Shakespeare, who is too often (I am convinced) utterly spoilt at school, because of unintelligent teaching, and against whose work the strongest emotional reactions are often set up. It is possible (and the experiment has been tried in Cambridge) to begin a fresh appraisal, first by sketching in the background of "scientific" beliefs (astronomy, astrology, physiology, psychology, chemistry, physics, alchemy) of his audience and then by examining, in minute detail, carefully selected individual scenes which can be shown (by comparatively small "transpositions") to involve problems of perpetual relevance to the human situation. Such might be: the study of progressive madness through an obsessional neurosis in *King Lear* (the whole play being superb material for the most pressing sociological problem of our time); the values of chastity as debated in certain scenes of *Measure for Measure*; the problem of romantic love and its rejection in *Troilus and Cressida*. It is not always possible to treat works of literature thus, but it looks as if drama in general can (perhaps because of its relative compression) be used to excite that kind of interest which cannot be immediately engaged in longer works.

In an intermediate term between consideration of the novel and of the drama as studies in human relationships, we might lead on to the study of these relationships in correspondence and in speech. For one paradoxical aspect of a scientific and technological age is the enormous power of words, for good and evil, in letters, speeches, diplomacy; the endless difficulties that arise from the misunderstanding of words; the ever-increasing need to learn to criticize dispassionately the power and limitations of words. At all levels civilized man is confronted with the certainty of this need to understand his fellows; almost daily he is confronted with examples, in business and in politics, of the manner in which words can give rise to false emphasis and distortion of thought and emotion. And the greater the scale of intricate cooperation required (as between allies in wartime, or in the business ramifications of great enterprises), the more carefully the exact function of language must be considered, with reflection, too, on the immense advantages enjoyed by those who can order words with fluency and vigor, at conferences and such like, for the purposes of persuasion. Our scientist should thus be confronted with examples —always numerous—of the problems of refracted and distorted fact, of conflicting evidence, of biassed reporting, which are all capable of showing him, positively or negatively, the need for individual judgment.

Poetry

The problem of poetry is far more difficult. Here again I believe that a strong emotional reaction has often been built up against it in schools. There seem to be various reasons for this. As always, the home background is involved; often the attitude is one of mockery, substantiated by the tendency, in a coeducational school, for girls to "take to" poetry more readily than boys. This reinforces the suggestion both of effeminacy and emotionalism, as well as the certainty that poetry is dealing with "values" which, at first sight, are so indeterminate as to be unworthy of a scientist's consideration. Nor do the schools help a great deal. The natural "instinct for harmony and rhythm" is readily vitiated by the imposition, often at the critical age of puberty, of poetry which cannot possibly be brought into any kind of alignment with the reader's real or imagined experience. (Perhaps all poetry that deals with love and death is in this category.)

If we could ensure that our scientists had been introduced to literature through the idea of language as *signals*, the transition to the idea of poetry as a highly specialized form of signals would not be too difficult. We could proceed from the idea of rhythm and the phonetic aspects to problems of statement, first through the consideration of meaning as problems of energy and static or dynamic charges, thence to the nature of imagery. It could be made plain that poetry is a method of making statements that can be made by no other means, and with a series of references of almost limitless complexity. Here, again, it should be possible to start with poetry based on, or related to, scientific terminology; examples from Shakespeare, Donne, Shelley, Bridges immediately start up into the mind.

If we can once establish the claims of poetry as a specialized method of statement, and as such entitled to respect, it seems to me that continuing interest in it should properly be left to grow, or flag, or wither, of its own accord. In any event we cannot hope that the percentage of confirmed readers of poetry should, among scientists, exceed that in any educated community. Its value in stimulat-

ing the "creative imagination" would, of course, vary enormously and could never be measured. But given the conditions and the approach, there would, I believe, be no doubt about its effect. For in that dark saying of Shelley's, "Poetry administers to the effect by acting upon the cause," there are latent innumerable possibilities of the development of the human mind (perhaps by infection), some realization of the virtues of humility, and a sense of the uncertainties latent in the most advanced speculations.

I believe that the "values" that will emerge from literature are, on the whole, best left to grow, through slight but wise guidance, from the thing read, once the desire to read has been aroused and maintained; that more harm than good is done by assuming the attitude that "you *ought* to read so-and-so." The dichotomy is there—the dichotomy that started at the end of the 17th century and has been growing steadily ever since. At the roots of it there is both an emotional antipathy (often a willful misunderstanding) and a tendency to rely upon the apparent fact rather than upon its more profound implications.

Perhaps it is too much to hope for what Oppenheimer calls "the happy symbiosis of science and the general culture of an age." We could, I believe, go far toward improving the present position. And among the most important things that should be done is to foster, by all possible means, the associations of the scientist with the arts man—informally and constantly, with unobtrusive encouragement of the free exchange of ideas. For this we must teach the arts man two things: to rid himself of the frequent defensive snobbishness (not uncommon on university staffs as well as among the students) and to acquire at least the basic vocabulary of the scientist, so that he may speak with him in the gate. For this is perhaps the crux of the matter: whereas the scientist knows, or thinks that he knows, the technical vocabulary of, let us say, the esthetician or the literary critic, the arts man will, unless he takes the trouble to master the minimum technical vocabulary of the scientist, find himself confronted with an impregnable barrier, which is easily converted by the less intelligent scientists into something resembling a *mystique*. One difficulty, of course, lies in the sheer physical means of providing this contact; the growth of the specialized institutions on either side of the fence is steadily decreasing the possibility of undergraduate intercourse on these lines, which still obtains, to a greater or lesser extent, in the colleges of the older British universities.

For it is the growth of the whole man that both sides are seeking, and in that growth, civilized intercourse between students—the free and informal exchange of ideas—is at least as important as any formal instruction that can be given in the classroom. If, in addition, we can insure that in every university there are a few teachers of stature, whether in arts or sciences, who can in their teaching move with some measure of ease from one side to the other and who can create the current sympathy which is essential to understanding, then we shall have done much. Is it a dream to think of a university in which the arts teachers will have studied at least the history of science, and in which all teachers of science will be equipped to teach English as an integral part of their work?

References and Notes

1. See the proposals of the "Principles of science" tripos, as published and discussed (but not yet approved by the university) in the Cambridge University *Reporter* during 1957.
2. I have suggested some of these in a little book called *The Apple and the Spectroscope*. The working of an image can be suggested by a valve, in which a current passes from cathode to anode, through a grid, which selects and filters the particles of meaning that pass over to the object from the image, as in "My love's like a red, red rose."
3. For example, changing meanings of words in relation to civilizations, manners, and sociological problems.
4. This would be perhaps in terms of optics—the graduations of shadow on the edge of meaning.

News of Science

Evolution of the Organization of the Federal Government for Scientific Activities: 1947 to the Present

Major Developments Since 1947

In the years since 1947, a number of significant changes have occurred in the organization of the Federal Government for scientific activities. New agencies with important scientific responsibilities have appeared. Several existing agencies have undergone reorganization, with the step-by-step evolution of organization for research and development in the military departments being of considerable importance. During this period federal scientific programs have burgeoned in size and diversity.

Atomic Energy Commission

The Atomic Energy Commission is exceeded only by the Department of Defense in the magnitude of its scientific activities. The war-born program of nuclear research and production was transferred from military to civilian control in January 1947, but it was more than a year later before the Manhattan Engineer District turned over the last of its contracts to the Atomic Energy Commission. The commission inherited from its predecessor a mode of operation which it continued and further developed. Most of its operations, including research and development, are performed under contract with industrial concerns, academic institutions, and other nonprofit organizations. An important but not large segment of research activity is carried out for the commission in the laboratories of other federal government agencies.

The commission conducts approximately two-thirds of its total research and development program in government-owned facilities operated under contract by industrial and institutional contractors. Some of these, like the Oak Ridge National Laboratory, the Los Alamos Scientific Laboratory, and the Argonne National Laboratory, had their beginnings in the Manhattan Project era. Others, such as the Ames Laboratory, Bettis Plant, and the Brookhaven National Laboratory, have been established since 1947.

In its early years, the commission managed its research and development program through five divisions: production, research and development, engineering, military application, and biology and medicine. In 1949 the Atomic Energy Commission placed the division of engineering within a new division of reactor