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Biographical Predictors of Scientific Performance

Criteria of scientific performance and creativity can be predicted from biographical information.

Calvin W. Taylor and Robert L. Ellison

This paper will present a summary of research on the use of biographical information to predict various criterion measures of successful performance and accomplishments in science (*1*). In our studies of the relationship of biographical information to success in science, over 2,000 scientists have filled out one of our 300-item multiple choice questionnaires. The majority of this work has been conducted in conjunction with (*2*) the National Aeronautics and Space Administration (NASA).

The term "biographical information" is open to some possible misinterpretation when applied to the measuring instrument, the Biographical Inventory, (hereafter called the BI), which has been used in these studies. The BI contains a wide variety of questions about childhood activities, experiences, sources of derived satisfactions and dissatisfactions, descriptions of the subject's parents, academic experiences, attitudes and interests, value preferences, and self-descriptions and evaluations. The items thus encompass a wide variety of information and are not limited to a narrow definition of what could be included within the rubric of biographical information. By using such a broad approach, one potentially can attempt to measure not only previous life history experiences and past environmental effects on a person, but also to assess the outcome or manifestation of the hereditary environment combination as it is personified in the individuals studied.

The intent in these studies was to exploit the biographical approach and thus determine and more fully understand the experiences, backgrounds, opinions, self-images, and attitudes which would aid in differentiating the highly productive and creative scientists from those who were less productive and creative. When the biographical characteristics, experiences, and self-descriptions were identified, the practical goal was to utilize these characteristics in developing an easily administered and scored biographical inventory which would aid in the identification of scientific talent at the college level. Hopefully, the inventory could be rewritten for the early high school level and used as a vocational guidance instrument, so that high school students who had scientific potential could be encouraged to further their development.

When this study was initiated in 1959, biographical information was considered to be one of the most promising means of identifying creative scientific talent. Previous research from a variety of investigators had indicated that biographical information was a potentially promising technique for the identification of creative scientific talent, although no one had made a definitive attempt to exploit this potential (*3, 4*). The approach had, however, demonstrated its usefulness in a variety of other settings for predictive purposes; for example, identifying successful salesmen, predicting college success, identifying leadership ability in the Army after World War II, and others.

Two studies were especially useful in laying the foundation for the later use of the biographical approach in the studies of NASA scientists. These were by Ellison (*5*), who tried out a large number of biographical items, and by Taylor, Smith, Ghiselin, and Ellison (*6*), who conducted an intensive criterion study and later administered a series of predictors including a biographical inventory. In both studies the initial validities found between the empirically keyed biographical scores and the corresponding criterion were extremely high, (.70 to .94). No cross validation was attempted in either of these two preliminary studies because of the relatively small sample size but the best items from both studies were identified and retained for future use in the NASA project. However, a priori scoring keys for the biographical responses worked very well on

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the sample of Air Force scientists and yielded better validities than any of the other 100 nonbiographical psychological test scores that were applied to 17 different performance measures of success in science.

In both of the above studies, the items that were keyed and retained for use in future research were somewhat arbitrarily selected; in other words, they were not identified strictly in terms of the usual level of statistical significance requirements. This was done with the conviction that a consistent relationship, even in the low levels of validity obtained in a number of studies, was a better method of item selection in the long run than one statistically significant correlation in any single study. Thus the approach has some actuarial features in that experience tables have been constructed with information about each item so that the valid information is utilized to the fullest possible extent.

The Form A Study of the BI

Based primarily upon the two previously mentioned studies, form A of the BI was constructed and administered to 354 NASA scientists at one large research center in 1960. The cooperation of the participating scientists and administrative personnel at each of the NASA centers was remarkable throughout these studies. The form consisted of 300 multiple choice items arranged into four sections: developmental history (up to age 21), parents and family life, academic background, and adult life and interests.

The criteria of performance used in the studies of NASA scientists can be classified into three types: criteria available from the official records at each of the NASA research centers, data on the number of publications and the number of patents collected from the scientists, and criterion measures which were constructed by the investigators for research purposes only and were completed by the first-line supervisors. For the first study an overall evaluation measure which we have termed an official rating was already available at the research center.

In addition to the number of publications and patents that each man had accumulated, the three criterion measures administered for research purposes only were: a productivity check list, a creativity check list, and three months later, a creativity rating scale of seven steps was administered. Both the creativity check list and the creativity rating scale were constructed on the basis of Lacklen's formulation for measuring creativity, namely, that the creativity of a contribution can be determined by its breadth of applicability (*7*). The correlation between scores on the creativity check list and the creativity rating administered 3 months later was .69. Considering the time difference and the different nature of the criterion forms, this reliability estimate was considered satisfactory.

In the data analysis, the sample of 354 scientists was arbitrarily divided (on an approximately random basis) into two subsamples of 178 and 176. A separate item alternative analysis was performed on each sample for each of three criteria. In the item alternative analysis, biserial correlations were computed for each alternative of each item against each criterion (*8*). After that analysis, a variety of scoring keys and weighting of alternatives was tried so that approximately 75 to 125 items per scoring key were retained with one or more alternatives scored in each item. Empirically derived keys were constructed separately for each criterion on each of the two samples and applied to the opposite sample so that a double cross-validation study was carried out. The average cross validity coefficient of the two official rating keys was .55 in predicting the official overall rating criterion and the average cross validity of the two creativity keys in predicting the creativity criterion was .52. The other criterion measures were also predicted with statistically significant correlations. In one of the two subsamples, complete data were available on the two creativity criteria. The cross validity coefficient of the best biographical score in predicting a combination of the two creativity criteria was .59, a remarkably high cross validity for only a single test and for such an early period in the history of creativity research and measurement.

If the above validity coefficient of .59 were corrected for unreliability in the criterion only—a very justifiable attenuation correction—the corrected validity coefficient would increase so that it would reach approximately .67. Thus with a perfectly reliable criterion measure, almost half of the variation in creativity performance of scientists could be accounted for with only one total biographical score—an extremely high degree of prediction. These results in a new field, involving important and difficult-to-predict job criteria, compare favorably with the best results that have been obtained in the prediction of academic success. The latter is a prediction area in which psychologists are well experienced. Further improvement in predicting this criterion could be achieved by obtaining subscores from the BI and combining them through optimum weights.

Since the BI would tend to measure somewhat different criterion variance than various intellectual, aptitude, motivational, or personality measures, the prediction of success in science might be improved significantly if the BI were supplemented by a combination of the most promising of these other measures.

Of the four sections of the BI, the adult life and interests section was the most valid, followed by the academic background and developmental history section, and finally, the parents and family life section.

The Form B Study of the BI

Before the second administration, a new form of the BI (Form B) was constructed based on the best items of the previous study. Many nonvalid items were eliminated to make room for some new items with the hope that the effectiveness of the BI would be improved.

At this center a revised form of the creativity rating scale was administered as the sole criterion measure collected for research purposes. Several official evaluations were already available and data were collected on the most appropriate. These ratings by supervisors included: knowledge of work, initiative, judgment, industry, reliability, and cooperation. In addition, the number of publications and patents produced by each scientist were obtained.

Although these scientists had different work specialities, at a different geographical location, and were measured on a slightly different creativity criterion than was used in the first study, the average cross validity coefficient for the form A total creativity score was .47 in predicting the creativity criterion of scientists at the new research center. This same biographical subscore also predicted most of the other criteria with statistically significant results. For example, the same score predicted the patents criterion with a biserial correlation of .35 in one of the subsamples in which only 15 percent of the sample had one or more patents. Despite the complexity of the criterion problem in measuring success in science, this result indicates that there is some common ground among various criterion measures and that a biographical score, even when constructed at a different research center, can overlap a significant portion of that common ground.

The same procedure was followed to further analyze the data. Briefly the total sample of 300 scientists was split into two subsamples of 148 and 152 and an item alternative analysis was carried out for each sample in a double cross-validation design. The results from the item analysis at the second center were generally not quite as high as those obtained at the first center, although a cross validity coefficient of .60 was obtained in predicting publications. The average cross validity coefficient for predicting the creativity criterion on the two subsamples at the second research center was .48. A comparison of this correlation of .48 with the correlation of .47 obtained by using the keys from the form A study indicates a high degree of stability in the biographical keys. This result also indicated that it would probably not be necessary to construct separate keys for each NASA research installation. Moreover, it provided some evidence that the same biographical key would give generally the same results in predicting creativity in different fields of specialization.

The official rating scores which were already available at the research center were, without exception, not as predictable as the other criterion measures, evidently because of the construction of the rating forms and the manner in which these ratings were obtained. In addition, in the inventory, there was undoubtedly some implicit item selection by the investigators to emphasize the prediction of the creativity criterion in comparison with other criteria. However, most of these other criteria were predicted with cross validity coefficients that were statistically significant. The item analysis revealed that items involving professional self confidence were most valid, followed by items measuring independence and autonomy.

The Form C Study of the BI

A form C of the BI was constructed in which the best items from the previous studies were used together with additional new items. This form was administered to approximately 800 scientists at a third NASA research center. In contrast to the other two centers visited, there was no existing rating procedure for the evaluation of the scientific personnel. Promotions were handled by letters of recommendations and personal conferences. Thus, the criterion measures collected at this center may have been influenced by this comparative lack of rating experience. The only measures collected besides data on publications, patents, and Government Service level were scale ratings of the following: quantity of work, skill in getting along with people, creativity, and an overall evaluation.

The procedures followed in the third study were the same as in the previous studies. After the total sample was divided into various organizational subsamples, average cross validity coefficients for the creativity criterion ranged from .41 on the total sample to .49 for one organizational subgroup. The other rating criteria were predicted at a somewhat lower level in the mid 30's. The average cross validity coefficients for the publications criterion was .62, and for the GS level criterion the average cross validity was .70.

The keys that were developed on the basis of the form A study yielded an average cross validity of .40 in predicting the creativity criterion, again indicating a high degree of stability for the biographical scores.

Some of the characteristics of creative people revealed by the BI studies provide a brief portrait of the creative scientist. Consistently the best subscore in the inventory for identifying creative scientific talent was "Professional Self Confidence." The scientists who scored high have confidence in themselves to perform at a very high level. Although not necessarily so, they are often confident of themselves in other spheres of activity. They are also very independent, which is a trait found to be relevant in almost every study of creativity. They tend to use themselves as a focal point for evaluation and are not swayed by the general consensus. They are also, as one might expect, intellectually oriented, a trait that developed relatively early in adolescence. The more successful scientists also have a high degree of dedication to their work, often to the exclusion of other hobbies, interests, and even family activities. They set very high levels of aspiration for themselves which they expect to achieve in the future.

Table 1 presents five of the biographical items and shows both the percentage responding and the correlations with the supervisors' ratings of creativity. The first two items provide information about the self-concept of the scientists as they described their own ability to do research and their reaction to a situation in which they responded whether or not they would publish their research results if such publication interfered with the desires of their supervisors. It will be noticed that those who said they would publish were rated slightly higher on creativity and that 75 percent of the sample said they would cooperate with the supervisor.

The other three items provide information about self-reported academic achievements and the age at graduation from high school. It will be noted that the relationships of these latter three items to the creativity criterion are relatively low. These findings correspond generally with those presented by Wolfle and by Hoyt (*9*). In our view, heavy emphasis should not be placed on academic achievement unless the particular organization in question has determined that academic achievement does have a demonstrated relationship to the work being accomplished. The last item is of some interest as those scientists who graduated from high school at an earlier age tended to be rated as more creative than those who graduated later, evidently indicating early intellectual achievement is a positive indicator of later performance in research.

Follow-Up Studies of the BI

All previous studies of the BI were concurrent studies as opposed to follow-up studies where the accuracy of the BI predictions could be checked for validity over an extended period. After the completion of the form C study, a series of follow-up studies were initiated using form C-1 of the BI. This form was identical to form C except that the instructions used were modified slightly to make the administration procedure of the inventory

Table 1. Examples of biographical items, the percentage responding, and biserial correlations of the item alternatives, with supervisors' ratings of creativity (sample size, 1000).

Biographical items	Percentage responding	Correlation with creativity criterion
1) What do you consider to be your capacity or ability to succeed in research?		
A. Superior	10	.38*
B. Above average	44	.19*
C. About average	42	−.29*
D. Slightly below average	3	−.25*
E. Does not apply	1	.00
2) Assume you are in a situation in which the following two alternate courses of action arise. Which *one* of the two would you be most likely to do?		
A. Finish my research through the stage of publishing it.	25	.18*
B. Cooperate with my supervisor by doing what he wanted me to do next.	75	−.18*
3) About what percentage of the students in your class did you surpass academically when you graduated from high school?		
A. 99%	12	.17*
B. 90%	35	.06
C. 80%	28	−.05
D. 60%	17	−.12*
E. 50% or less	8	.05
4) About what percentage of students in your class did you surpass academically when you graduated from college?		
A. 99%	5	.26*
B. 90%	27	.21*
C. 60%	37	−.10†
D. 40%	7	.02
E. Don't know	24	−.19*
5) How old were you when you graduated from high school?		
A. 15 or younger	2	.21†
B. 16	14	.15*
C. 17	48	.04
D. 18	31	−.10†
E. 19 or older	5	−.20*

* Significant at the .01 level. † Significant at the .05 level.

more comparable to the actual hiring situation. This form was administered to 622 scientists as they reported for work at several NASA centers. About a year later criterion data were obtained on the performance of the newly hired research professionals.

Because of the widely dispersed geographical locations of the NASA centers, a psychologist did not assist in the collection of data. This may have affected the criterion data, since the study procedures and rationale could not be explained as thoroughly as in previous studies. But the data analyses were similar. The keys developed on the basis of previous research yielded cross validities ranging from .05 to .44, depending on the participating research center. When an item analysis was conducted on the data, it was found that only a small improvement occurred in the magnitude of the validities. In other words, this result indicates that the keys developed on the concurrent studies were almost as effective as the specially developed keys in the follow-up studies.

While these results were not of the same order of magnitude as those obtained in the concurrent studies, the investigators consider the limitations inherent in the criterion data to be responsible. This in turn has at least three facets: many of the criterion ratings appeared to be affected by a likeability factor; the scientists had been working on the job for a limited period of time so that an accurate assessment of their performance may have been difficult; and finally, the inventories and the criterion data were collected by mail, which may have reduced their accuracy.

Further research will be needed to resolve this question. The results that have been presented previously as well as those presented in this report indicate that with better criterion data more satisfactory results would have been obtained.

The Early Identification of Talent

As mentioned previously, a long-term goal of this research has been to develop an instrument that was both appropriate and valid for younger age groups. Some research has already been carried out on this question (*10*). The National Science Foundation Summer Science Program for high school and college students provides a unique opportunity for research. In some of the programs the students actually participate full time in research activities and thus some relevant criterion measures could be obtained. In these studies the BI was modified for younger age groups. Since some items had to be rewritten and the scoring was based upon data from mature scientists, we expected the revised BI not to work very well, if at all, under the circumstances. A further problem was that we now sought predictive (short range follow-up) validities rather than concurrent validities. The results indicated that the BI was among the best predictors of creativity in research and could be applied to markedly different age groups.

We thought that the initial BI constructed for administration to NASA scientists would probably be more appropriate for college seniors than for high school students, since college seniors more closely resemble the adult samples on which the BI was developed. Some data have been obtained on this latter issue already, although the criteria were not as directly pertinent as those used in the study of high school students (*11*). These studies evaluated fellowship selection information at the University of Utah, where the research committee awards approximately 40 graduate fellowships per year in all fields. Selection has been based largely on grade point average and letters of recommendation. For research purposes, a modified biographical inventory was administered to a number of seniors and graduate students who applied for fellowships. A year later their graduate student performances, including their research potential, were rated. Again the BI scores proved to be among the most valid predictors of these criteria. In one case, a BI score by itself predicted the next year's performance of the graduate students more effectively than did the collective judgments of the official fellowship committee which based its decisions on a full folder of application materials from each fellowship candidate.

These studies on student groups demonstrate the potential contribution of biographical information to the early identification of creative scientific talent.

Productivity or Creativity or Both?

Among the many unanswered questions in creativity research is the question of whether the same factors are involved in predicting at different ages and at different levels of creative performance. Our biographical research generally indicates that the same items that predict creativity in adult scientists predict creativity in high school students. In addition, the same characteristics of successful scientists obtained from biographical studies of NASA research professionals correspond to the findings of those studies that have included or even focused solely upon highly eminent scientists (*3, 12*). Thus, it is apparent that many of the same characteristics are involved in predicting different levels of creative performance. This problem could be approached directly by processing data from the NASA studies, first by subdividing the samples according to creative performance or level of education and then analyzing the subsamples separately. However, in our earlier studies of Air Force scientists (*6*), the number of years of education was unrelated to 12 of the 14 criterion factors, and to none of the creativity criteria. It was only related to the number of professional societies to which a person belonged and whether he was efficient in completing his paper work (a factor called "productivity in written work").

A related question concerns how well do biographical characteristics predict productivity in science as opposed to creativity. Although some biographical items have differential validities in predicting productivity and creativity, the majority of the items are related to both criteria. These findings agree with the rational point of view presented by Bloom (*12*) and others, that without a certain minimum amount of productivity, for example, publications and quantity of work completed, there is a low probability of creative achievement. We have been somewhat more successful in predicting supervisors' evaluations of creativity than of productivity, but as mentioned previously, the major focus of these studies has been upon creativity criteria, so that biographical items were formulated with creativity more than productivity in mind. It is evident that considerable additional research needs to be conducted before the above questions can be adequately answered.

Because of the consistently promising and positive results in studies where biographical information has been used, there has been an increasing use of psychological tests of this type. One outcome has been the initiation of a research project in a large pharmaceutical company (Richardson-Merrell, Inc.) which was based upon the previous NASA effort. In this study (*13*) a biographical inventory (constructed by Taylor and Ellison for research use in industry) was administered to a large number of scientists and information was obtained on their creativity and general scientific competence. Each participating scientist was rated by his supervisor, his peers, and, in some cases, his subordinates. Results of this study showed that the empirically constructed keys yielded cross validity predictions of the criteria in the .30's and .40's. Also, since the biographical items used in this study contained many of the same items that were used in the NASA studies, it was possible to score the test protocols of the pharmaceutical scientists with the NASA-derived keys. The results were significant and have important implications. It was found that a combination of the NASA creativity keys, when applied to the biographical information responses of the pharmaceutical scientists, yielded validities with the creativity criterion in the high .30's.

These findings indicate that the results of the NASA studies may be applied not only to different age groups but also to diverse samples of scientists (in this case, the physical and biological sciences and both a government agency and private industry). This study, therefore, suggests that biographical information may be employed to identify scientific talent found in a variety of environments.

Chambers (*14*) studied the personality and biographical factors of mature scientists who are highly creative in research work and those of scientists who are much less creative. In addition to significant differences between creative scientists and their comparative control groups on several personality variables, he also found significant differences for 16 biographical items. He was thus able to present a biographical and personality profile of those highly creative scientists and those not so creative.

W. A. Owens and his associates (*15*) have made several studies of engineers and scientists relating biographical data to creativity, professional interests, and research competence. In another study, Albright and Glennon (*16*) found that biographical information could discriminate between supervisory and research-oriented scientists at all levels of a laboratory organization. Also, Smith, Albright, and Glennon (*17*) demonstrated the value of the personal history technique in the prediction of scientific competence and creativity within a highly select group of research scientists.

In a recent study by McDermid (*18*) of the technical and engineering personnel of the Hammond Organ Company, it was found that only biographical data proved to be significant as predictors of both supervisory and peer ratings of creative performance.

The June 1965 national research conference on the use of biographical information, chaired by E. R. Henry (*19*) and supported by the Richardson Foundation, produced a consensus of the 16 participants that in professional and other complex fields, the biographical approach is at least as good and is usually better than other techniques for predicting job performance.

Summary

The biographical approach to the identification of scientific talent has shown significant results in a variety of situations which included different laboratories, fields of specialization, and age groups. Much remains to be accomplished, however. The biographical approach needs to be validated in other organizational settings employing relevant criteria. Although this kind of research is being initiated, a number of studies are needed to define the advantages and limitations. The use of biographical information to identify the creative and other talents of executives, composers, administrators, and artists has been largely unexplored. Furthermore, the meaning of the biographical items has not been correlated with existing psychological theory and knowledge. All evidence to date indicates that the investigation of biographical information and its relationship to various criteria of performance and other psychological measures is a rapidly expanding area of investigation which will make further contributions to the identification of talent in a variety of fields.

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NEWS AND COMMENT

Oppenheimer: "Where He Was There Was Always Life and Excitement"

Hans A. Bethe

The author, professor of physics at Cornell University, was a longtime colleague of the late Dr. Oppenheimer. During World War II he served as director of the theoretical physics division at Los Alamos Scientific Laboratory, where Oppenheimer was director.

I. The Scientist

J. Robert Oppenheimer, who died 18 February, did more than any other man to make American theoretical physics great.

His mind was all the time concerned with the most fundamental questions in physics. This attitude of concentrating on the fundamental difficulties and ignoring the easy problems he communicated to his students. "What we don't understand we explain to each other," he once said in describing the activities of the physics group at the Institute for Advanced Studies, at Princeton. There was always a burning question which had to be discussed from all aspects, a solution to be found, to be rejected, and another solution attempted. Where he was, there was always life and excitement, and the expectation of excitement in physics for generations to come.

Oppenheimer started in physics at the most opportune time, taking his B.A. at Harvard in 1925. In 1926 Schroedinger discovered his equation, and already that year Oppenheimer had written his Ph.D. thesis in Göttingen on an important application of that just-invented theory. He calculated the photoelectric effect in hydrogen and for x-rays. Even today this is a complicated calculation, beyond the scope of most quantum mechanics textbooks. In 1926 Oppenheimer had to develop all the methods himself, including the normalization of wave functions in the continuum. Naturally, his calculations were later improved upon, but he correctly obtained the absorption coefficient at the K edge and the frequency dependence in its neighborhood. He was disturbed by the fact that his theory, while agreeing well with measurements of x-ray absorption coefficients, did not seem to be in accord with the absorption of hydrogen in the sun. This, however, was the fault of the limited understanding of the solar atmosphere in 1926, not of Oppenheimer's theory.

For 4 years, 1925 to 1929, Oppenheimer traveled from one center of physics to another—Cambridge University and Göttingen as a Ph.D. student, Harvard and California Institute of Technology as a National Research Fellow, then Leyden and Zurich as a fellow of the International Education Board. In Zurich he was influenced by Pauli, probably the man with the deepest understanding of quantum mechanics. In Göttingen, after completing his Ph.D., Oppenheimer worked with Max Born, one of the inventors of the then new quantum mechanics. Their paper on the structure of molecules is still the basis of our understanding of molecular spectra.

In 1929 Oppenheimer accepted a position as assistant professor at the University of California, Berkeley. Simultaneously he held an appointment at California Institute of Technology in Pasadena, where he regularly spent part of the year. This was the beginning of his great school of theoretical physics. In the 14 years before Los Alamos, a large number of the best theoretical physicists in the United States, including Christy and Schiff, did their work for the Ph.D. with him. Soon his school became famous and attracted postdoctoral fellows like Serber and Schwinger. His lectures were a great experience, for experimental as well as theoretical physicists. In addition to a superb literary style, he brought to them a degree of sophistication in physics previously unknown in the United States. Here was a man who obviously understood all the deep secrets of quantum mechanics and who yet made it clear that the most important questions were unanswered. His earnestness and deep involvement gave his research students the same sense of challenge. He never gave his students the easy and superficial answers but trained them to appreciate and work on the deep problems. Many of them migrated with him between Berkeley and Pasadena every year.

The problems of nonrelativistic quantum mechanics had been pretty well