Aptitude and Achievement.[1]

By Prof. J. McKEEN CATTELL.

THERE was published in 1890 in *Mind* an article entitled "Mental Tests and Measurements," and in 1896 in the *Psychological Review*, established in the meanwhile in co-operation with Prof. Baldwin, an article entitled "Physical and Mental Measurements of the Students of Columbia University." This was the first series of tests used with a large number of individuals, and it still remains the most extensive undertaking of this character. The students were tested at the beginning of the freshman and the end of the senior year, the women of Barnard College as well as the men of Columbia College.

About an hour was given to the examination of each student, and some thirty measurements were made, ranging from height, weight, and lung capacity, through keenness of sight, discrimination of pitch and reaction time, to memory, imagery, and association. In addition, some forty records and observations were made, ranging from colour of eyes and hair to an estimation of intelligence and straightforwardness. Further, the student at home filled in a blank answering some eighty questions, ranging from the ages and, if deceased, cause of death of his grandparents, to what profession or business he proposed to follow and in what calling he would prefer to succeed if he had his choice. Other information was also available, including class standing in different subjects, success in athletics, and social interests. It is possible to follow the careers of alumni in after life and to measure their children when they in turn come to college at about the same age. In addition to the Columbia students, these tests were made on members of the American Association for the Advancement of Science at three annual meetings, measurements having been obtained of men so distinguished as Simon Newcomb and William James. At the St. Louis Exposition of 1904 a laboratory was set up and tests were made by Prof. Woodworth and Dr. Bruner, both on the visitors and on the racial groups that were represented.

In working over the tests, Dr. Wissler used for the first time in psychology the methods of correlation developed by Francis Galton and Prof. Pearson. The correlations among the grades in different studies were significant and have been the basis of many subsequent studies. The lack of correlations among the measurements was at the time disappointing. It is due in part to the attenuation from measurements that are only accurate when deduced from averages, in part to a real lack of correlation in different traits. For example, a student who is accurate may be as likely to be quick or slow as one who is inaccurate. There is no correlation, but one-fourth of all students will be above the median, one in a hundred in the first tenth, in both accuracy and quickness, and will have a great advantage. The correlations—due to the circumstance that the same abilities and training are involved—discovered among complicated performances, such as class work and intelligence tests, have led to their cultivation and to the neglect of the simpler measurements. The cultivation is desirable, the neglect unfortunate. It is of interest to any one to know where he stands among others in these traits and determinations; some of them, such as colour-blindness or acuity of hearing, which can be measured in a couple of minutes, may be of real use. It is also the scientific method to be followed in analysing the more complicated processes, such as those going under a term so ambiguous as general intelligence.

Estimates of character and of other psychological traits are difficult and untrustworthy. No correlation has been found in the Columbia laboratory between size or shape of head and ability of any sort. There is no known relation between complexion, forehead, nose, chin, or other features and psychological traits. The reading of character by physiognomy or graphology is the occupation of charlatans. It is difficult or impossible to tell even the sex of the individual from the features of the face or from the handwriting. These are, of course, legitimate subjects of study. The full and side face have been photographed through a centimetre netting with a long focus lens, thus obtaining in a moment a large number of determinations, which are on the average as exact as can be got by direct measurement. The method can be used to advantage with children or savages, who do not like to be measured, and it is useful in recording and preserving a large number of determinations, some of which may prove to be of unexpected value. Photographs of the face were cut in parts to determine by what features we recognise the individual, and estimate the age, sex, etc. A study was also made in which individuals were judged first from a photograph, later after a five-minute interview, and then by individuals who knew them well.

It is possible to put judgments of character on a quantitative basis. In the earliest undertaking of this character, five instructors in Columbia University were graded on a percentile scale by twelve fellow-instructors and graduate students. Twenty-four traits or qualities were included, ranging from physical health to efficiency and leadership. There were used the psychological categories of intellect, emotion, and will, together with the quantitative differences to which they have a certain analogy, breadth, intensity and quickness. All these qualities are useful, but it is especially desirable that a scientific man should have broad intellect, an artist intense emotions, a soldier or statesman quick will. We can fancy that these are unit characters which are combined by chance in Mendelian fashion. The probable error in position in a centile order for different traits estimated by twelve observers was only 4 places, ranging from 3 to 5·2, and apart from constant errors there is thus a close agreement. The chances, for example, are even that a man ranked 51 for integrity, with a probable error of 5, is more honest and straightforward than 45 of a hundred of all scientific men and less so than 44. A man ranked 95 for courage with a probable error of 3 is to the best of our knowledge more courageous than 9400 of the 10,000 scientific men of the country, and the chances are even that this position is correct within 300

[1] From the address, entitled "Some Psychological Experiments," of the retiring president of the American Association for the Advancement of Science, delivered at the Kansas City meeting on December 28, 1925.

places. There was greater agreement on mental balance than on physical health; there was least agreement on cheerfulness, most on energy, perseverance, and efficiency.

There is a certain amount of validity in judgments of personal traits, character, and performance, and individual differences in the reliability of the judgments of those taking part in these experiments have been measured, showing a variation in competent observers covering a range of about two to one. It is an accepted truism that success in business and in other directions depends on the wise selection of associates and agents and on the ability to predict how others will act in given circumstances. When we learn to look upon our observations, recollections, beliefs, and judgments objectively, stating in numbers the probability of their correctness, there will be an extraordinary change in our attitude in religion, politics, business, and all the affairs of life.

Before the selection of a thousand students of Columbia University and a thousand American scientific men, a study was made of the thousand most eminent men of history, and this was the basis for the later studies by order of merit. From each of six French, German, English, and American biographical dictionaries or encyclopædias were selected about 2000 of those allowed the longer articles. From the some 6000 individuals so determined were taken those who appeared in at least three dictionaries, and from these were selected those given the greatest average space, the several dictionaries being reduced to a common standard. Thus was obtained not only the thousand men given most attention, but also the order in which they stand. The method further permitted the assignment of a probable error of position, which can be used as a measure of differences in eminence, and, if we assume the distribution of the probability curve, the differences between eminent men and average individuals.

Curves may be drawn showing the historical distribution of eminent men by nationality and by performance. After the Greco-Roman period and the so-called Dark Ages, there is a rise in numbers from the tenth century onwards, but with definite fluctuations in productivity. In the fifteenth century, Italy, England, France, and Germany had nearly the same number of eminent men. Italy was in the lead, but then falls, as does Germany, while England and France rise, their curves crossing through the centuries with nearly an equal number of distinguished men, England surpassing in the number of highest eminence. France reaches its culmination at the end of the eighteenth century. Germany rises rapidly from the second half of the seventeenth century, and the American curve then begins with much promise for the future.

An analysis of the kind of performance shows that France has excelled in war, science, and scholarship, England in politics, poetry, and philosophy, Italy in art. Of the eighteen great musicians, Germany has produced ten, Italy six. Of the fourteen great explorers, England has produced five, Spain four. Though text-books and treatises on history, at least until the most recent period, are mainly concerned with wars and politics, there have been fewer eminent sovereigns, soldiers, and statesmen than scientific men, philosophers, poets, artists, and the like. The rising curves for science, the falling curves for philosophy and the church, are significant. Soldiers have been surpassed in numbers by men of science, and the curves predict a gradual cessation of war and the predominance of science. Similar curves have been made for the percentage of the total population of different countries engaged in war through the centuries, and though the data were inadequate, they also point to the gradual elimination of war. But, of course, the projection of curves is a scientific method that must be used with the utmost caution. By similar methods a list of 1000 American scientific men who died prior to 1900 has been compiled, and the changing interests can be shown by curves. A quantitative study of history is a possibility of the future.

Data have been collected concerning some of the 1000 eminent men of history and a supplementary list of 10,000 has been used, with the view of placing information in regard to them on a statistical and quantitative basis, determining how they differ among themselves and from others, and the conditions favourable to performance. Our present information is from anecdotes and examples from which almost anything can be deduced. We do not even know whether history depends on its great men or whether these are by-products of economic and other forces. We do not know the extent to which their performance depends on heredity and on opportunity.

The distinctions hold not only for men of eminence, but also extend to differences adapting ordinary individuals to the work that they can do best. Thus three types of people, intergrading but often well defined, are those most satisfied and competent when dealing, respectively, with personal and emotional relations, whether the poet or the salesman; with material objects and definite situations, whether the military leader or the mechanic; and with abstractions, whether with the Deity or the atom, or simply with words and figures. In the transportation services, most of the employees have functions separated on the lines of these three types. The clerks, bookkeepers, and stenographers are concerned with words and figures; the conductors and pursers must remember faces, be obliging, ready to answer questions, interested in the affairs of the passengers; these traits are disqualifications for motormen and engineers, who should be concerned about objects and machines. By a rough natural selection those tend to become clerks, conductors, or engineers who are best suited for the work, but probably more than ten per cent. of the employees could be transferred with an average increase of more than ten per cent. in their efficiency; new employees could from the start be assigned to work for which they are best fitted. By the use of the psychological tests that we now have and by research to perfect these tests, the corporations concerned with transportation could effect a direct saving measured by tens of millions of dollars a year, indirectly of a comparable sum through the greater welfare and contentment of their employees.

In addition to the groups already noted, a study has been made of American men of science, selected by the order of merit method. The sciences were divided into twelve groups and the number in each was taken approximately proportional to the total number of scientific workers, ranging from 175 chemists to 20 anthropologists. In each science the men were arranged in the order of the value of their work by ten leaders. The average positions and probable errors were then calculated, giving the order in each science. These were interpolated to give a list of about 2000 names, but in the main only the first thousand have been considered. The list was obtained in 1903 and again in 1910. In 1920 it was compiled for the third time, but by a different method, used partly for its scientific interest, partly in order to avoid too great demands on the time of a few leading scientific men and to prevent any inbreeding from a limited number of judges.

The names and addresses of the scientific men included in each science in the two previous selections were sent to those on the list and they were asked to increase it by about 20 per cent. All those who received more than one vote were then asked to make nominations, and those who received the most votes were added to the list up to a number of names twice as large as was to be selected. The names were then sent in alphabetical order to each of those included, and he was asked to check about half the names to indicate those whose work he regarded as of most merit, with a double check for about one in twenty whose work he considered the most important. Some 2000 scientific men were asked to take part in the selection, and about 1000 complied. The probable error of the position of the individuals was nearly the same as before. The measurement of the validity of a vote has application from the decision of a committee to a national election.

The scientific men are thus arranged in the order of the value of their work with a probable error which shows the correctness of the position assigned to each and also measures the differences between them. It consequently becomes possible to measure the scientific productivity of a region of the country or of an institution and its contemporary strength, with the changes that occur at different periods. The single figure giving the gain or loss in position of a scientific man in the course of ten years condenses a great deal of information and is dramatic in its implications. When we put knowledge concerning men of science on a statistical and quantitative basis, we may hope ultimately to determine the hereditary and environmental conditions favourable to the production and to the productivity of workers in science.

There are large variations in the origin and in the present residence of scientific men throughout the United States. Their birth rate per million of population was 109 in Massachusetts, and decreased from that centre to 47 in New York, 23 in Pennsylvania, 9 in Virginia, less than 2 in the Gulf states. Their present residence tends to correspondence with their place of birth, but some cities and states obtain more scientific men than they produce, and conversely. Scientific activity is moving westward. Of younger men added to the list, the birth rate fell in Massachusetts from 109 to 85, in New York from 47 to 36, whereas it increased in Michigan from 36 to 74, in Minnesota from 23 to 59.

In academic production and possession of scientific men, Harvard leads by a wide margin, though the Johns Hopkins has given nearly twice as many doctorates to those who have attained scientific standing. In 1920 there were at Harvard 73 of our thousand leading scientific men. The numbers in other large institutions were—Columbia, 42; Chicago, 39; Yale, 35; Johns Hopkins, 35; Cornell, 33; California, 31. From 1905 to 1920 the net gain was at Yale, 9; at Harvard, 7; at the Johns Hopkins, 5; at California, 4. Chicago and Cornell were stationary; the net loss at Columbia was 18. The men can be weighted, in which case the relative strength of Harvard becomes greater. The ten strongest departments in each of the twelve sciences have been determined, Harvard among universities standing first in mathematics, physics, chemistry, botany, zoology, pathology, and anthropology; second in geology and physiology. The Johns Hopkins had one of our leading thousand scientific men for 37 students. At Harvard the ratio was 1 : 75, at Yale, 1 : 105; at Columbia, 1 : 202. In the fifteen-year period the Department of Agriculture had a net loss of 9, the Geological Survey of 6, the Smithsonian Institution of 5; the Bureau of Standards a gain, of 11. The Carnegie Institution and the Rockefeller Institute had large gains, as had also the industrial laboratories. The movement of scientific men to the research foundations and laboratories is one of the notable changes of the past twenty-five years.

The list of a thousand scientific men permits not only the measurement of scientific merit and a study of the origin and distribution of scientific workers, but also offers opportunity for obtaining vital and other statistics. Thus, to take an example, the average size of the completed family of the scientific men is 2·2. Voluntary control increased from 48 per cent. of marriages prior to 1880 to 70 per cent. of those contracted in the 'nineties. Childlessness was involuntary in two-thirds of the cases; the standardised two-child family was desired in six cases out of seven. Or again, the brother of a scientific man is two hundred times as likely as another to be himself a scientific man.

We need scientific knowledge concerning scientific men and the conditions favourable to scientific work and to the scientific career. In the course of the week during which these remarks are being written, Secretary Hoover in an address to the Society of Mechanical Engineers has stated that the United States is behind most European nations in scientific research, and President Butler in his annual report has stated that Columbia University cannot replace " older scholars of distinction and large achievements," because " a choice must be made from a larger or smaller group of mediocrities." It may be that we are inferior to other nations and that we now produce fewer scientific men of distinction than formerly, but both statements are open to question. The circumstance that they are made by men of wide information and can be neither proved nor disproved shows the urgent need of correct information.

It is the business of psychology to secure such knowledge, to determine how those fit for scientific research can be selected, what training should be given to them, what positions, opportunities, and rewards are most effective. Scientific men should apply scientific methods to their own work and to securing the widest co-operation. Books and journals, including technical publications for scientific men, others that will interest the "average man" in science and in the wider application of the scientific method, are leading agencies. Science Service, for which the American Association shares the responsibility, should be made a large factor in the dissemination of science. But of all agencies for the promotion and diffusion of science, scientific societies are the most important—the national societies in each science, the state and local academies, most of all the association in which these are united and which at its annual meetings and at all times advances the interests of science and of scientific men and impresses on the widest public the weight and magnitude of modern science.

In spite of the limited value for science of direct introspection, our mental life is part of the real world, and is that part which is of the greatest concern to each of us. It may be, as has been suggested, that psychology lost its soul long ago and is now losing its mind; but it cannot lose consciousness. Our perceptions, thoughts, intentions, and feelings are not only elements in sensori-motor arcs; for us they are also the end to which the whole creation moves. So far as production goes, consciousness may be only a spectator; but it is the ultimate consumer. We shall have in due time a scientific psychology of human welfare, of the things that are beautiful, good, and true. But it will not come until we get these things instead of talking about them; for science has meaning and value only in its usefulness. Psychology may supply economic values equal to those of the physical and biological sciences, human values of even greater significance.

Scientific research and the applications of science in the course of 150 years have increased fourfold the productivity of labour; they have doubled the length of life. Science has made it possible for each to work at routine tasks half as long as formerly and at the same time to consume twice as much wealth as formerly. Fourteen hours of labour, shared by women and children, once provided hovels, lice, and black bread for most people, luxury for a few. Seven hours of labour will now supply comfortable homes, warm clothes, and healthful food for all. If the resources provided by science were properly distributed—as they will be when we have an applied science of psychology—there is now sufficient wealth to enable all to share in the desirable luxuries that science has created, and to enjoy in full measure the most nearly ultimate goods of life—home, friends, things to do, freedom, self-respect.

The better lives secured through the increased wealth provided by science, together with the applications of science to hygiene, medicine, and surgery, have doubled the length of life. In the nations of the west, pestilence and famine have lost most of their terrors; of the three evil fates, only war survives from a pre-scientific and barbarous past. Much is crude and ugly in the modern world; atrophied instincts and aborted impulses must be replaced by the products of a science of psychology before living can become free and fine. But those who call our industrial civilisation materialistic and ignoble have narrow thoughts and scant idealism. They fail to imagine what it means in terms of love and suffering that of ten infants born, formerly only two or three survived childhood, while now eight or nine may live to have children of their own.

The applications of science have abolished slavery and serfdom, the need of child labour, the subjection of woman; they have made possible universal education, democracy, and equality of opportunity, and have given us so much of these as we have. Science has not only created our civilisation; it has given to it the finest art and the truest faith. The advancement of science should be the chief concern of a nation that would conserve and increase the welfare of its people.

The Progress of Directional Wireless Communication.

By Dr. R. L. SMITH-ROSE.

FROM the earliest days of practical wireless communication, it was realised that one of the most important services which this art would render to humanity was its contribution towards the safety of life at sea. The possibility of a ship being able to keep in communication with the remainder of the world during the longest voyages, and, in time of distress, to broadcast an appeal for assistance, has removed much of the terror of shipwreck and fire at sea. A later development, which bids fair to rank second in importance to the above, is the direct application of wireless to aerial and marine navigation. There are, broadly, two methods by which a wireless signal may be used to determine the direction of any given fixed point. In the first, the direction of arrival of the signals from any transmitting station is determined by means of a direction-finder. The second method involves the transmission of a rotating beam of large or small angle and its reception on any suitable receiver.

The wireless direction-finder makes use of the fact that in electromagnetic waves travelling over the earth's surface, the magnetic force of the waves is horizontal and perpendicular to the direction of transmission. If a closed loop or coil of one or more turns with its plane vertical is used to receive such waves, the strength of the signal E.M.F. induced in the loop will be proportional to the cosine of the angle between the plane of the loop and the direction of arrival of the waves. Hence, if the loop is rotated about a vertical axis, the strength of the signals received will pass through successive maximum and zero values at intervals of 90°. A consideration of the case shows that the rate of change of the resulting signal strength is greatest when passing through the zero position, which is therefore the most sensitive condition for the determination of the direction of arrival of the waves. In this zero position the plane of the loop is perpendicular to the direction of the incoming waves and thus of the transmitting station.

There are three practical forms of wireless direction-finder in use to-day operating on this fundamental principle of the simple rotating loop: and it can be shown, both theoretically and experimentally, that the accuracy is of the same order for all the systems, each of which has its own field of application. The