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TRAINING THE RESEARCH WORKER

IN his annual report for 1947–48 to the Trustees of the Carnegie Institution of Washington, Dr. Vannevar Bush, president of the Institution, again refers to the appropriate relationship between the governing board and the scientific staff in such institutions, and particularly in regard to the shaping of programmes of research. Dr. Bush's discussion of these relations is of considerable general interest, particularly when greater attention is being paid to the organisation of research staff in industry and when the general conditions and conduct of academic research are being re-examined.

Dr. Bush at the outset recognizes frankly that the matter cannot be considered entirely without reference to political considerations. The division of the world into two sharply contrasted groups has repercussions in the field of science and of scientific research, if no more than as affecting the ideas which men hold about the freedom of science. Dr. Bush believes firmly that progress in pursuit of knowledge is made rapidly and securely only when individuals are free to entertain any hypothesis, and when the survival of hypotheses is determined solely by the rigour of test against cold facts and not by any external arbitrary rulings; and he finds it difficult to believe that such a system will not speedily outdistance any other system in which political dogma is allowed to dictate the teaching and practice of science.

Dr. Bush then emphasizes that, while programmes of research should arise from the integrated aspirations and judgment of the scientific staff, the question is more complex than at first appears. Due weight must be given to the imaginative power of the qualified mind; but something more is required than seeking out the unusual man and giving him untrammelled opportunity and generous support. In spite of all that has been accomplished by individual genius, the sound progress of a body of science requires even more the individual who combines with outstanding intellectual urge of a personal nature the ability to co-operate with colleagues of equal attainments and ambitions; the obdurate lone worker can, in fact, impede the evolution by a group of scientific men of a joint integrated programme of research. The relation of master and disciple is the simplest form of internal organisation for research, and when it is successful it is one of the most salutary forms; and the Carnegie Institution is seeking to give it larger opportunity as younger men are brought in in greater numbers through its fellowship plans. Dr. Bush insists, however, that the central question is that of the way in which a group of scientific colleagues of equal stature plan in concert and interrelate their affairs, so that out of their combined thinking there comes a group or departmental programme which not merely meets the approval of a governing board but also affords a firm basis for the continuing effort of qualified minds.

The fundamental distinction between the conception and the process of research must also be kept in mind. At the outset, departmental research pro-

grammes are based upon the imaginative thinking of qualified individual minds. But, as Dr. Bush rightly observes, a collection of discrete projects aimed at individual objectives does not constitute a programme in the sense in which the term is used by an institution or a firm. Conceived as a synthesis or summary of joint effort planned for performance, a programme in this latter sense involves the choice of alternative methods and of sometimes widely separated objectives. Its preparation represents the first stage in the process, as distinct from the conception, of research.

Regarding, therefore, a well-prepared programme as something greater than the sum of its parts, Dr. Bush suggests that the most important single attribute of a scientific staff is the ability to perform as a group this function of estimating and balancing, integrating and interrelating. He reminds us that it is easy to overlook the fact that the organised joint effort which we know as research to-day, and which has so much expedited the maturing of science, is a relatively recent development. Indeed, in his analysis of the theory of the organisation of research, Dr. Bush simultaneously outlines the essential principles on which 'operational research' is based, and although he scarcely uses the word 'planning', his discussion provides a clear answer to the question how far it is possible for research to be planned.

This links up with some comments made by Sir Walter Moberly in his recent book "The Crisis in the University", where he quoted with approval Sir Henry Dale's words on the importance of the universities maintaining in Britain and elsewhere their full independence, and his emphasis on their function of promoting research with no immediate objectives but to widen the boundaries of knowledge. Like Dr. Bush, Sir Walter stresses the vital necessity of the academic values of a passion for truth, thoroughness in pursuing it to its end, a delicate precision in analysis, a judicial temper, a willingness to learn from all quarters, and an uncompromising insistence on freedom of utterance. No university can stand which does not uphold such basic values. Nevertheless, Sir Walter recognizes that a new balance must be found between teaching and research, and his remark that any teacher who tolerates intellectual dishonesty is out of place in the university gives the clue to the type of reform he would suggest. Entering his own protest against the tendency to attach too much weight to the number and bulk of published papers, Sir Walter challenges as roundly as Sir Charles Grant Robertson the practice of regarding all postgraduate work as research. It is not often that there is such public admission of the obvious truth that the neophyte can only rarely make original contributions of real value. Adulation of postgraduate research is apt to ignore the fact that in aspiring to add to the world's stock of knowledge the tyro in research may miss the more important objective of educating himself. Indeed, the search for some theme of research within his powers and in which he can make some contribution may, as Sir Walter remarks, lead the young investigator far from the centre to themes that are peripheral and often trivial; and it should be remembered that the great majority of those who take the bachelor's or master's degree by research are intending to pursue a career in research.

What Sir Walter says on this theme amounts to, in essence, a plea for more real thinking on the subject of research. A university needs to encourage and honour not only discoverers of facts but also explorers of ideas and appraisers of values. If it does this and can at the same time mark out those relatively few whose talents appear to fit them pre-eminently for a career of research, it will have done more to meet the needs of academic research, the research institutions and industrial research departments than by fostering large schools of directed research the output of published work of which is impressive only on paper. Speaking to the Central Council of the Association of University Teachers in Manchester on May 20, Mr. W. A. Wightman suggested, indeed, that the postgraduate side of a university department sometimes degenerates into a research factory organised solely for the advancement of knowledge in the chosen field, and manned by an ever-changing succession of workers whose business it is to do what they are told to do by the director. Under such conditions, the process of research, as defined by Dr. Bush, has not begun, nor can there be any fostering of the ability to co-operate which Dr. Bush rightly values. Mr. Wightman's statement was doubtless a deliberate exaggeration; but there is real danger in the position to which he directs attention. Early in the same week, again in Manchester, Sir John Stopford, in addressing a meeting of the University Court, also stressed the importance of ensuring that both teacher and student have leisure to think. At Leeds on May 20, an eloquent plea for the universities to play their part in the defence of the freedom to declare what we believe to be true, and to maintain it in speech and writing, came from Sir James Chadwick; and Dr. Mouat Jones also referred to the challenge of Sir Walter's book, although he took a less sombre view of the situation in the universities of Britain.

It is at least encouraging to find within one week university spokesmen in Manchester and Leeds recognizing so frankly that a firm grip upon the essential verities and values of humanity and civilization should be a central care of our universities, and our great need for understanding human nature. Sir John Stopford laid the main stress on the need for providing an effective means of bringing together the humanities and the sciences, and made the useful suggestion that, as new halls of residence come into being, the creation of junior residential fellowships might help to broaden the contacts and interests of students. Such aspirations, however, pre-suppose leisure for the university teacher or investigator and diminished pressure on the student, which involve further consideration of the question of numbers.

It must not be overlooked, however, that higher technological education is linked up with university education. Little progress appears to have been made in that field since, on May 27, 1946, the Lord President of the Council announced his acceptance of the general recommendations of the Barlow Committee on scientific man-power, which included endorsement of a recommendation of the Percy Committee regard-

ing the development of a limited number of technical colleges in Britain. Implementation by appropriate means of this common recommendation might well simultaneously ease pressure on the universities and make a valuable contribution to the professional training of graduates in research. If the increase of the student body is to come mainly, if not entirely, through the increase in university awards and scholarships, the question of quality becomes doubly important. Public expenditure on such a growing scale can only be justified when the training provided at the universities is such as to develop the first-class minds the nation needs, and to supply men and women who are capable of filling the responsibilities of leadership which a democratic society rightly expects of them, and also serving the community in those many capacities which demand character, ability and high standards of professional and technical skill.

Sir Walter Moberly has little to say on this matter in his book; he himself appears to lean to wider professional courses as providing the most hopeful line of advance, and he raises the issue whether professional training could be carried on as well anywhere else as in a university. This issue, of course, was frankly stated in the University Grants Committee's last report; but it requires much fuller discussion than it has yet received. Fresh impetus to its consideration may be derived from Mr. Winston Churchill's reference to technical education in his address on March 30 to the Massachusetts Institute of Technology.

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ROCKET BALLISTICS

The Mathematical Theory of the Motion of Rotated and Unrotated Rockets

By R. A. Rankin. (*Philosophical Transactions of the Royal Society of London*, Series *A*: Mathematical and Physical Sciences. No. 837, Vol. 241.) Pp. 457–585. (London: Cambridge University Press, 1949.) 30*s*.

VERY little of a vast literature on rocket research has yet been published in book form or as papers in scientific journals. This is perhaps inevitable, since the development of the modern rocket has been due to the requirements of the War, and the numerous existing reports and papers, in many fields of scientific and technical endeavour, still carry a security ban. In recent years a book has been published, "The Mathematical Theory of Rocket Flight", by Rosser, Newton and Gross (for review, see *Nature*, **161**, 3; 1948), which represents an American contribution and which deals with the ballistics of unrotated rockets. A paper by Dr. R. A. Rankin is the first extensive presentation of the wider theory including rotated rockets, and is by far the most important British paper so far published.

Dr. A. D. (now Sir Alwyn) Crow was entrusted in 1936 with the task of examining the possibilities of a rocket as a weapon of war, and under his direction at the Research Department, Woolwich, Mr. W. R. Cook and his staff laid the foundations of the theoretical ballistics. In a few years, working closely with such experimental results as became available, they had developed a two-dimensional theory which played an important part in the study of the behaviour of the early unrotated rockets which were later to prove their value as weapons both of offence and defence. A start was made in 1938 to establish a three-dimensional theory, and Mr. C. L. Barham with the systematic use of complex variables and vector methods extended the theory and obtained solutions which could be handled numerically. Many other mathematicians who were members of the original team, and of the larger group which was gathered together under Prof. L. Rosenhead early in the War, have all made their contributions to the present theory. Dr. Rankin in his paper pays gracious tribute to these other workers, including Mr. A. T. Wadley who, with Dr. Rankin, prepared an unpublished Ministry of Supply monograph on the subject; but to him personally must go the credit for the major part of the work on rotated rockets.

Rocket ballistics is concerned essentially with the behaviour of the rocket during the burning period of its propellant, and thereafter its motion is similar to the gun shell and can be treated accordingly. It becomes thus a matter of investigating the motion of a body which is losing mass continuously in the form of a high-speed gas jet and subject to external atmospheric and gravitational forces. If the rocket were perfectly symmetrical and the gases discharged uniformly, their resultant thrust were axial, and there were no disturbing forces such as wind, it is a relatively simple matter to establish the equations of motion and to integrate them numerically. Even so, extreme care must be taken in the derivation of the equations if errors are to be avoided, and if the principle of the conservation of momentum is to be correctly applied to the system of particles comprising the rocket and the escaping gases.

It is, however, the problem of the deviation of the rocket from its expected path that is of chief interest. Even in a group of rockets all of nominally the same dimensions, etc., there occur variations due to manufacture which lead to the very high dispersion of a salvo of rockets as compared to a group of gun shells. This dispersion, which is usually random in a set of rockets, has not yet been completely explained. It may be due to uneven gas-flow through the nozzle of the rocket, to distortion of components during the burning period, or to some other cause. It is, with experience, possible to predict fairly closely the dispersion of a rocket if it is similar to one of which the characteristics are known; but for a new rocket it is not so easy, even if due allowance is made for manufacturing tolerances. Similarly, the effect of wind or of initial launching conditions which cause a deviation has to be explained and predicted, which can usually be done.

The setting up of the complete equations in order to be able to consider asymmetries is in itself a major task, and this the author has done with commendable rigour and clarity. He next discusses the approximations which have to be made if the equations are to be integrated. These fall naturally into two classes: those which are sufficiently small to be neglected, and those which are assumed constant during the burning period. It is not possible in a paper of this nature to give all the numerical values that enable these assumptions to be made, but they can in most cases be readily justified. It must be realized, however, that the solutions obtained refer only to a class of rocket (solid propellant, high acceleration) for which these assumptions hold good, and do not