SCIENCE

VOL. 73 FRIDAY, JUNE 12, 1931 No. 1902

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS

New York City: Grand Central Terminal
Lancaster, Pa. Garrison, N. Y.

Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

QUALIFICATIONS OF A RESEARCH PHYSICIST[1]

By Dr. ALBERT W. HULL

GENERAL ELECTRIC COMPANY

I AM going to show you, later, that the figure of merit of a research physicist is expressible in degrees of ignorance rather than knowledge. My first application of this theorem is the willingness, or temerity, to address you upon this subject, about which you know so much more than I.

Please note the narrowness of the subject. Research physicists are a small class—perhaps too small to be called a class. They are a part of the so-called creative group, which is rated at the top of the human ladder by certain students of society such as Dr. Charles R. Gow[2]; and by certain others as akin to the mentally unbalanced. Whether high or low doesn't concern us here. I am merely leading up to the first qualification of a research physicist, which is that he must be born that way.

The aptitudes with which a man is born determine, often uniquely, his field of successful activity. By field is meant, not a specified profession, but some one of a group of related activities which utilize the same qualifications. The most common classification recognizes three types of native ability: the research type, the engineering type, and the executive type. Sometimes the research and engineering types are classed together and a teaching type differentiated. For example, President Hadley[3] summed up these qualifications for Yale undergraduates as follows:

> Speaking broadly, men may be divided into three types or temperaments: the scientific type, consisting of men whose power lies in observing and arranging and put-

[1] Address presented before the American Association of Physics Teachers, Bureau of Standards, April 30, 1931.

[2] Charles R. Gow, "Foundations for Human Engineering," Macmillan, 1930.

[3] A. T. Hadley, "Choosing a Career," *Yale Alumni Weekly*, March 3, 1916.

ting facts in order; the literary type, whose interest lies in communicating ideas to others, and in thus influencing the opinions and actions of their fellow men, and the practical type, which is interested neither in the arrangement of facts nor in the communication of ideas, except as a means of achieving concrete results in the way of business or politics or some form of human endeavor. From the first type come our physicians, our engineers, our accountants, and our consulting experts of every kind. From the second type come our teachers, our preachers, our journalists, and our jury lawyers; from the third, our merchants, our manufacturers, our railroad men, and our consulting lawyers.

It is preferable, I think, to differentiate the research and engineering types, since both the temperament and the training required for these two fields are fundamentally different, as will be shown later.

The point to be observed is that each profession utilizes certain inherent powers. If a man is endowed with these powers in a high degree he can be highly successful; if in small degree, his success in this profession will probably be small, in proportion to his low starting-point.

O'Connor,[4] who has applied the methods of research physics to the personnel problem, has devised some excellent tests for mechanical aptitudes, and has used them to measure the effect of training upon these aptitudes. He finds that repetition of a given operation increases the speed with which both good and bad operators perform this operation to about the same extent, so that their relative standing remains unchanged; but that this practice does not increase the ability of either to perform a similar but slightly different operation.

For example, two girls, who originally required 12 and 6 minutes respectively to pick up 300 pegs, improved with practice until, at the 30th trial, their times were 8 and 4 minutes, respectively. The ratio remained 2 to 1. Twenty girls were selected and divided at random into two groups. After an initial test, which showed the same average time for each group, one group was given two weeks training in a different task, similar to the first except that tweezers were used instead of fingers. Upon repeating the original test the two groups were found to be still equal. Similar tests extending over a period of years instead of weeks led to the same conclusion. Considering the variety in the work of a physicist, these examples teach that the clumsy manipulator will probably remain so through life.

A second test, which is applicable to physicists, is designed to measure the power of space-visualization. It consists in the assembly of a dissected block. Two college room-mates, graduates of a technical school, required 30 sec. and 30 min. respectively to perform this test. Upon repetition the first maintained his 30 sec. record, but could not improve it, being limited by the time required for manipulation; while the second gradually improved until, after 20 repetitions, he equalled the first. The two were then given another block, identical with the first except that it was half as large. The first man assembled it in 30 sec., the other required 20 min. The difference between these two men is not in manipulative skill, for both were equally fast when they knew what to do; but in space sense, one of the prime requirements of a research physicist.

I would like to emphasize still further the importance of these native aptitudes and the degree to which they are unchanged by training.

A prominent executive has rated his engineers, some two thousand in number, according to their performance in their particular fields, designating each by a number. That is, a first-class man in any field would be rated 100, etc. Independent ratings were made by three different observers from different departments, and these were compared with the relative standing of the men in the company, as evidenced by their salaries. In only 2 per cent. of the cases were the differences between these four ratings as great as 5 per cent. Moreover, when these relative ratings were compared with the previous standing of the same engineers over a period of years, it was found that they had changed very little.

These results are significant. They indicate that the chances of a man's success in a given field are determined by qualifications that are fundamental and not easily changed. Whether these inherent traits are hereditary or are acquired early in life is immaterial for the present purpose. In either case, they are firmly fixed by the time the young man presents himself at the college gates.

I have recently had occasion to observe the work of two individuals, one a college graduate and the other a boy of 13, whose space-visualization is so vivid that they connect up the most complicated networks with extreme rapidity and close the switch with confidence. I have never known either to make a mistake. Contrast the future outlook of these men, in the field of experimental research, with that of another, who, in spite of an excellent college and teaching record, charming personality and earnest effort, always had at least one wrong connection, and after two years' trial was pronounced a failure at research work. It was observed that this man was a good contact-maker, and, fortunately, a position was found for him where he could utilize this quality, with his general scientific training as a background. He is now extremely successful and happy.

[4] J. O'Connor, "Born That Way," Williams and Wilkins, Baltimore, 1928.

Not only must the research man have the necessary aptitudes, but he must have no extra ones. O'Connor has called attention to this fact also, and has given many examples which show that unused aptitudes produce dissatisfaction and half-heartedness. For example, a man who makes social contacts easily and enjoys doing so is not likely to be content with the quiet life of a research worker. O'Connor concludes,[5] "The larger the number of gifts, the greater the ultimate goal gained, but, all too often, because of the uneasiness engendered by unemployed aptitudes, the gifted man, wasting year after year, ultimately ends as a failure." You all know such men.

The research worker should therefore be endowed with a retiring personality, in addition to mechanical aptitude or power of space-visualization, analytical ability, and, preferably but not necessarily, manual dexterity. To these we may add the health qualities, energy and enthusiasm, without which all success is circumscribed.

These considerations affect vitally the question of the training of physicists. We can not inculcate or cultivate appreciably the aptitudes that make a physicist possible. We can only add to them certain attitudes and habits and a small store of facts. Without the inborn aptitudes, our trained physicist is like an over-rigged ship, destined to flounder. But what harm? Will not the ship, taught by experience, repudiate its rigging and become eventually a useful and succesful barge? The answer of experience is that in most cases it will not. The unsuccessful graduate seeks still more training in the hope of compensating his handicaps, and so builds ever higher the barrier preventing his escape. The emphasis placed upon science during the last ten years has led some to think that it is better to be a poor physicist than a good mechanic. Such belief leads to tragedy. The good mechanic is a happy, self-respecting, indispensable member of industrial society; the man who feels that he is unsuccessful, be it in science or any other field, is destined to a life of dissatisfaction and unhappiness, and of questionable usefulness. The heart-aches of these men are at your doors, if you have given them the training that thus unfitted them for life.

I have emphasized this question of aptitudes because I believe it is the first duty of every teacher to test and advise those who come to him for training. Satisfactory tests are not at present available, but can be discovered by the same methods which are unraveling spectra and nuclei, the methods of research physics. A beginning is being made, notably at Columbia, Iowa and Ohio State universities. One of the most hopeful signs is the growing custom among graduate schools of canvassing the universities for men with graduate qualifications, and canvassing by industries for men with engineering, accounting and salesmanship qualifications. These canvassers choose wrongly about as often as rightly to-day, because of the lack of proper tests. We can do no greater service to our young men than to assist the development and use of these tests.

Assuming that we have chosen our men, what can we teach them? Not very much, if we accept the opinion of some 1,500 engineers to whom Dr. C. R. Mann, of the Carnegie Foundation, addressed the question: "What are the essential qualities of a successful engineer?" The replies showed an average estimate of:

41 per cent. character
17.5 per cent. judgment
14.5 per cent. efficiency
14 per cent. understanding of human nature
13 per cent. technical knowledge

Assuming that the student's advancement in character, judgment, efficiency and understanding of human nature is no more rapid in college than it would be elsewhere, this means that college training, if perfectly successful, can supply only 13 per cent. of the qualities which an engineer needs, according to the judgment of his peers.

The requirements of a research man are different from those of an engineer. In particular, knowledge is of even smaller relative value. I have no questionnaire to quote you. Instead, I will quote the opinion of one of the greatest research leaders, Dr. W. R. Whitney: "The asset of engineering is exact knowledge. The valuable attributes of research men are conscious ignorance and active curiosity."

In these words he characterized the difference between research and engineering for a group of engineers.[6] It reads like a chemical formula. "The asset of engineering is exact knowledge. The valuable attributes of research men are conscious ignorance and active curiosity."

Do you accept this analysis? It is to be assumed that these qualities are in addition to innate aptitude and the undefinable group known as character, and that the list is purposely incomplete. For the present purpose it is sufficient to agree that conscious ignorance and active curiosity are *among* the most valuable attributes of a research man, and that exact knowledge is not among them.

If you agree, then I would like to ask the question: Are we teaching or can we teach these qualities? We have schools reputed so learned that you can

[5] J. O'Connor, *loc. cit.*, p. 204.

[6] W. R. Whitney, "Stimulation of Research in Pure Science." SCIENCE, 65: 285–9, 1927.

always tell their graduates, but can't tell them much. Have we any that teach conscious ignorance?

The value of this attribute may not at first sight be apparent. Apart from the fact that the know-it-all graduate is unbearable to others, is unwilling to stoop to the task for which he is fitted, and is largely immune to further learning, there is a very special significance to research workers of this attitude of conscious ignorance. *If you know the answer beforehand you will always find that your experiments yield that answer.* You are all familiar with examples of this type, some glaring and obvious, hence comparatively harmless, others difficult to detect, stumbling blocks of science. Our journals are full of theses of students who conclude, quite without evidence, that their professor's theory was correct. Such professors are guilty, in some degree at least, of scientific homicide. Unwittingly, but just as surely, they are killing the scientific honesty of their students. Two glaring cases of such self-deception have come to my attention recently, neither of which is as yet known to the scientific world, and perhaps never will be, but will remain as stumbling blocks. What will become of the authors?

Conscious ignorance is a negative quality and becomes dynamic only when joined to active curiosity. Dr. Whitney is fond of the story of the land turtle, whose curiosity led him to leave the water in search of wider experience, and as a result he not only lives better, but has developed a brain, whereas the water turtle has only the rudiments of a brain.[7] It may be more than a myth that the elephant who couldn't restrain his curiosity and wears an elongated nose in token of it developed into one of our most intelligent animals, while the ichthyosaurus is extinct.

Active curiosity looks for the facts behind the formulas. Ask the average physicist why water rises in a small tube and he may answer, "Because of capillarity." The average chemist will probably tell you that the reason iron doesn't dissolve in strong nitric acid is because of its passivity. Has he added any information in substituting his long word for your short one? If our curiosity is of the kind that is satisfied by a name, it will not lead us far.

I think we may agree that active curiosity, curiosity that not only craves to know and is unsatisfied by names or authority, but does something about it, is one of the most valuable attributes of a research man. Dr. Whitney puts it first. He says[8]: "The most important function of colleges and universities is appreciating inquisitiveness and stimulating research."

If we thus agree, we may analyze our methods of teaching from this view-point, and we need not be surprised if we find that they are unsuited. Our educational system has grown up around the basic idea that knowledge is the magic key to life. As the field of education expanded we have continued to apply the same principle and the same methods. It would be surprising if, in this expansion, we did not find some fields where other objectives and other methods were more important, or arrive at a time when knowledge is a sufficiently common commodity to be within the reach of all who know how to value it. In this case the attitude, the will to find out, becomes the key.

Let us consider the question of lectures from the standpoint of training a research physicist. Is the best lecturer one who explains so lucidly that you are left with a comfortable feeling of understanding, or one who, out of the fullness of his experience, opens out before you the unattainable yet challenging expanse of the subject?

I must leave the answer to you with one suggestive example. Several years ago I listened to a lecture by Sir William Bragg on a subject about which I knew nothing. During the discussion I inquired if he had found a relation between crystal structure and magnetism, and he replied with his charming simplicity, "No, we haven't been able to get the crystal structure of iron. We have some measurements but we can't make much out of them." The next year found me deep in x-ray crystal structure research, trying to find the structure of iron.

With this same objective in mind, of teaching attitudes rather than facts, what is your opinion of textbooks as compared with original sources, or of assigned reading as compared with assigned subjects, or of assigned subjects as compared with assigned problems or experiments?

It is said of the great Agassiz that his invariable practice was to give his students as a first assignment a specimen of something, a fish or a flower, and leave them for three days with absolutely no instructions except to observe.[9]

I have been asked to comment on the kind of training desired for industrial research. For many reasons, I should prefer to follow the advice of President Jewett,[10] to discuss only the qualities desired, leaving to those better qualified the question of matter and methods. I will, however, transmit without comment two suggestions received, the first representing the opinion of three engineering executives, that "training in fundamentals is more useful than in specific subjects"; the second from a prominent

[7] C. J. Herrick, "Brains of Rats and Men," Chicago University Press.

[8] W. R. Whitney, "Stimulation of Research in Pure Science." SCIENCE, 65: 285–9, 1927.

[9] Charles R. Gow, *loc. cit.*, p. 118.

[10] F. B. Jewett, "Modern Business Looks at Secondary Education." *School and Society*, 31: 415–19, 1930.

director of research, who makes the following comments:

Graduates in electrical and mechanical engineering are generally more adaptable than physicists to the problems of industrial research and development relating to physics. They more readily adapt themselves to the handling of apparatus and equipment and are usually more successful in the use of their hands. They have in general a better physical insight and a greater appreciation of practical requirements for carrying through a developmental program.

It probably does not make a great deal of difference what specialized type of training is received by a certain few men with a natural inclination to industrial problems.

We do feel however that too little stress has of late been placed upon the fundamental physics by most American universities, especially in graduate work. The universities are producing physicists who apparently are well qualified to publish worth while researches in spectroscopy and atomic structure, but who have had almost no training in basic mechanics, hydrodynamics, electrical theory and thermodynamics, such as was taught thirty years ago. We believe that in an industrial laboratory, the physicist or engineer who has the fundamental classical background is of greater value than a physicist who has almost exclusively specialized in the modern physical developments.

The qualities that are desirable for successful life are many. Some must be inborn; others, such as attitudes, habits, skills and facts, may be taught. Each combination of qualities fits a man for certain activities.

The qualifications of a research physicist, as I have pictured them, consist mainly of aptitudes and attitudes. The essential aptitudes are, first, a space-sense that will enable him to devise tests, and, second, a retiring personality that gets pleasure from quiet accomplishment, without the need of public applause. The attitudes are, first, an open mind, more anxious to learn the truth than to show its knowledge, which I have called conscious ignorance; and, second, active curiosity, intent on finding out, nerved to spurn delights and live laborious days for the thrill of discovery at the journey's end. President Jewett, of the Bell Laboratories, calls this the spirit of romance. "The thrill," he says, "of adventuring forth intellectually into the unknown and of charting out there paths which others can follow, is equal to that of him who looks on a new land for the first time; and the number of such journeys that can be taken is limitless."[11]

Consciousness of ignorance, combined with active curiosity, is the spirit of youth. Beware of the man who tells you, "I did that 20 years ago." He is old. He is through, either as investigator or as useful teacher.

If knowledge and experience, culminating in judgment, are incompatible with conscious ignorance, then we are better research men without judgment. I believe they are not incompatible. Conscious ignorance and active curiosity are attitudes which may be caught like contagions, cultivated like choice flowers, and retained to old age. We may be young in attitude, though old in experience. To the spirit of youth each observation is a romance, a revelation. This is the spirit of research.

It is in this spirit that we may hope to see the vision of a still greater science. In the words of Dr. Whitney:

We ought to realize that there may be a more valuable use of knowledge and truth than commercial developments, and by aiming at the full appreciation of creation we may do more than simply conquer and control our local environment. Perhaps industrial uses of new knowledge are after all only by-products or ways of advancing to something better.

We advance more often by finding in Nature that which we may learn to use than by making or forcing from Nature that which we think we want.

THE PROGRESS OF ROENTGENOLOGY AND ITS CONTRIBUTION TO MEDICAL SCIENCE[1]

By the late Dr. PRESTON M. HICKEY

DR. G. W. C. KAYE prefaces his recent monograph with this passage from Hamlet:

Come, come, and sit you down; you shall not budge;
You go not till I set you up a glass
Where you may see the inmost part of you.
(*Act III, Sc. 4*).

Little did Shakespeare's world realize that in Hamlet's comment to his mother lay the story of a present-day miracle.

[1] Read before Section N, the American Association for the Advancement of Science, January 1, 1930, by Carleton Barnhart Peirce, A.B., M.S., M.D., of the University of Nebraska College of Medicine.

"I regret most sincerely that illness prevents my former preceptor, Dr. Preston M. Hickey, from reading the paper to you. I appreciate more than words can express the honor of presenting for him the initiatory paper of the American Roentgen Ray Society upon its affiliation with the American Association for the Advancement of Science."

[11] "Research and the Individual," *Bull. of Purdue Univ.* 26, July, 1926.