Productivity in Research and Development[1]

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PRODUCTIVITY, perhaps the most difficult concept to define as a factor in the administration of research and development, is an intriguing area for research in manpower. What it meant by productivity? Or what are the criteria for judging the results of research and development activities? And assuming that criteria can be established, how can measures be developed for evaluating the performance of research and development workers? Let us assume, further, that means have been discovered for selecting individuals with aptitudes for research and development at a high level of proficiency, additional analyses must be made to search out the characteristics of highly competent research and development workers so that a real understanding can be applied to the evaluation of productivity. Only after such a basic understanding can the problem of productivity be solved from the following points of view: (1) developing research workers (including preservice education and in-service on-the-job education and training), and (2) managing these workers efficiently.

The program of research under the sponsorship of the Manpower Branch is directed toward providing more effective instruments for use in the selection, placement, training, and supervision of scientific and engineering personnel in research and development.

Factors Underlying Productivity

Two basic studies attempt to get at the factors underlying productivity: the determination of the characteristics of research and development workers through job analysis, and the discovery of the psychological factors involved.

Characteristics of productive scientists and engineers. The objective of this study, under John C. Flanagan, American Institute for Research, was the identification and definition of the characteristics of effective research and development scientists and engineers, as a basis for developing an instrument for evaluating the productivity of such workers. Through interviews with over 500 research workers in supervisory positions in 20 laboratories, descriptions of especially effective or ineffective on-the-job behaviors (3,347) were collected. A check list, giving both effective and ineffective behavior, was constructed for each unique group of behaviors. When items had been constructed for all the data, they were grouped into homogeneous and nonoverlapping units as a "Check List of Critical Requirements for the Evaluation of Scientific Personnel," under the following major areas of a scientist's work:[2]

1) *Formulating problems and hypotheses,* including identifying and exploring problems, defining the problem, and setting up hypotheses.

2) *Planning and designing the investigation,* including collecting background information, setting up assumptions, identifying and controlling important variables, developing systematic and inclusive plans for the use of equipment, materials, and techniques, anticipating difficulties, determining the number of observations.

3) *Conducting the investigation,* including developing methods, materials, or equipment, applying methods and techniques, modifying planned procedures, applying theory, attending to and checking details, analyzing data.

4) *Interpreting research results,* including evaluating findings and pointing out implications of data.

5) *Preparing reports,* including describing and illustrating work, substantiating procedures and findings, organizing the report, using appropriate style in presenting report.

6) *Administering research projects,* including selecting and training personnel, dealing with subordinates, planning and coordinating the work of groups, making administrative decisions, working with other groups.

7) *Accepting organizational responsibility,* including

[1] The opinions expressed in this article are those of the author and are not to be construed as reflecting the policies or opinions of the Navy Department.

[2] This study is reported in (1) *Critical Requirements for Research Personnel: A Study of Observed Behaviors in Research Laboratories.* American Institute for Research, Pittsburgh, Pa., March 1949; and (2) *Technical Appendices for Critical Requirements for Research Personnel.* American Institute for Research, Pittsburgh, Pa., March 1949.

performing own work, assisting in the work of others, subordinating personal interests, accepting regulations and supervision.

8) *Accepting personal responsibility,* including adapting to associates, adapting to job demands, meeting personal commitments, being fair and ethical, showing interest in work.

Factors correlated with creativity and productivity among research scientists. The general problem to be investigated, under Donald W. Taylor, Stanford University, is the determination of what abilities, motives, interests, traits of personality, childhood experiences, kinds of professional training, or academic achievements are related to originality or creativity, productivity, and general success among scientific men.

The general plan is to make an intensive study of a fairly large number of men actively engaged in research. Preliminary work is now underway in the Naval Electronics Laboratory. The investigation will be divided into three chief parts. The first part will be concerned with the development of criteria—i.e., of measures of originality or creativity, of productivity, of general success, and possibly of other characteristics. The second part will involve the use of a variety of methods, such as the biographical information blank, interviews, analysis of academic achievement, intelligence tests, interest inventories, civil service tests, recommendation forms, and personality evaluation. This study was started in April 1950.

Applications of the "Critical Requirements" Techniques

Four studies utilize the "critical requirements" developed through job analysis. It will be noted that this study of criteria has been used as a basic tool for all the studies in this section.

Development and refinement of criterion measures for evaluating performance of scientific work. This study, also under John C. Flanagan, has, in the main, been a field tryout of an Observational Record Form for Research Personnel. This form, based on the *Critical Requirements for Research Personnel* previously mentioned, is being used to record observations of *outstanding* and *unsatisfactory* job behaviors in research and development work, so that supervisors may be more effective in training, supervising, and evaluating their employees.

Three problems in connection with the use of this type of observational form are being studied, namely, the relative effectiveness of (*a*) a long versus short observational record, (*b*) comprehensive versus abbreviated training in the use of the form, and (*c*) daily, weekly, and monthly recording by the supervisor.

The study should provide an effective observational record form, instructional materials, including a manual, and a training program in the use of the form and manual.[3]

Development of selection instruments to measure aptitudes for scientific work. The selection of the beginning worker who will be productive in research and development depends in large part on determining whether the applicant possesses the aptitude for this function. It was desirable that a more effective instrument be available for identifying early in their career that very small percentage of professionally trained scientists and engineers who have talent for research and development. This study, under John C. Flanagan, undertook the development of an aptitude test applicable to the selection of junior professional workers in research laboratories.

This test then was developed as a measure of potentiality for, rather than proficiency in, research work. Further, the items were selected so that they could measure and be validated in terms of the critical requirements already established. This study has resulted in the development of a test of 170 items organized into three subtests.

The study has contributed to the theory of test construction by the development of a method of detailed hypotheses or "rationales" regarding the most suitable approach to the measurement of each of the critical requirements for research personnel. The aptitude test is now being tried out experimentally and, after further validation, will be offered for use in future civil service examinations, and for the use of universities in admitting students to graduate work in the physical and engineering sciences.[4]

Development of measures of proficiency in scientific work. This study, likewise under John C. Flanagan, is concerned with the development of test items for determining an applicant's proficiency in specific areas of scientific work. In contrast to the items in an aptitude test, these items are directed to the measurement of the technical background in a field of specialization.

This study, begun in February 1950, is at present concerned with the measurement of proficiency in critical job tasks, in the form of work samples and miniature job tasks, samples of necessary types of information, and measures of specific skills required.

[3] The instruments being used in this study are: (1) *Observational Record Form for Research Personnel.* American Institute for Research, Pittsburgh, Pa., June 1949. (2) *Manual for the Use of the Observational Record Form for Research Personnel.* American Institute for Research, Pittsburgh, Pa., June 1949.

[4] The techniques used in the study are reported in (1) *Development of a Test for Selecting Research Personnel.* American Institute for Research, Pittsburgh, Pa., January 1950. (2) *Technical Appendices for the Development of a Test for Selecting Research Personnel.* American Institute for Research, Pittsburgh, Pa., January 1950.

Recommendation blank to aid in the selection of scientific and technical personnel. In order to assess the qualifications of an applicant for a position, it is necessary to obtain a valid evaluation of his work performance or capabilities from his previous supervisors or teachers. The commonly used letters of recommendation have proved to be unsatisfactory. Therefore, this study, under Harold A. Edgerton, was undertaken to provide a technique or form that would give more valid evidence on the ability of applicants. Phrases descriptive of the performance or probable performance of research workers were compiled on a "more effective" and "less effective" basis. These phrases were supplemented by letters of recommendation from laboratory supervisors and university instructors.

Approximately 600 descriptive phrases were selected and organized into three lists, which were sent to some 400 heads of departments of physics, chemistry, and engineering in selected universities. On the basis of 250 completed returns, a sufficient number of phrases was secured to develop three forms. One of them was the conventional list of phrases, with the 1, 2, 3, 4, or 5 rating to be given on the applicable items. The other two were set up as "forced-choice." In the latter the phrases are grouped, on the basis of statistical values, into blocks composed of four to six phrases. The rater does not indicate how well or how poorly the applicant has performed, but rather in each block chooses one phrase as MOST DESCRIPTIVE and one phrase as LEAST DESCRIPTIVE. This means that the performance of the applicant is being described, which is more objective than "opinion." This technique then allows the one who receives the form to make an evaluation of the report on the applicant's performance.

An example of one block is:

Most	*Least*	
A	A	Never satisfied with superficial answers.
B	B	Easily breaks problems down into component parts.
C	C	Wants to be included in every activity and conversation.
D	D	Uses more complex equipment than necessary.
E	E	Does not push self or ideas.

Experience has shown there is some resistance to the use of this kind of form, partly because the respondent is not able to produce or predict a desired outcome. In addition, some object to the fact that the phrases in the block are not strictly related, as the example above shows.

These forms have been validated and are now being used experimentally in connection with civil service examinations.[5]

Other Productivity Studies

Several studies have been carried on to meet urgent problems before the basic investigations were under way or completed.

Selection of physical scientists. This study, under Willis Schaefer, was concerned with an analysis and validation of a test battery, which had been developed by the Test Development Unit of the U. S. Civil Service Commission. The Navy was directly concerned in that, in lieu of a separate examination for naval laboratories as in 1947 and 1948, it was decided to participate in the civil service nation-wide examination. Therefore, on invitation of the commission's Test Development Unit, this study was undertaken. The analyses and validation were based on 20 tests that had been administered to 826 chemists, physicists, and engineers in eight government installations. A variety of criteria was obtained, including supervisor rating, colleague ratings of performance, originality, research ability, etc., civil service grade, and age in grade. From this analysis, five tests appeared to be of most general usefulness, namely, surface development, mathematical formulation, hypotheses, subject matter (of the discipline), and biographical information blank. The first four of these were utilized in the 1949–50 "P-1" and "P-2" examination, which included a written test. The results of this test are being analyzed at present.

Study of candidates resulting from P-1 examinations. The Navy, along with other governmental agencies, industry, and the graduate schools, turns each year to the universities and colleges for candidates for the beginning grades of professional work. This study, under C. Thomas Clifton, was undertaken to discover the results of the Navy's recruiting and examining program in securing its proportionate share of the better and potentially more productive talent from recent graduating classes. The recruiting effort of one Board of U. S. Civil Service Examiners was examined to determine the "candidate caliber" resulting from its examining program. This analysis was based on 3,600 candidates for two nation-wide examinations conducted in 1947–48 and 1948–49. These candidates came from a potential population of 53,000 graduates in the scientific and engineering fields.

The "candidate caliber" was determined by an analysis within the partially overlapping groups of those who (1) applied for the examination, (2) took

[5] This study is reported in *Development of a Recommendation Blank to Aid in the Selection of Scientific and Technical Personnel.* Richardson, Bellows, Henry & Co., Inc., New York, June 1949.

the examination, (3) passed the examination, and (4) accepted or rejected offers of positions. This analysis made use of the candidates' civil service examination records and, where available, the candidates' college records.

The findings of the study showed (1) that there was definite improvement in the 1948 program over that of 1947, (2) that where recruiting teams composed of senior Navy scientists visit schools, more candidates are attracted, (3) that the examinations appear to select the better qualified (in terms of college grades or class rank), (4) that most appointees come from the upper half scholastically, but are of lesser quality than eligibles. The latter situation is due in part, at least, to the time lag in the steps of announcement, application, examination, eligibility, and offer of appointment. The findings of this study are being utilized by the board concerned in planning its current recruiting-examining program.

In-service training. The Navy, and also other research organizations, recruit young scientists who have completed only their undergraduate education, or perhaps limited graduate work. These men, if they are to be really productive, must receive further training, both "academic"—that is, in the subject matter of their disciplines—and on-the-job or in-service training, largely in terms of the needs of their immediate occupational specialty or position. An analysis of the "training" program of most laboratories shows that the program consists primarily of academic courses, most frequently of courses for university credit, even when offered within the laboratory. This is a necessary kind of training or education. Even senior scientists need to continue their study, with the ever-increasing rate of advance and specialization.

This study, under Douglas E. Scates, has been primarily limited to the development of techniques and instruments for determining in-service training needs. Six such instruments have been developed and evaluated through use in surveys of training needs at two different types of research and development installations—(*a*) a field installation, where 581 professional and subprofessional employees completed three questionnaires, and 261 were interviewed; and (*b*) a departmental bureau, where 261 professional employees completed a training need questionnaire, and 51 employees were interviewed.

Service reports on these surveys have been submitted to the installations concerned. The data obtained are now being analyzed, and a report will be prepared.

Methodology of research. Each year the government laboratories recruit a large number of college graduates in the physical sciences and engineering as junior staff members in research and development work. It is not to be expected that their undergraduate training could or should have given them any control or understanding of research methodology. However, this is needed, if these junior scientists are to be productive in research. While plans are being developed to undertake a full-scale attack on this problem, a listing of the offerings on methodology of research (as distinct from the philosophy or history of science) given in the catalogues of the some 90 American universities granting the doctorate in science, has been made, and preliminary analysis, under Alice V. Yeomans, of these courses is under way.

Future Plans

Within the general objective of this project, namely to derive criteria and to develop methods for evaluating, and increasing the productivity of scientific and engineering personnel, research on this problem will be continued. At present, either by continuing some of the subtasks mentioned above or by new subtasks, further work is planned on (*a*) identification of creativity in research workers, (*b*) the personal characteristics of research workers, (*c*) scientific and engineering functions, (*d*) the definition of occupational specialties, (*e*) motives that drive productive research and development workers, (*f*) morale factors and problems, and (*g*) personal attitudes and reactions.

From these studies it is expected that better tools for use in assessment of the capacities of potential workers and evaluation of the job performance will result, and methods and materials suitable for increasing the on-the-job productivity of workers will be developed.