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ABSTRACT

What are the characteristics of successful students in research training programs and what are the characteristics of successful programs of this type? What are the characteristics of successful mature researchers and what research environments facilitate research of high quality and quantity? Since very little research deals directly with these questions, answers to them are sought in related research literature, and suggestions are made for research that is targeted to this area of investigation. Correlates considered in forecasting success of students are those of previous training and experience, and those of personal and intellectual qualities. Factors considered in determination of characteristics of successful training programs are those of faculty quality, student quality, institutional setting, and academic content of the training curriculum. Productivity of scientists is found to be related to personality profile, intellectual correlates, and work patterns. Themes that stand out in an appraisal of a research environment are: relationships with other scientists in the research setting, relationships and interactions with administrators and supervisors, diversity of interests and activities in the organization, and finally, physical and financial resources available to the scientist. (MF)

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IDENTIFYING AND FOSTERING PRODUCTIVE RESEARCHERS

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An Occasional Paper from ERIC at Stanford
The Clearinghouse on Media and Technology

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IDENTIFYING AND FOSTERING PRODUCTIVE RESEARCHERS

This paper reviews research on a problem of long-standing interest to educators and policymakers, as well as social scientists: identifying and fostering talented, productive scientists.[1] More specifically, it attempts to answer two questions about research training:

1. What are the traits and prior experiences of students who successfully complete research training programs?
2. What are the characteristics of research training programs that have been notably successful in training productive researchers?

The first two sections of the paper are devoted to research on these questions.

The latter two sections extend the first two topics to characteristics of productive mature scientists and their optimal research environments. These are "scientists who are well qualified to conduct research independently and thus contribute significantly to the research programs of their sponsoring institutions." Two further questions are pertinent:

3. What are the characteristics of researchers who have been productive in their professional careers?
4. What research environments seem to facilitate research of high quality and quantity?

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[1]This research review was originally requested by Dr. William McEwen, chairman of the Health Services Research Training Committee of the National Center for Health Services Research and Development (U.S. Public Health Service). In making it available now to a wider audience, we hope that it will be of some use to policymakers as well as behavioral scientists and others who plan and evaluate training programs and research environments.

PROBLEMS WITH THE STUDIES

Very little research deals directly with these specific questions. For example, I found no studies in which the subjects were actually graduate students in science *and* in which the variables of interest were factors in their success or failure in graduate study *per se*. I was more likely to find studies of the same or similar problems in non-scientific fields or in scientific fields at a level other than that of graduate training (e.g., high school, undergraduate, etc.) In other words, there *is* a relevant literature, but it requires careful inferences from the findings of studies that are often indirectly related to the population in question. I have tried to "cover my tracks" in drawing these inferences.

In so doing, I have made (sometimes implicit) value judgments as to the merits of a study. The literature comes from diverse branches of science and employs a wide range of methodologies. As you would expect, the quality of the research is very uneven. I have avoided excessive technical detail, because I don't want to cloud the important substantive issues; when detail is needed to clarify a study's meaning, I have tried to make it as much to the point as possible. At other times I have simply weighed the conclusions of a study judiciously, according to the strength of the inferences their methodologies will bear. The point is to make the relevant generalizations, not to write a critique of the research literature.

With those *caveats* in mind, let us consider research information on training productive researchers.

CHARACTERISTICS OF SUCCESSFUL STUDENTS

In the literature "success" of graduate students usually means one of two things: (1) high subjective ratings by judges of performance in the course of earning the Ph.D.; or, more frequently, (2) receiving the Ph.D. itself. In other words, faculty members' high evaluation of a student's progress or simply receiving the Ph.D. may mark him a success.

Whatever the "success" criterion, studies typically try to relate it to one or both of two types of student characteristics: (1) educational background and experiences or (2) personality and intellectual-accomplishment factors. That is, they examine the successful graduate student with respect to certain factors on which he might be expected to be different from less successful students.

PREVIOUS TRAINING AND EXPERIENCE

Some studies of the productivity problem have looked for a relationship between a successful graduate student and his "nurturance" -- the institutional characteristics of his undergraduate school or the social environment created there by faculty members and his fellow students.

The quality of their schools. The idea that certain schools -- or "types" of schools -- were especially prolific in producing future scientists came out of a series of studies done in the early '50s by Robert Knapp and his colleagues (Knapp and Goodrich, 1952; Goodrich, Knapp and Boehm, 1951; Knapp and Greenbaum, 1953). Two of these reported on the undergraduate origins of outstanding American scientists, but did not include information on their graduate research training. The third (Knapp and Greenbaum, 1953) began with a consideration of "successful" graduate students. From a population of graduate students at 25 schools, these authors selected those who had received their bachelor's degrees within about four years of the date of the study and had also received some distinction at the graduate level. By "distinction" they meant a fellowship, scholarship or prize in competition at the graduate level or the Ph.D. degree itself. Knapp and Greenbaum found that about 50 undergraduate schools produced "successful" graduate students at the rate of 10 or more for each one thousand students graduated; all the other undergraduate schools were heavily skewed toward one "success" per thousand graduates. *In other words, they found that successful graduate students at the schools which produced most of the country's Ph.D.'s came from a relatively few undergraduate institutions.* Although the particular schools vary somewhat from field to field of graduate study, Knapp and Greenbaum's results at first seem to suggest the existence of an "elite" group of undergraduate schools from which all our prospective researchers should come.

Other data suggests that *it may be that certain types of schools rather than certain "elite" schools, yield more students who choose to seek graduate training in science than other types of schools.* Thistlethwaite (1959, 1963) and Astin (1963a) studied the correlation between graduate-school populations and the type of undergraduate institutions they attended. For example, they wanted to see if graduate students in the natural sciences came in disproportionate numbers from colleges or universities, public or private schools, all-male or coed campuses, etc. In general, they found that natural-science Ph.D.'s tended to come disproportionately from professional and technical schools, all-male campuses and public universities; while arts-humanities-social science graduates more typically came from colleges (private and public), all-male schools and private universities. They also found that graduate students in the sciences and social sciences came from undergraduate schools located mostly in the Midwest, West and -- to some extent -- the South. Northeastern colleges produced more humanities graduate students. The fact that Knapp and Greenbaum's "elite" producers of scientists are also schools of the type most likely to produce science graduate students makes the "elitist" notion partly spurious. The idea of types gives us a broader base from which to select future research trainees.

Finally, data on the quality of students who choose "elite" schools further clarifies the problem. Thistlethwaite (1963), unlike Knapp and Greenbaum, considered the quality of the students who enter undergraduate schools in studying their production of science graduate students. That is, he accounted for the abilities and aspirations of the "inputs" in evaluating the college's "output." This is reasonable, since Holland (1957) had earlier found that winners of the National Merit Scholarships and Certificates of Merit chose the schools that Knapp and Greenbaum called "highly productive" of subsequent Ph.D.'s at a rate higher than would ordinarily be expected. In fact, Knapp and Greenbaum showed that their 50 highly productive schools turned out graduates who later earned the Ph.D. at a rate four times that of other schools; Holland found that top high-school graduates were choosing to attend those same fifty schools at about the same rate. The reason often given for their choices was a school's "good reputation" or "good academic standing" -- accolades which could conceivably be related to their tendency to produce people who later made successes in academic fields.

To sum up, Holland's findings show that certain elite schools may produce star graduates -- but not from undistinguished raw material. Their students are good when they come in. However, it says nothing about the very real possibility -- raised by Thistlethwaite's correlations between "type" of school and graduate student populations -- that undergraduate experiences nurture the talents of future scientists. Knapp and Goodrich (1952) found that successful natural scientists had attended undergraduate schools whose student bodies showed average intelligence-test scores markedly higher than would be expected. This suggests that students in these schools may have benefitted from stimulating intellectual environments sustained in part by their fellow students' high IQ's. Recent research suggests that the level of student-body "intellectualism" in a student's undergraduate school is an important consideration in predicting that student's graduate-school performance (Hansen, 1969).

The quality of faculty and student associations. Thistlethwaite (1960, 1968) and Astin (1963b) have studied the influence of student and faculty "subculture" on undergraduates' aspiration to do graduate work. On the basis of a College Characteristics Index and, later, from a set of rating scales he developed himself, Thistlethwaite (1960, 1963, 1968) concluded that *students and faculty in the sciences tended to "press" for very different values and interpersonal characteristics* -- an idea similar to C. P. Snow's "two cultures," the scientific and the humanist. For example, in the natural sciences the student ethos includes aggressiveness, scientism and social conformity. Faculty members maintain informal student-faculty contacts, but they supervise students closely and use very directive teaching methods. In the arts-humanities-social sciences, students value humanism, breadth of interest, reflectiveness and participation. Faculty members maintain a flexible approach, and their teaching is energetic and controversial. Although students are very likely to be members of one of these subcultures because of their majors, living situations, etc., these different student-faculty environments do not appear to change the aspirations of students to do graduate work. Students who go to graduate school generally seem to have had the aspiration to do so when they entered college, often because they considered it to be a natural concomitant of their career choice. As will be seen below, later -- and presumably initial -- aspiration appears to be primarily a product of personal and intellectual characteristics, not friends and mentors at the late stage of undergraduate school (Astin, 1963a).

This is not to say, of course, that influential "others" at any point in one's development may not make a difference in aspirations. Many successful scientists recount the influence of particular teachers -- usually those whose characteristics of masterfulness, warmth and professional dignity -- in their professional careers (Knapp and Goodrich, 1952). And Thistlethwaite (1968) reports that many students have changed their aspiration to do graduate work after becoming involved in professors' research as undergraduates. Furthermore, case studies of different productive schools show that they attempt to foster an atmosphere that rewards intellect and encourages challenging discussions of academic and other issues among professors and students alike.

However, the personal and intellectual characteristics that are commonly associated with good scholarship generally transcend specific undergraduate experiences. A notable exception seems to be the case of students with initial aspirations to do scientific research who then choose an undergraduate major in an applied science like engineering; these students tend to decide against doing graduate work more than other students.

PERSONAL AND INTELLECTUAL CORRELATES

Few studies emerged that directly concern the question of successful students in the context of specific training programs. One is a Ph.D. dissertation examining correlates of success in graduate (masters and doctoral) programs in Farm Management, Rural Sociology and Rural Education at Cornell (Santos, 1966).

Success and academic record. Santos began by asking a panel of professors in the three programs for their criteria of a successful graduate student. He then developed rating scales on each of the criteria suggested and asked each student's adviser to rate the student on each scale. The individual's rating on the scale was then weighted according to the importance accorded it by the panel of judges, and a total "success score" was computed for each of the 179 subjects. The next step was to correlate these success ratings with other information about the students. Santos found that *the highest stable correlates of success were the recommendations in the graduate-school applications, the undergraduate grade point average and the graduate-school grade point average (GPA).*

These particular correlates are not surprising, given Santos' "success" measure. Recommendations, undergraduate record and graduate course performance almost inevitably compose an important part of an adviser's evaluation of his students -- and advisers were doing the success ratings in this study. More objective measures of success might have given us more confidence in Santos' findings. Fortunately, they have a comforting face validity anyway. Furthermore, advisers' evaluations may often be valid indicators of a student's promise (Bloom, 1963). University of Chicago professors told interviewers they generally felt that their previous students who had subsequently become successful researchers had also been notably successful as graduate trainees.

Santos' findings converge with those of other studies using different approaches (for a detailed review, see Hoyt, 1965). Harmon (1963) did a follow-up study of candidates who won government awards for graduate study to estimate the extent to which the criteria for their selection had predicted their success in the training programs and in the first few years thereafter. Ninety percent of the competitors for the 1949 Atomic Energy Commission fellowships (forerunner of the National Science Foundation awards) returned mail questionnaires in 1956. The data included information about progress on their degrees and their post-Ph.D. activities (if the degree had been completed). He then asked NSF selection committees to rate the questionnaires on the amount of "scientific competence" they reflected. These ratings were correlated with the respondents' positions on the criteria used by the 1949 selection committee to award the AEC grants. Although the predictive validity of the selection criteria generally appeared to be very low, recommendations in the student's file and his undergraduate grade point average usually showed the closest relationship to graduate and post-doctoral success. This convergence with Santos provides some balance for the natural skepticism over Harmon's use of self-report questionnaire measures as a basis for the success rating. *Both the studies affirm the usefulness of at least some ratings of a prospective graduate student based on his previous academic performance. Recommendations, which commonly come from former teachers, were found to be especially good predictors of graduate-school success.* Further, graduate school records in turn appear to be good predictors of later research productivity.

Some studies have found that academic predictors (e.g., undergraduate GPA, subject's retrospective report of his satisfaction with his undergraduate academic performance, etc.) were sometimes, but not always, good correlates of scientists' output (C. Taylor et al., 1965; D. Taylor, 1963). However, recent research indicates that the usefulness of both undergraduate grades and test scores as predictors of graduate-school performance improves when some measure of undergraduate-school "quality" is also considered (Hansen, 1969). Bloom (1963) reports that undergraduate grades and aptitude-test scores in the field of graduate study itself were better predictors of graduate success than over-all GPA and general scores. It may be that trainees can best be evaluated on their aptitude and competence in the specific fields in which they want further research training. (Lannholm, 1967, 1968, provides a detailed summary of studies of the predictive value of Graduate Record Examination scores and graduate-school performance.)

Success and personality profiles. Successful student researchers appear to show rather distinctive personality profiles. In their subjective criteria for successful students, Santos' judges most often mentioned general personality characteristics, rather than specific academic accomplishments with which they later proved to be correlated. The criteria they mentioned and their relative weights included: ability to think analytically and critically (10); knowledgeability (3.6); ability to do research (3.3); creativity (3.3); ability for self-direction (2.8); degree of motivation (2.4); performance in course work (1.8); skill in communication (0.7). These closely correspond to Bloom's (1963) results from interviews with Ph.D. advisers at the University of Chicago.

Evidence like this has led to attempts to use biographical data from highly productive career scientists to construct an inventory to identify potentially productive scientists at the undergraduate level (Taylor, Ellison and Tucker, 1965). Of course, it is impossible to know how valid predictions based on such an inventory would be. But the biographical profiles of productive scientists are interesting for their convergence with the findings of Santos and Bloom, as well as with some data from Raymond Cattell (1963) and Donald MacKinnon (1962). In general, positions on items designed to tap characteristics like *self-determination, individualism, task orientation (as opposed to social orientation), openness, discipline, perceptiveness, etc.,* were highly related to productivity in the career scientists and so were considered likely predictors of future scientific creativity. (For a detailed review of psychological studies of creativity, see Golann, 1963.)

The biographical-prediction study found little relationship between information on scientists' parents and family and their productivity.

However, some work has suggested that *certain types of family backgrounds may predispose a youngster to a scientific career.* Holland (1957) found that students whose fathers' occupations involved physical labor or the sciences or social sciences were more likely than children of fathers in business or the "persuasive" occupations to choose undergraduate schools with good records of subsequent Ph.D.'s. Astin (1963) found a similar difference by father's occupation in students' aspiration to seek graduate training. (Holland interpreted this finding as the result of different values toward achievement in society as a result of their fathers' occupations. However, he has no data to test this idea.)

Thus, graduate students provide a great deal of predictive data in their application files. Of course, as every person who has ever grappled with an admission quota knows, their transcripts and recommendations are not infallible criteria. A student that fits the general profile that "successful" students tend to show can't be guaranteed to be another Pauling or Lederberg; but the probability is reasonably high that if the major data points converge, he will be a successful research trainee and a productive scientist.

A FINAL WORD

This review of the characteristics of successful graduate students provides some tentative answers and raises possibilities for further study of the problem. Here are the minimal issues that further research should consider:

1. The definition of "successful" should include objective, as well as subjective, measures of a student's work. These measures should be taken as near as possible to the end of a student's graduate training. In other words, judges' ratings should be considered in conjunction with such factors as the number and kind of projects he has pursued, the number and quality of his publications and research reports, etc.

2. The sample of graduate students should be selected to

represent the whole range of types of undergraduate schools which have been different in their "productivity" of science graduate students.

3. Careful, complete data should be obtained on a range of personality and intellectual variables, as well as on the academic and research experiences of the subjects.

CHARACTERISTICS OF SUCCESSFUL TRAINING PROGRAMS

Talented students need an appropriate training environment to become productive researchers. The literature suggests that four major factors of research training programs contribute to their effectiveness: (1) quality of the faculty; (2) quality of the students; (3) status and setting of the institution, and (4) academic content of the training curriculum.

FACULTY QUALITY

Although faculty and student influences may not change a student's aspiration to do graduate work, they may nevertheless be important in shaping his social and professional perspectives and values. In other words, one vital factor in the training environment is the social/intellectual milieu -- a situation where a promising student can find stimulating interaction with other scientists, young ones, as well as more mature ones.

Characteristics of successful teachers. The penultimate testimony to the influence of great teachers may be the case study of a midwestern undergraduate college, undistinguished save for the presence of two remarkable science teachers. Their influence alone appeared to keep the school among the top undergraduate producers of distinguished scientists (Knapp and Goodrich, 1952).

At the undergraduate level "masterfulness, warmth and professional dignity" characterized the successful science teacher (Knapp and Goodrich, 1952). They may be viewed as models who demonstrate the proper role behavior for a scientist and who communicate to students "enthusiasm for the intellectual life" (Thistlethwaite, 1968). *In other words, good teachers have great skill in interpersonal relationships; and they also show a level of active professional competence that the student can recognize and emulate.*

Involvement in research. This aura of scientific competence may be related to a faculty member's own research activity. Bresler (1968) found that undergraduate students at Tufts rated as their best teachers those who were also doing research and had published articles. Presumably research activity indicates an enthusiasm for and involvement in one's subject matter that carries over into the classroom. This fact is even more important in graduate study, where a faculty member's research involvement and his teaching responsibilities overlap extensively. Furthermore, on-going faculty research typically provides opportunities for graduate students to become involved in research -- a factor that significantly betters the chance that students themselves will subsequently become productive researchers (Bloom, 1963). In short, *faculty members in research training programs should themselves be researchers. Not only does it enhance their teaching, it increases the likelihood that students themselves will become involved in productive research.*

STUDENT QUALITY

Faculty quality inevitably affects the nature of the other factor in the training program's intellectual milieu, the students. In his 1966 report on graduate education Carrter reported that two-thirds of the winners of Woodrow Wilson and National Science Foundation fellowships chose to go to the top ten schools *on faculty quality ratings*. Of course, from the student's point of view this correlation makes good sense; the quality of his teachers may directly affect his later career. Scientists' post-graduate school publication record has been found to be more highly related to the prestige of his graduate-student sponsor than to the graduate school he attended (Crane, 1965). Zuckerman (1967) found that Nobel laureates had been distinctly more selective of their teachers than had a matched sample of less distinguished scientists. Conversely, they were also more selective of the students they accepted. In other words, a high correlation between quality faculty and quality students may reflect the selectivity of both. Good students want the expertise and prestige of major scholars in the field; top faculty members want only the most able pupils and collaborators.

Students as "shadow faculty." *Fellow graduate students may be viewed as forming a "shadow faculty" from which a young researcher gets a large proportion of the information and stimulation needed for his development.* One study showed that young researchers get their ideas from informal discussion with colleagues twice as often as from the technical literature they encounter in more formal ways (Shilling, Bernard and Tyson, 1964). If the participants in those informal discussions are bright, creative colleagues, productive research is more likely to result.

To sum up, the presence of good teachers in a research training program is a starting point in a partially self-sustaining reaction. Their teaching and research attracts bright students, who succeed and thus enhance the reputation of their teachers, who can in turn attract more and brighter students to perpetuate the tradition. Without stimulating faculty and good students, a research training program literally has little chance of producing researchers of note.

THE INSTITUTIONAL SETTING

The presence of both good faculty and good students may well be due to the prestige of the institution and department under which the program is developed. Crane (1965) found that scientists at "major" universities were significantly more productive in the number and quality of their publications than scientists at "minor" universities. Wispé (1969) found that psychologists in large departments are more productive than those in smaller departments. Recalling that productive researchers are also highly effective teachers, it may be that the "major" or more prestigeous schools -- by virtue of having the most productive researchers -- may provide the best research training programs as well. This conclusion is strengthened by the high correlation we found between faculty quality and the calibre of student "shadow faculties."

Where does this leave the lesser institutions? How valid are their training programs on this particular dimension? Carrter (1966) analyzed the reasons behind his informants' rankings of the quality of departments. The most-listed departments were also the best known ones, perhaps because of their previous production of top researchers, and the visibility of their faculty members. If a department was listed infrequently, it was usually by those informants who were close enough to it geographically to know of factors that had recently distinguished it but that had not yet had time to become widely known. Two correlates of these up-and-coming departments were especially important: their faculty salaries and the reputation of the university's library. In other words, departments that could be considered to be improving were those that were willing to pay to attract higher-quality faculty members and those that had library resources to attract serious scholars of both faculty and student status.

To sum up, an institution's prestige is inextricable from that of its faculty and students. Institutions that offer good quality in both, or that have the resources to attract both, are probably best suited to the training of productive researchers.

Outside resources. *One further institutional factor is the potential it offers for contacts between the training program and academic and non-academic researchers in the particular field.* Studies of scientific information flow (for a review, see Paisley, 1965) suggest that the ideal training environment permits many informal contacts, not only within the training facility but also with creative scientists outside the laboratory. Younger scientists, who travel to conferences and professional meetings less than older ones, depend on informal contacts with visitors and colleagues in the more immediate environment for stimulation. For example, Shilling, Bernard and Tyson (1964) found that discussion with visiting scientists was positively related to research productivity.

ACADEMIC CONTENT

A final criteria for evaluating a training program is the curriculum. What courses will be offered and required? Is the training broad or intense, flexible or prescribed?

Diversity. A recurring theme from historians of science is that diversity

-- in an individual's own interests and within his environment -- is conducive to productivity (Price, 1961; Kuhn, 1963; Koestler, 1964; Pelz, 1956, 1967). These writers view a creative idea as the interface of diverse intellectual elements. Therefore, the more diversity of intellectual interests and activities in a research setting, the more likely fruitful intersections of ideas. Pelz (1967) considers this a "creative tension" in the research environment. He found that scientists were more productive when they had two or three areas of specialization. He also found that the more productive research environments included scientists with several different substantive interests.

The university is an ideal place for this kind of substantive diversity. Where many academic specialties are flourishing, students may be exposed to several of the sciences at once. It is this breadth and diversity that provide a creative tension. In other words, an ideal curriculum balances breadth of education against intensity of training in specific skills. This requires a flexible attitude of the faculty. They can encourage breadth, but students will probably profit most from diversity when they are allowed to "follow their noses" into departments and courses that converge meaningfully for them. This is possible when the program is always viewed as developmental; not rigidly prescribed, but developing in line with the needs of the students (Haubrich, 1966).

In short, potential diversity in the curriculum of a training program facilitates students' productivity. Diversity probably has its greatest effect when colleagues have different substantive interests, but essentially similar scientific values (Pelz, 1967).

Research experience. One feature of research training programs seems to be of overriding importance: the availability of opportunities for students to do original research, singly or in collaboration. University of Chicago Ph.D. advisers told an interviewer that students who "ingest as much knowledge, information and skill as possible but whose only research during their graduate work appears to be the dissertation. . . do not turn out to be very productive in their post-Ph.D. careers." On the other hand, "Where the research role is emphasized, where the individual is given many opportunities to do research. . . or where he actively seeks out research opportunities as a graduate student, he becomes highly creative and productive" later on. *In other words, the role of research in graduate training needs to be an explicit and challenging provision of training programs.*

Further investigation is needed to suggest a proper balance between requirements vs. flexibility, diversity vs. intensity (of scope), research vs. ingestion. Proper planning of a research training program takes them all into account.

CHARACTERISTICS OF MATURE SCIENTISTS

We have dealt with the literature relevant to the training and productivity of young researchers. At a still relevant, but less detailed, level this section and the next are concerned with the mature scientist and his work situation. What characteristics seem to correlate with his productivity, and what environments facilitate it?

Instead of describing studies in detail, I will just attempt to draw out the major propositions that seem to be related to three factors in the scientist's productivity: (1) his personality profile; (2) intellectual correlates; and (3) his work patterns.

PERSONALITY PROFILE

Creative scientists show a distinctly different average personality profile from that of the general population, as well as from that of the smaller college-educated population (Cattell, 1963; Roe, 1953; Taylor *et al.*, 1965; Pelz and Andrews, 1966). These propositions, drawn mainly from Cattell's findings, are representative:

1. On the average researchers are significantly different from the average man in that they are more exact, precise and reliable; more intelligent; more dominant; more inhibited; more emotionally sensitive; more radical, and more given to controlling their behavior by an exacting self-concept.

2. In comparison to the general college population, researchers are uniformly lower on all the personality dimensions that comprise a general factor of extroversion. (Cattell reasons that the extrovert is constantly tuned in to a plethora of external stimuli, leaving few input channels free for scanning the environment. The introverted scientist is better able to scrutinize the world around him.)

3. Compared to outstanding teachers and administrators, outstanding scientists are significantly more exact,

precise and reliable, less emotionally stable, more self-sufficient, more Bohemian, more radical.

Cattell found that these quantitative trait measurements corresponded closely to the qualitative dimensions he had discerned from the biographies of hundreds of outstanding scientists, long dead.

In general, contrasted to almost every comparison group, scientists stood out as being more exact, precise and reliable, more intelligent and less extroverted. Of course, deviations from that average profile are expected; but few of us would be surprised to find a gifted scientist with those general characteristics.

Age. This final factor related to productivity is a demographic, rather than a personality, characteristic. Pelz and Andrews (1966) found that productivity peaked for most scientists in their late 30's and early 40's, dropped off but peaked again in the middle and late 50's. The drop-off was less marked for scientists who were highly "inner-motivated" (as opposed to externally motivated).

INTELLECTUAL CORRELATES

We have already discussed the Knapp and Goodrich (1952) data on the undergraduate origins of distinguished scientists. They were found to have come predominantly from a relatively small number of colleges (either liberal arts or state-supported agricultural schools, plus a few eminent universities), the student bodies of which showed higher average IQ's than other undergraduate student bodies.

In most cases academic records have proven to be good correlates of later productivity (e.g., Bloom, 1963; D. Taylor, 1963; Taylor, Smith and Ghiselin, 1963; Harmon, 1949). Donald Taylor (1963) reports significant but low (.09 - .29) correlations between supervisors' ratings of industrial scientists' productivity and aptitude tests (namely, mechanical comprehension and productive thinking).

One factor in later productivity has not been carefully tested, but is suggested by Bloom's (1963) interviews with graduate-student advisers at the University of Chicago and is intuitively compelling. That is the idea that a productive mature scientist gets an early start in original research, presumably as a graduate student. Zuckerman (1967), in her study of the productivity patterns of Nobel laureates, found that they start to publish earlier (as well as peaking later, ending later and publishing more) than a matched sample of less eminent men. *Thus, a consideration of a man's early publication record may say much about his probable productivity as a mature researcher. Few other indicators, short of subjecting applicants to a battery of aptitude tests, appear to have much power.*

WORK PATTERNS

The large majority of studies of scientific productivity have focused on the effects of various work patterns and conditions. The conditions will be discussed in the next section, but patterns are largely a function of the individual and so properly belong under a consideration of individual characteristics. The literature has dealt primarily with three questions:

> Does he work best alone or in groups?
>
> Does he have a single intense research interest, or are there two or three topics on which he is interested in working?
>
> What kinds of information does he typically seek and from what sources?

Here are the major findings with respect to each:

1. Alone vs. groups. Cottrell (1960) holds that even though "science attracts the solitary mind," even the most solitary researcher must sometimes make contact with his fellow scientists in order to maintain his effectiveness. Generally, the empirical literature supports his contention. While older scientists actually collaborate in research less than younger ones, they more often enjoy informal contacts with other scientists outside their own laboratories

(Shilling et al., 1964). However, Zuckerman's (1967) sample of Nobel laureates appeared to collaborate more after winning the prize, both to meet the manpower exigencies of solving major scientific problems and also as a noblesse oblige effort to share the prestige of the prize with deserving younger colleagues (sometimes as second or later authors). Perhaps even they, and almost certainly less eminent scientists, stand to profit from the "creative tension" that comes from group research efforts (Pelz, 1967). To summarize, *while mature researchers may be fully competent to undertake and successfully complete major research on their own, their obligations and well-defined interests are often so great and contacts with other creative scientists so stimulating that collaboration is still an efficient way to maintain productive research.*

2. Diversity of interests. The idea of "creative tensions" from a diversity of interests (Pelz, 1967) appears to include two dimensions. One is that of research specialties. Pelz found that effective researchers liked both the security of having one main project on which they spent a great deal of time and they liked the diversity of having several specialties, even if they weren't spending much time on the others. The second dimension is that of professional responsibilities. Pelz's subjects seemed to perform best when they had both "pure" research and developmental ("applied") or service responsibilities. On both dimensions the researcher potentially encounters a large number of diverse elements, ripe for productive synthesis. Age changes in performance often appeared to be attenuated by periodic changes in projects (Pelz and Andrews, 1966).

3. Information-gathering patterns. The general conclusion from the literature is that creative mature scientists

are more willing than their less creative, as well as their younger, colleagues to tackle heavy reading in their area of interest. They spend more on-the-job time reading, less talking to others or participating in discussion groups (Shilling, Bernard and Tyson, 1964; Maizell, 1960; Parker, Lingwood and Paisley, 1968). However, in the sample of communication researchers they studied, Parker, Lingwood and Paisley found that interpersonal contacts with other researchers were the best predictor of the amount and diversity of output. Generally, though, the difference between their correlations between output measures and interpersonal sources (.32 - .34), on the one hand, and impersonal sources (.28 - .30) on the other is negligible. The important implication is that the productive researcher devotes a considerable amount of time to seeking information, either from the journals or from his colleagues who are carrying on their own productive research.

4. Other patterns. Highly productive scientists were, by their own report, exceptionally involved in or committed to their work (Pelz and Andrews, 1966).

One question that arises from these findings has to do with causal sequence. That is, does a man perform well because he is highly involved in his work, or does he become highly involved because he has experienced the rewards of success. Farris (1966) found that performance was as highly related to factors when they were measured after performance as when they were measured before. Unfortunately, causal analysis techniques have not been used at a sufficiently sophisticated level on this problem to permit strong inference of the sequence of causation. At best we can simply say that certain characteristics of scientists and their working environment appear to be highly associated with their productivity.

FACILITATING RESEARCH ENVIRONMENTS

Finally, we have the question of the research environment that best facilitates the work of productive researchers. This literature is probably the best developed of any we have reviewed, coming as it does from several relatively well-developed traditions (e.g., sociology, operations research, industrial engineering, etc.). Four themes stand out, and I shall summarize them as concisely as possible: (1) relationships and interactions with other scientists in the research setting; (2) relationships and interactions with administrators and supervisors; (3) diversity of interests and activities in the organization; and, finally, (4) physical and financial resources available to the scientist. (A major work in this area, complete with excellent summaries, is Pelz and Andrews, Scientists in organizations, 1966.)

INTERACTION WITH COLLEAGUES

The invisible college -- the other researchers with whom a scientist interacts and from whom he gets information and inspiration for his own work -- has been a recurring concept in studies of information flow and productivity. Here are some relevant propositions from the literature:

1. While scientists appear to value their independence and freedom, the most effective of them regularly interact with colleagues (Pelz, 1967).
2. The average scientist spends about one-third of his time in scientific communication (Ackoff and Halbert, 1958); and his productivity is highly correlated with the amount of intradepartmental communication in which he engages (Hagstrom, 1965). However, older scientists are less likely than younger ones to participate in research groups with colleagues; but they are also more likely to make contacts outside the laboratory situation (Shilling, Bernard and Tyson, 1964).
3. Group research efforts are most effective when member's average tenure in the organization is low enough so that

they still have an interest in "broad pioneering," but high enough so that their interests have not narrowed to highly specific areas (Pelz, 1967).

In short, research environments that provide opportunities to encounter other productive researchers, balanced by the freedom to pursue individual projects, appear to facilitate productivity.

INTERACTION WITH ADMINISTRATORS, SUPERVISORS

Scientists tend to cite as their most valued information sources persons of higher rank than they in their own organization (Hertz and Rubenstein, 1953). *When his supervisor or administrator is also a valued colleague, the scientist's working situation would seem to be optimal.* Here are some propositions from the literature:

1. The scientist performs better when the supervisor/administrator works in the scientist's own discipline and when the administrator is viewed as highly competent and motivated (Pelz, 1956).
2. There appears to be a curvilinear relationship between performance and the amount of autonomy permitted. Generally, autonomy improved performance up to the point where the scientist had to assume about half the weight of responsibility for the project's operation; then his efficiency as a researcher decreased. The optimal situation seems to be that in which the administrator gives neither complete autonomy or complete direction, but interacts frequently and gives the scientist the opportunity to participate in critical decisions. *In other words, the most effective research administrators employ participatory rather than directive or* laissez-faire *leadership* (Pelz, 1956, 1967).

DIVERSITY OF INTERESTS AND ACTIVITIES AMONG OTHERS IN THE ORGANIZATION

We have already introduced the idea of "creative tensions" in the research environment -- the balance between many interests and activities that provides opportunities for creative interfaces between the diverse elements. *With respect to research environments, then, it would seem that the more diverse the interests of colleagues who then interact with each other in the research organization, the greater everyone's resultant productivity.* Let us summarize the major conclusions about the role of diversity in a productive research environment:

1. Scientists were more productive when they had opportunities for frequent contacts with colleagues who had other research interests or had had previous research experience in a different environment (e.g., academic, if they now work in industry) -- especially if their scientific values were the same (Pelz, 1956).

2. The best situation is personal liking between scientists of conflicting scientific ideas. It was also found that this kind of constructive challenging of ideas was best when it was relatively infrequent (e.g., less than daily) (Pelz, 1956, 1967).

PHYSICAL AND FINANCIAL RESOURCES

Scientists need money and equipment to carry out research projects. However, these factors appear to interact with other factors in the research environment. For example, Meltzer (1956) found that the availability of funds for research was only effective depending upon the amount of autonomy with which a scientist and/or his organization could use them. If there was little freedom to propose and conduct creative research projects, greater availability of funds made little difference; but if there was optimal freedom, funds markedly increased productivity. Conversely, if little research money was available, more freedom didn't help; but if available funds were complemented by a free hand to do research, productivity rose.

Use of funds. Of course, how the money is used makes a difference in productivity, too. While additional personnel to carry out the project are often necessary, the availability of research assistants and of paid consultants has been found to be negatively correlated with individual productivity (Shilling, Bernard and Tyson, 1964). Presumably (although no data on this point were available), use of funds to buy equipment would not show a negative correlation.

In short, it may be that available funds increase productivity if an individual is free to undertake a project to which he plans to devote major interest and from which he hopes to make a contribution worthy of journal or book publication. If, on the other hand, available funds trap him into launching a project which provides only administrative headaches and holds no real interest or value for him, individual (but not necessarily organizational) productivity is not likely to increase.

Organizational prestige. Finally, the prestige of the research organization may be related to individual productivity. Crane's (1965) study of scientists at major and minor universities showed that major university scientists were significantly more productive in their major and minor publications than minor university scientists. She concluded that minor universities provide less stimulating research environments. Shilling, Bernard and Tyson (1964) found that university labs were more productive than other types of organizations, and that private universities generally had more productive research organizations than public universities. So major private universities -- or organizations of comparable stature and independence -- would seem to be the optimal environment for productive research.

A FINAL COMMENT

The literature reviewed here contributes some useful propositions to the science of human behavior. It also suggests guidelines for evaluating -- and, perhaps, enriching -- the potential productivity of scientists, young and old. In other words, the variables that have been studied can generally be used to predict -- and sometimes explain -- how productive a scientist or an environment with certain characteristics will be.

Unfortunately, not much can be done to modify many of the variables. For example, policymakers can do very little with the finding that the fathers of productive scientists are likely to have held certain types of occupations. On the other hand, knowing that association with able colleagues stimulates productivity among younger and older scientists alike may lead to policies that will create such "enriched" research environments. This potential for modification is essential if a variable is to be of practical use in guiding policy on the development of future productive researchers.

It is hoped, then, that this paper has served two purposes. It was meant to review research on productivity and has indeed summarized a number of studies, many of which show interesting convergent findings. Perhaps more important, it has emphasized the relative poverty of studies in this area that involve policy-relevant variables. Some specific suggestions for further research to correct this deficiency have already been made. Others will undoubtedly develop from this and other overviews of available studies. In general, their effectiveness will be judged by a two-fold criterion: not only must they be theoretically interesting; they must also be relevant to policy makers who are responsible for raising up a new generation of productive researchers.

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