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Human Learning and Individual Differences: the genetic dimension

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ABSTRACT It is argued in this paper that from the point of view of education, individual differences in both temperament and intelligence are of the utmost importance, and that their disregard must account for a good deal of the unsatisfactory state of modern education. Bright and dull children, introverted and extraverted children, stable and unstable children react in quite different ways to different methods of education and teaching and, unless these differences are taken into account, overall averages are meaningless and often hide the true effects of any given method or system. It is further argued that genetic factors exert a very strong effect on individual differences in temperament and intelligence and that these genetic differences are fundamental for any realistic improvements in educational methodology.

(1) Introduction

Psychologists, educationalists and politicians tend to be rather impatient with the concept of individual differences because it obviously makes their task of finding answers to specific problems much more difficult. If all human beings thought alike, behaved alike and indeed, were alike, how much easier would experimental psychology, educational practice and the government of human beings be! The wish is often translated into practice, and in many ways psychologists, educators and politicians behave as if human beings were in fact all alike. Looking through dozens of volumes of the Journal of Experimental Psychology, or the Quarterly Journal of Experimental Psychology showed that in almost every case experimenters left out of account individual differences in temperament and ability, and conducted their analyses as if they had been dealing with a set of monozygotic twins. Much the same was found to be true when journals of social psychology, industrial psychology and educational psychology were studied; mention

of in-dividual differences was infrequent and set experiments were usually conducted without taking such differences into account.

One obvious consequence of these practices is the increasing size of the error variance and the small size of main effects; in addition, there is a lack of replicability in many psychological studies which is truly frightening. The reason, of course, is that much of the variance that goes into the error term could be rescued by the inclusion of personality measures in the design and execution of the experiment. Interaction between personality and independent variables often accounts for a much larger proportion of the variance than the main effects by themselves and this interaction variance boosts the error term when no measures of personality are used. I have discussed this problem at great length (Eysenck, 1981), and will not do so again here, except to point out the absolute necessity of taking into account individual differences in whatever area of psychology we may be working and whatever psychological problems we may be addressing.

Individual differences in personality may be conveniently divided into two great groups, namely those relating to *temperament*, using this term to encompass all the non-cognitive aspects of behaviour and those pertaining to *ability*, using this term to denote all the cognitive aspects involved in human behaviour. Both temperament and ability are involved in human learning and hence, educators should be familiar with psychological knowledge concerning the relevance of these variables. Few psychologists would doubt the importance of abilities in this context (Cronbach & Snow, 1977; Estes, 1982) and I will not make any effort here to document the point.

(2) Learning and Temperament

The relevance of temperamental variables such as extraversion-introversion and neuroticism-stability may be less widely known; I have reviewed the field elsewhere (Eysenck, 1978), and will only mention a few typical studies here to illustrate the point.

Let us consider the effectiveness of the so-called 'discovery' method, as compared with traditional direct instruction. Such comparisons as have been carried out to study the relative superiority of the one or the other have usually failed to disclose any marked differences. Leith (1974) examined the possibility "that the greater readiness of extraverts to become bored by routines but likely to respond to stimulus variation, and of introverts to be disturbed by changes of set but able to maintain attentiveness to a highly-prompted task, would result in a methods \times personality interaction". Two hundred students took part in the experiment, which involved teaching materials for a course in genetics (for naive students). They were tested one week, and again five weeks, after the end of the course with a series of largely transfer items. Non-anxious subjects were better learners than anxious subjects but the major finding was a highly significant interaction effect between personality and method. On both testing occasions introverts and extraverts learned equally well on the average; thus there is no overall superiority of one method over the other. But extraverts performed much better than introverts with the discovery method, while introverts learned much better than extraverts with the direct teaching ('reception') method. Some of the differences observed amounted to something like 90% superiority; this is a tremendous difference. This experiment illustrates very clearly the danger of comparing different methods of teaching without measuring temperament at the same time and looking for different reactions of different personality types to the methods of teaching under examination.

As another example, consider a study in which Leith & Trown (1970) studied the optimal placing of rules in school learning tasks. The learning task was a programme on vectors from which rules were extracted and given either before or after sections of the programme containing practice examples. In general, the evidence favoured superiority of rules following practice, but there was also a significant interaction with personality. Both post- and transfer-tests showed that this occurred because the 'rules before' was significantly poorer than the 'rules after' condition for extraverts of both above and below average ability, while there was no significant differences between the treatments for introverts. Thus the treatment affects the extraverts but not the introverts.

Another area which shows marked personality interaction phenomena is that of paired learning, i.e. learning in a situation where two learners are paired with each other. Consider first the study by Leith (1974) in which pairing was on the basis of anxiety/neuroticism, pairs being either similar on scores on this variable or opposite, i.e. one anxious, the other stable. Quite extraordinary improvements over the 'same' pairings were shown by the 'unlike' pairings. Opposite anxiety pairs showed something like a one hundred percent superiority over same anxiety pairs on the transfer test. Scores were also obtained for extraversion-introversion pairings. When working individually, introverts were significantly superior; this superiority vanished when the students worked in pairs. Homogeneous pairs here worked better than heterogeneous pairs, regardless of whether the pair was made up of two extraverts or two introverts. These results open up fascinating vistas of both research and educational practice.

Another experiment by Trown & Leith (1975) illustrates differential ways of dealing with anxiety. Almost 500 boys and girls took part in the experiment, which contrasted the effects of 'supportive'/'explorative' strategies in mathematics teaching in four junior schools, the mean age of the children being 10 years and 6 months. "In the case of the supportive strategy, the sequence employed, over each of the 12 sections of learning material, was that of teacher-provided statement and of organising principle, followed by related pupil activity with mathematical models and subsequent restatement of principle by the teacher. Such statements were both spoken and written on the blackboard. The same activities with models were used in the exploratory strategy but this time at the beginning of each section of the learning sequence. Each statement of principle by the teacher was now delayed until pupils had been given the opportunity to perceive the relationships themselves, and had been encouraged to attempt an appropriate generalisation".

Anxiety level distinguished between those who were able to profit greatly from the learner-centred exploratory approach and those whom it clearly handicapped, with high anxiety pupils showing the handicap. The teacher-centred supportive strategy, on the other hand, was almost equally effective at each level of anxiety. Overall differences between strategies, i.e. neglecting the temperamental interaction, were minimal; thus neglect of the personality dimension would have led to the quite erroneous conclusion that strategies were identical in their effects. The results of the experiment, as the authors emphasise, are very germane to an evaluation of the Nuffield mathematics scheme, suggesting that this may improve the performance of some (non-anxious) children and make worse the performance of other (anxious) children. Such a conclusion cannot, of course, be based on the results of a single experiment, and cannot be extrapolated to other subjects, but it does suggest the importance of proper experimental investigation of interaction effects.

As a final example, consider a study by McCord & Wakefield (1981) who tested

the hypothesis that the arithmetic achievement of extraverts would be better than that of introverts in those classrooms in which teacher-presented rewards predominated, while the arithmetic achievement of introverts would be better than that of extraverts in those classrooms in which teacher-presented punishment predominated. Five classrooms were rank-ordered according to the ratios of teacher-presented reward to teacher-presented punishment, and a total of 101 fourth and fifth grade students from the five classrooms were then administered the Junior Eysenck Personality Questionnaire and an arithmetic pretest. Forty school days later, the students were administered the arithmetic posttest. The results very significantly supported the hypothesis and additional analyses indicated the presence of other interactions involving the P and N scales of the J.E.P.Q. with reward-punishment.

Two things should be noted. The first is that these are not accidental and purely pragmatic findings; all the observed effects of temperamental variables were in fact predicted on the basis of personality theory and all were highly significant in the predicted direction. This means that we now have a nomological network which embraces both personality variables and educational practices and enables us to design our methods of teaching in accordance with specific rules developed on the basis of personality theory (Wakefield, 1979). The other point to be noted, a consequence of the first, is that our instruction of teachers should now include, quite prominently, facts about children's personality, their development, their measurement, and their interaction with learning and school achievement. Such knowledge could of course only be of practical importance if repeated, and preferably annually repeated, personality measurement of children were to be universally introduced in our schools, as surely it should be, complementing similarly repeated annual measurements of the intelligence and special abilities of the children.

So far we have only discussed what might be called applied aspects of the interaction between education and personality, learning and temperament. However, for a real understanding of the relationships we must go down to a more microscopic level and look at the relationship between temperament and laboratory tests of learning, remembering and accessing. It would take us too far to review the vast literature which has accumulated in these fields; an excellent review is available in the book on *Human Memory* by M. W. Eysenck (1977). There seems to be little doubt that retrieval, for instance, is considerably quicker in extraverts than in introverts but that consolidation of the memory trace is stronger in introverts than in extraverts. There are many consequences for classroom teaching which follow from these general findings, and it seems sad that few teachers are taught the facts about the relationship between temperament and learning/memory.

(3) Genetic Factors in Temperament and Ability: principles

We must now turn to the problem of genetic factors in temperament and ability. It is unfortunate that a discussion of these problems is very much impeded by two factors which will probably not be in dispute. The first of these is that behavioural genetics does not normally form part of the training of psychologists or educationalists and that hence their comprehension of the complexity of the subject is not very high. The second point is that political and ideological considerations are often dragged into the debate which are strictly irrelevant to the factual content of the hundreds of experiments that have been conducted in the past. A few words will be said at the end about the social consequences of genetic theories and facts; in our discussion, however, we will try to remain entirely on the factual level. The lack of understanding of genetic principles shown by psychologists and educationalists is made particularly clear when the many misunderstandings of even the very terms used by behavioural geneticists are considered. It will be the task of this section to clarify some of these misunderstandings, and to suggest ways of interpreting the research findings which are more in line with reality. A detailed presentation of the methods, concepts and interpretations of modern behavioural genetics has been given elsewhere (Eysenck, 1979); obviously this brief article cannot go into the necessary details to carry conviction.

We may start by laying to rest a common belief which is quite erroneous, namely that behavioural genetics is concerned exclusively with *heritability*. Behavioural genetics is concerned with apportioning the total variance shown by the phenotype of any particular characteristic, trait or ability into portions attributable to a variety of genetic and environmental causes. One of these is what is called additive genetic variance, which may be defined as the additive action of different gene loci in producing a given effect. The proportion of the total phenotype variance which is produced by the additive genetic variance is called the *narrow heritability*; it is certainly of interest to establish what this may be, but it is far from the be all and end all of behavioural genetics.

In addition to the additive genetic variance there are also various factors of a genetic kind which combine to produce what might be called non-additive genetic variance. One of these is dominance, as opposed to recessivity. Another is epistasis, due to interaction between different gene loci. Last but not least, there is genetic variance due to assortative mating, i.e. the increment in total variance attributable to degree of genetic resemblance between mates on the characteristic in question. Thus the total genetic variance, $V_{\rm G}$ is the sum of four components:

$$V_{\rm G} = V_{\rm A} + V_{\rm D} + V_{\rm Ep} + V_{\rm AM}$$

The phenotypic variance divided by the *total* genetic variance is what is called the *broad heritability* and, unless there is no non-additive genetic variance, the broad heritability will be larger than the narrow heritability. The broad heritability may be symbolised in terms of the equation:

$$h^2 = \frac{V_{\rm G}}{V_{\rm P}}$$

Thus we have a rather complex set of factors on the genetic side; we also have a rather complex of factors on the environmental side. First of all there is additive environmental variance which is independent of the genotype. This in turn may be of two types. One is called within-family environmental variance, the other between-family environmental variance. Between-family environmental variance arises from such differences between families as socio-economic status, parental occupation and education, differential neighbourhood and schooling which distinguishes between families, etc. Within-family environmental variance refers to events which happen to children within the same family, such as having an older or younger brother or sister, falling ill while your brothers and sisters do not fall ill, having a particularly good or bad teacher, etc. These two types of environmental additive variance have to be carefully distinguished and there are methods of assigning weights to them.

Next we have variance due to interaction i.e. non-additive effects of genotypes and environments. This means that different genotypes may respond differently to the same environmental effects. If a particular change in the environment raises the I.Q. of every genotype subjected to it by, say, 10 points, the environmental effect is said to be additive and is the kind of environmental variance we have been talking about in the last paragraph. If, however, on the other hand, some genotypes gain 20 points and some 10 points, while some show no gain at all and some show a loss, the environmental effect is called non-additive (because it does not add the same increment to every individual) and thus the environmental change *interacts* with genotypes to produce different phenotypic effects in different genotypes.

A rather different type of interaction is called the *covariance* of genotypes and environments. This arises when genotypic values and environmental values are correlated in the population. An example would be children with genotypes for high intelligence being reared in homes with superior environmental advantages for intellectual development.

Thus the phenotypic variance, $V_{\rm P}$, may be symbolised as follows:

$$V_{\rm P} = V_{\rm G} + V_{\rm F} + V_{\rm GE} + \text{Cov GE} + V_{\rm c}$$

In this formula V_e is the error variance due to unreliability of measurements. Most formulae for estimating heritability include this error variance on the environmental side, which is strictly speaking inadmissible. What should be done is to measure the amount of genetic and environmental effects on that part of the phenotypic variance which is not subject to error, i.e. the 'true' phenotypic variance. A correction for attenuation is therefore called for and should always be included in estimates of heritability.

(4) Genetic Factors in Temperament and Ability: heritability

A number of consequences follow from our discussion so far. In the first place it will be seen that, contrary to the opinion of most psychologists, behavioural genetics are not concerned particularly with genetic factors, thus forming a natural contrast to the large group of environmental psychologists who have no time for or interest in genetic factors. Behaviour geneticists attempt to estimate the variance due to all factors, genetic, environmental, and interactionist in nature, which determine the total variance of the phenotype. Hence their concern is not segmental, but attempts to cover the whole field. The majority of psychologists, by leaving genetic factors out of consideration completely, take a very narrow and jaundiced view of the phenotype, and hence are unable to formulate any causal hypotheses, or prove or disprove such hypotheses. The position of the behavioural geneticist is not, in fact, at an opposite extreme to that of the environmentalist; it lies precisely in the middle between the extremes occupied by the biotropes and sociotropes, as Boring used to call them, i.e. those who for ideological or other reasons overemphasise biological determination or social determination of conduct respectively. It is suggested that there is in fact no alternative to the kind of programme outlined by the behavioural geneticist if we want to give a complete account of the causes of human behaviour. All the factors mentioned above require to be taken into account and the behavioural geneticists have worked out methods for estimating their relative importance; this is a vital contribution to psychology which is often underestimated.

Another point, which is very important in interpreting published data, is the following. At first sight it may seem odd, unusual and perhaps upsetting to find that different authors give different estimates of heritability of a given characteristic, say I.Q. Thus estimates may vary from something like 50% to something like 80% and most people will feel that our knowledge cannot be very secure if such diversity can still exist. However, such a view would neglect the fact that different authors may

talk about different heritabilities. Let us take a given study in which the narrow heritability is 60%, the broad heritability 70% and the broad heritability corrected for attenuation is 80%. Any of these values might be quoted by the author, depending on his intention and on the particular interpretation of the data he is interested in. To the expert reader it will be clear which type of heritability the author is referring to and whether he has corrected for attenuation or not; hence no difficulty arises, but for the uninformed reader there are considerable problems, particularly if he does not understand the existence of different definitions of heritability. The position is worsened when we are dealing with a comparison of several different studies, with one author quoting the narrow heritability, another the broad heritability uncorrected and a third the broad heritability, corrected. Add to this the inevitable chance errors which might increase or depress the estimate by between 5 and 10 points and we see immediately that we may find a wide variety of estimates which, however, may be reduced to a considerable degree of uniformity by agreeing on the particular type of heritability we are discussing. In what follows we will be concerned mainly with the corrected broad heritability and, where findings are dealt with where authors have calculated other types of heritability, then necessary corrections will be made.

There are other reasons for finding that different authors may come up with different heritabilities. They may have used different types of I.Q. tests and undoubtedly some are more subject to environmental determination than others; tests of fluid ability, to use Cattell's terminology, may be less subject to such influences than are tests of crystallised ability, for instance. Different I.Q. tests certainly differ in test-retest reliability and unless the observed heritability is corrected for attenuation, this will by itself produce considerable differences in the results. The populations tested will differ in many respects, such as range of I.Q. within the population tested, or even the variety of environmental effects shown. Thus American samples may show a greater variety of environmental effects than British samples, where conditions are much more homogeneous; this would lead to a greater degree of heritability in the British than in the American population. Recent studies in the U.S.S.R., Poland and the DDR (East Germany) have shown heritabilities which are perhaps in excess of those found in capitalist countries. This may be due to the allegedly greater degree of social equality found in communist countries. Thus differences in heritability are to be expected when we are comparing different countries, or different populations within the same country, and do not argue against the value or importance of heritability estimates.

These considerations lead up to the very important generalisation that heritability estimates are *population parameters*; they pertain to a given population, tested at a given time, and cannot necessarily be extended to other populations, at other times. Because the average height of English males is 5 ft 10 in, we cannot argue that this is a universal truth. English males 200 years ago were certainly shorter than this, and American males are probably taller at the moment. Heritability estimates have no universal validity, but pertain to given groups only; this is an absolutely vital aspect of behavioural genetics which is frequently misunderstood.

Equally, it will be clear that heritability estimates, being population parameters, do not apply to individuals, but only to populations. Thus it would be meaningless to say that a given individual's I.Q. is determined to the extent of 80% by heredity and 20% by environment. Behaviour genetics deals with variances and hence with populations; it does not deal with the individual case.

The lack of understanding of this fundamental fact is shown most strongly by a

criticism made by a former President of the American Psychological Association, and widely quoted in many psychological textbooks. What was suggested was that the attempt to estimate the relative importance of heredity and environment was as absurd as to try and estimate whether the length or the width of a given field was more important. Clearly it is impossible to make such an estimate, but then of course there is no variance attaching to a given field, which does not form a population. Hence the whole example is quite irrelevant to a discussion of behavioural genetics. If we postulate a population of 1000 fields say, differing in length and width, and thus in area, then we could soon calculate the relative importance of length and width in producing the 'genotypic' differences between fields as far as area is concerned.

Another idea which is very common, but completely false, is the notion that because a trait or an ability is largely determined by genetic factors, therefore it is in some way fixed and immutable. This does not follow at all, as will be obvious if we take the character of heritability as a population parameter seriously. To take a somewhat extravagant example; at the present moment the size, shape and consistency of the female breast is determined very largely by genetic factors. However, in recent years we have acquired techniques of plastic surgery, silicone injection and hormonal treatment, all of which considerably enlarge the environmental effects we can bring to bear in this field. It is by no means Utopian to suggest that in 50 years time a behavioural genetical study of the size, shape and consistency of the female breast in California will show that genetic factors play almost no part at all in producing differences in the phenotype.

The same considerations would undoubtedly apply to temperament and ability, the difference being that we have not in fact succeeded very well in discovering methods of affecting the phenotype favourably. However, there are straws in the wind which, if taken seriously, might lead us to a better understanding of the factors involved. Thus there is evidence that glutamic acid may increase I.Q., particularly of dull children (and rats!); it seems that there may be an improvement of learning ability due to the facilitatory effect of glutamic acid upon certain metabolic processes underlying neural activity (Zimmerman et al., 1949). It is well known that glutamic acid is important in the synthesis of acetylcholine, a chemical substance necessary for the production of various electrical changes occurring during neural transmission and the rate of acetylcholine formation has been shown to be increased four to five times by adding glutamic acid to a dialysed extract of brain. Furthermore, it is known that the concentration of this acid in the brain is disproportionately high, as compared with the concentration of other amino acids or with its concentration in other body tissues. Also, of all the amino acids, glutamic acid alone is capable of serving as a respiratory substrate of the brain in lieu of glucose. This further points to the involvement of glutamic in neural functions.

Hughes & Zubek (1956) postulate that the cerebral metabolism in the dull may be defective in some way, while that of the bright is normal; then glutamic acid might facilitate or improve the defective cerebral metabolism of the dull, while having no particular effect on the normal metabolism of the bright. This is not an ad hoc hypothesis because the relationship between cerebral metabolism and mental functioning has been demonstrated by Himwich & Fazekas (1940). A more detailed discussion of the evidence, taking into account many recent papers, is given by Weiss (1982).

An interesting example of how metabolic effects can be taken into account and used in manipulating what are in effect genetically transmitted intellectual disorders is work on phenylketonuria. This is a disorder caused by a single autosomal recessive gene which produces oligophrenia in children so afflicted, whose I.Q. is about half that of other children of their own age. Here we would seem to have a mental defect clearly attributable to a single gene and hence apparently completely 'fixed'. However, closer attention to the actual processes which are inherited suggests that what is involved is a disorder of the metabolic processes involving the incomplete absorption of phenylanaline, which, not properly broken down, becomes toxic. This toxic effect, which produces the I.Q. deficit, can be avoided by giving the child an analine-free diet and this is fortunately possible. When this is done, the child grows up with a normal I.Q. Thus, by first isolating the genetic effect and then demonstrating its precise nature, it is possible to change the environmental influences in such a way as to avoid the genetic effect altogether.

It is interesting to ask why the observed effects of glutamic acid have not led to a much more intensive research effort and why it is not being used in mental defective institutions and in attempting to increase the I.Q. of dull children. The answer seems to be that ideological preconceptions have made this impossible; psychologists and politicians are at one in disregarding genetic effects and biological causes, in favour of educational and social factors. Thus hundreds of millions of dollars and pounds are spent on attempts to 'improve' educational facilities although it is known that the effects are at best ephemeral and at worst non-existent, while no money at all is devoted to investigation of genetic and biological factors, although here the prospects are very much brighter.

We must now turn to another frequent misunderstanding of the genetic case, relating this time to the actual possibility of environmental intervention. We will argue below that something like 80% of the total phenotypic variance in I.Q. testing is due to genetic causes and 20% to environmental causes when we have eliminated measurement errors through correction for attenuation. To most people this suggests an almost complete absence of environmental effects, but this is a completely erroneous interpretation. It must always be remembered that variances are squared S.D.s, and that hence we should use square roots of variance estimates in order to arrive at more directly interpretable estimates of genetic and environmental effects. John Carroll (personal communication) has made some estimates of possible gains in I.Q. units (σ =17), when different improvements in environment are made. On the assumption of a broad heritability of 0.80 and assuming perfect reliability of the trait measurement he shows that, if we assume a scale of environmental advantages ranging around the mean of the population, then an improvement in the child's environmental advantage by one standard deviation will add 8 points to his I.Q., an improvement of two standard deviations will add an improvement of 15 points, one of three standard deviations an improvement of 23 points, an improvement of four standard deviations will add 30 points of I.Q., an improvement of five standard deviations will add an improvement of 38 points of I.Q. and one of six standard deviations will add an improvement of 46 points of I.Q. Of course there are very few children three standard deviations below the mean as far as environmental advantages are concerned and it would be an almost impossible task to change environment in such a way as to transform it into one 3 S.D.s above the mean. However, changes of 2 or even 3 S.D.s might be feasible and hence we might say that under very favourable circumstances we might effect an improvement in the I.Q. of very environmentally handicapped and retarded children of something like 20 points; this is a considerable amount, and certainly worth having. This calculation will also demonstrate immediately how wrong are those who argue that because geneticists

assess the broad (corrected) heritability at something like 80%, therefore they must also believe that it is useless to undertake any improvements in environmental conditions. This clearly is not so; all possible improvement that can be made should be made in the environmental conditions under which children are brought up and taught and considerable gains can be made even though differences in I.Q. are largely inherited. Only ideological blindness can misinterpret the effects so as to suggest therapeutic nihilism as a consequence of genetic determination of individual differences.

(5) Genetic Factors in Temperament and Ability: method

How do behaviour geneticists in fact conduct their investigation in order to get some firm grip on the quantitative estimation of the varied portions of the variance in which they are interested? Most psychologists will think of twin studies and adoption studies, but there are many more types of investigation which can be carried out in this connection, all of which give us information very important for a consideration of this problem. A much more detailed account is given elsewhere (Eysenck, 1979), and the list given here is by no means exhaustive; it does, however, list the major methods used.

In the first place, we have studies of identical twins brought up in separation. Here the calculations are relatively simple, because any departure from a perfect correlation between twins must be due to environmental factors. (Measurement errors must of course be corrected for.) Several studies (excluding those of Cyril Burt, which have been suggested to include invented data) average around 0.75 where no correction is made for attenuation, but the corrected figure of about 0.82 is probably too high because identical twins brought up in separation are usually found to grow up in families of similar socio-economic status. This does not make much difference, as can be shown by the fact that cousins, who also tend to grow up in families of similar socio-economic status, show correlations of only about 0.15, but a suitable correction should be made. When this is done the best estimate is around 80% for the broad heritability.

The second method widely used is a comparison between monozygotic and dizygotic twins, where MZ twins would be expected to be more similar than DZ twins if genetic factors are important. This has been found pretty universally to be so, with MZ twins being almost twice as similar with respect to I.Q. as DZ twins. It has often been suggested in criticism that perhaps MZ twins are treated more alike by parents and teachers, and this is certainly true. However, it has to be demonstrated that the ways in which they are treated alike (dressing alike, etc.) has any relevance to the development of intellectual abilities. Loehlin & Nichols (1976) carried out a special experiment on 850 sets of twins, trying to see whether the factor of being treated alike had any influence on the similarity between the twins with respect to temperament and ability; their finding was that there was no such influence at all, thus disproving this criticism.

We next come to familial resemblance. This simply means that two people should be more similar with respect to I.Q. and temperament the greater their degree of consanguinity. In other words, parents and children or siblings should be more similar with respect to personality than should uncles and nieces or cousins. Indeed, it is possible to predict the degree of resemblance that would be expected between any relatives on the basis of genetic theory and the observed figures come very close to the predicted ones on the hypothesis of something like 80% genetic determination of individual differences.

A fourth method of investigation is that of adopted children, where clearly the genetic background is provided by the biological parents, the environment by the adoptive parents. The universal finding has been that children are more like their biological parents than their adoptive parents and oddly enough the similarity to the natural parents seems to increase the longer the child is with the adoptive parents. It has been noted in criticism that the placement of children for adoption is not random, so that children of middle class parents are likely to be adopted by middle class adoptive parents. Insofar as this does occur, it would seem to increase the apparent influence of environmental factors and thus lead to a very conservative estimate of heritability; if indeed the children of middle class parents are adopted by middle class parents, then this alone will increase the correlation between the child's I.Q. and that of his adoptive parents, thus giving an unduly high estimate of their similarity.

The fifth method to be discussed is that of regression to the mean. Many people have an entirely wrong notion of what is implied in heritability, even when this is fairly high. They have in mind something like Fig. 1, where the very dull parents (at the top) have very dull children (at the bottom), very bright parents have very bright children, etc.; this suggests a very direct degree of I.Q. consistency between generations, but genetically the picture is quite false. What we have, instead, is a tendency for the children of very bright parents to be less bright than the parents, i.e. to regress to the mean, with the children of very dull parents similarly regressing to the mean, in the opposite direction. What happens is shown in Fig. 2, where it will be seen that of the four children of very dull parents, one is very dull, two are dull and one is average. Similarly of the four children of very bright parents, one is very bright, two are bright, and one is average. Of the children of average parents, one is very bright, six are bright, ten are average, six are dull and one is very dull. Thus the merry dance of the chromosomes produces regression effects which are directly responsible for the social mobility so clearly observable in all non-caste societies. Unless preserved by force, I.Q. advantages and social advantages associated with them will be lost in something like five generations.

It is sometimes suggested that regression effects are merely statistical, but they do have a very meaningful genetic cause. Consider Fig. 3, which shows matings of two types of parents where the children on the average will either regress downwards to the mean, or regress upwards. Only one set of alleles is shown, with A denoting dominant high intelligence, and a denoting recessive low intelligence. The meeting of two Aa parents, i.e. of parents who are phenotypically bright will result in children one quarter of whom are phenotypically dull (aa); hence the mean of the children's I.Q. will be lower than that of the parents, and will have regressed to the mean.

For the other set of parents (AA and aa), these will on the average be rather dull, because the recessive genotype is represented in the phenotype (aa). However, all the children show the combination Aa, and hence all are phenotypically bright; hence their mean I.Q. will be higher than that of the parents, and they will have regressed to the mean in the upward direction. Thus the statistical effects find an explanation in Mendelian theory.

It has been suggested above that intelligence is transmitted by means of genes which show dominance and recessivity. The evidence for this is found in two types of investigations, which are really one the reverse of the other. If relatives produce



FIG. 1. Diagram illustrating erroneous view of relationship between parental and filial I.Q.

children, as in father-daughter or brother-sister matings, or in the marriage between cousins, it is expected that the children will have lower I.Q.s than they would if their parents had not been related. This is called *inbreeding depression*, and is caused by the fact that in relatives recessive genes are more likely to appear at the same gene loci and hence to find expression in the phenotype. There is ample evidence from several large-scale studies that this is indeed so, as far as cousin marriages are concerned, and the effects are known to be disastrous when the relationship is even closer, as in father-daughter or brother-sister matings.

The opposite effect is seen in what is called *heterosis*, or hybrid vigour. Here we have matings between members of different races, and hence the likelihood of finding recessive genes at the same loci is less even than it would be in unrelated members of the same race. There is good evidence for heterosis of this kind to occur and the effects are just about what one would expect from a consideration of the effects of inbreeding depression.

These are the main types of investigation that have been done but in addition, of course, one can look for direct evidence for such factors as assortative mating. Many studies have been reported in which the intelligence of husbands and wives has been measured and correlated, with the effect that in typical European or Northern American marriages correlations of 0.5 to 0.6 are frequent, and these measures enable us to obtain a reasonable estimate of the true relationship. The causes of assortative mating are not known, of course; it may be that like attracts like, or it may simply be that people meet their marriage partners in the kind of society in which they live, so that university students are more likely to meet university



FIG. 2. Diagram illustrating correct view of relationship between parental and filial I.Q.

Regression to the mean Aa Aa Parents : AA Aa Aa Children: aa AΑ Parents : aa Aa Aa Αa Aa Children:

FIG. 3. Genetic basis of regression to the mean.

students of the other sex, and hence marry them not because they are of equal intelligence, but because they happen to be available. However that may be, the fact of assortative mating is undoubted, and one of its effects is to increase the standard deviation of I.Q. in the next generation. Advocates of biological equality can serve their aim by insisting that bright males should marry dull females and vice versa; inverse assortative mating would lead to a narrowing of the range of I.Q. in the next generation.

(6) Genetic Factors in Temperament and Ability: results

It is possible to make numerical estimates from all these different methods of investigation and what is most impressive is that these estimates tend to agree very closely, suggesting a heritability, corrected for attenuation, of approximately 0.80 (for the broad heritability), and of 0.70 (for the narrow heritability). Both assortative mating and dominance form part of the non-additive genetic variance but it is doubtful if epistasis is an important factor. On the environmental side, betweenfamily environmental variance is approximately twice as important as within-family environmental variance, as one might have expected. These figures, of course, only apply to the populations which have been studied, i.e. European, North American and Western communist countries; whether they would apply to native African or Asian populations it is impossible to say. Neither should it be assumed that these figures would apply to Western Europeans or North Americans 200 years ago or 200 years hence.

The genetic architecture as far as temperament is concerned is in part similar to and in part different from that of ability. There is, contrary to received opinion, a very strong additive genetic component, nearly as strong (when corrected for attenuation) as that which appears in the analysis of ability. However, there is little or no evidence for assortative mating, and none for dominance. At first sight the failure of dominance to appear may seem surprising, as such factors as neuroticism and psychoticism might seem to be harmful from an evolutionary point of view, and factors which show "fitness" tend to develop along lines of dominance and recessiveness. However, it might be argued that as far as neuroticism is concerned *lack* of fearfulness and conditioned anxiety might, over the lengthy period of development of the human species, have been as harmful as exaggerated fearfulness, leaving a middle position as the most advantageous from the evolutionary point of view. As regards psychoticism, we will devote a whole section of this paper to a discussion of possible advantages possessed by high P scorers. Extraversion-introversion does not need much discussion, as there is no obvious advantage to either high E or low E, respectively.

On the environmental side, there is also a marked difference between temperament and ability, in that for temperament within-family factors seem all-important, whereas, as we have seen, for ability, between-family environmental factors are twice as important as within-family environmental factors. This is not only surprising, but it also has far-reaching effects on the theory of personality development. Most accepted personality and psychiatric theories, including those of Freud, Laing, etc. postulate as causes of abnormal personality development the behaviour and influence of the parents, the 'ice-box mother', 'double-bind' occurring in given families, etc. These are all between-family environmental effects and as such are ruled out by the genetic analysis. Personality theorists do not usually look at genetic analyses as providing evidence for psychological theories but it is difficult to see why such evidence should be disregarded.

Why is it that for such a long time it has been assumed and argued in most textbooks of psychology and personality, that genetic factors are relatively unimportant as far as temperament is concerned? There are several reasons for this. In the first place, genetic studies require large numbers in order to give decisive evidence for or against the applicability of a given model and it is only in recent years that large numbers of twins or other consanguinity groups have been employed in this connection. In the second place, it is only in recent years that proper methods of analysis have become available and have been widely used in studies of this kind. In the third place, the earlier studies were very much handicapped by the lack of measuring devices; there is no doubt that the tests used in the famous study by Newmann *et al.* (1937) had little validity and also little reliability. Furthermore, the tests were explicitly designed for adults, but were given to a group with a mean age of about 13, including children as young as 8. Even in that study the only test which would now be considered acceptable (a neuroticism questionnaire) gave results indicative of quite strong genetic influence; these results were misinterpreted and disregarded by the authors. Modern theories of personality (Eysenck, 1981) give us a much wider choice of good and acceptable personality tests for the purpose of studying the influence of genetic factors.

(7) Temperament and Ability: originality and creativity

We have so far treated temperament and ability as quite separate, but of course there are relations between the two (Baron, 1982). While the most interesting of these is the relationship between personality and what has become known as 'divergent thinking', i.e. the area of originality and creativity. This is often considered to be part of the ability rather than the temperament area but it is doubtful whether this is a proper allocation; Spearman (1927) has already suggested that what was then called 'fluency' was an expression of extraversion, rather than a separate type of ability, and there is much evidence for this view (Eysenck, 1977). Fluency is part of the syndrome of 'divergent thinking', but it deals more with the production of responses rather than their originality; the proper correlate of originality would seem to be P (psychoticism), as pointed out by Eysenck & Eysenck (1976). This hypothesis was based on a good deal of psychiatric research.

Some of this work took its origin from the widely held hypothesis that genius and madness may be closely allied. This common observation suggests that people who are highly original and creative may differ from the ordinary run of people by showing personality qualities often associated with schizophrenics and other psychotics. A number of genetic studies have indeed supported such a view. Heston (1966) studied offspring of schizophrenic mothers raised by foster-parents and found that although about half showed psychosocial disability, the remaining half were notably successful adults, possessing artistic talents and demonstrating imaginative adaptations to life to a degree not found in the control group. Karlsson (1968, 1970) in Iceland found that among relatives of schizophrenics there was a high incidence of individuals of great creative achievement. McNeil (1971) studied the occurrence of mental illness in highly creative adopted children and their biological parents, discovering that the mental illness rates in the adoptees and in their biological parents were positively and significantly related to the creativity level of the adoptees. Findings such as these clearly support speculations, such as those by Hammer & Zubin (1968) and by Jarvik & Chadwick (1973), to the effect that there is a common genetic basis for great potential and for psychopathological deviation.

Assuming for the moment that the P scale does measure, at least to some extent, the essence of the continuum from normality to psychosis and assuming for the moment that the hypothesis linking creativity and originality with mental abnormality possesses some virtue, then we should be able to test this hypothesis in a variety of ways. It was first tested, in an unpublished study referred to by Eysenck & Eysenck (1976), by D. W. Kidner.

He administered several of the Wallach & Kogan (1965) tests of originality to male and female students, nurses and teachers, and found significant relationships between originality and creativity, on the one hand, and high P scores on the other. He also found that 'acceptance of culture', i.e. agreement with cultural mores, was negatively correlated with P and also with creativity and originality.

Other studies more marginally relevant to the hypothesis under investigation are reported in the book by Eysenck & Eysenck (1976), but we will turn now rather to a more recent study by Woody & Claridge (1977) which is particularly impressive.

The subjects of their study were 100 university students at Oxford, both undergraduate and graduate. The students constituted a wide sampling of the various fields of specialisation at the university. They chose students as their subjects because of evidence that creativity is significantly related to I.Q., up to about I.Q. 120, but that it becomes independent of I.Q. above this level (Canter, 1973). The tests used by them were the EPQ (Eysenck & Eysenck, 1975) and the Wallach-Kogan Creativity Tests, somewhat modified and making up five different tasks (instances, pattern meanings, uses, similarities and line meanings). Each task was evaluated in terms of two related variables: the number of unique responses produced by the subject, and the total number of responses produced by the subject.

The Pearson product moment correlation coefficients between psychoticism and creativity scores for the five tests are as follows. P with number of unique responses scores: Instances = 0.32; Pattern Meanings = 0.37; Uses = 0.45; Similarities = 0.36; Line Meanings = 0.38. P with uniqueness scores: 0.61, 0.64, 0.66, 0.68, 0.65. It will be seen that all the correlations are positive and significant and those with the uniqueness score (which is of course the more relevant of the two) are all between 0.6 and 0.7. These values are quite exceptionally high for correlations between what is supposed to be a cognitive measure and a test of a personality trait, particularly when general intelligence has effectively been partialled out from the correlations through the selection of subjects. There were effectively no significant correlations between E and N, on the one hand, and creativity on the other. It is interesting to note, however, that the L score of the personality questionnaire, which up to a point is a measure of social conformity, showed throughout *negative* correlations with creativity scores, seven out of ten being statistically significant. L is known to correlate negatively with P (Eysenck & Eysenck, 1976).

Studies not using the P scale have come up with traits of 'creative' persons not dissimilar to those characteristic of the high P scorer. Getzels & Jackson (1962) found that 'divergers' were unconventional and independent of judgment (see also Torrance, 1962). Hudson (1966, 1968) also noted the conformity of the converger, and the rebelliousness of and failure to 'fit in' of the diverger.

It might be said in criticism of the studies so far reviewed, that they deal with psychological tests of creativity and originality in normal and not very distinguished people, and that what is normally understood by originality and creativity demands something more than that. The objection is a reasonable one, although it should not be taken to infirm the remarkable success achieved by Woody & Claridge's empirical testing of the hypothesis linking P and creativity. The only study of what most lay people would consider genuine creativity has been reported by Götz & Götz (1979a, b). Their work significantly extends that of other investigators who tried to link creativity in the arts with personality (e.g. Csikszentmihalyi & Getzels, 1973; Barron, 1972; Eysenck, 1972; Eysenck & Castle, 1970; and Drevdahl, 1956). Some of these studies are difficult to interpret, but we may note that Eysenck (1972) and Eysenck & Castle (1970) found that art students were significantly more introverted and neurotic than non-art students. Götz & Götz (1973) pointed out in criticism that art students in general may not be particularly creative, but when a group of highly gifted art students were compared with less gifted and ungifted subjects, they found that the highly gifted students also had low scores on extraversion and high scores on neuroticism.

In the study under review Götz & Götz (1979a, b) administered the EPQ to 337 professional artists living in West Germany, of whom 147 male and 110 female artists returned the questionnaire; their mean age was 47 years. One outstanding result of this work was that male artists were significantly more introverted and significantly more neurotic than non-artists, while for females there was no difference on either of these dimensions. As the authors suggest, it is perhaps true that in our Western World it is mainly women with average or higher scores on extraversion who have the courage to become artists while the more introverted and possibly more artistically gifted women do not dare to enter the precarious career of the artist. We must now turn to scores on psychoticism. Here the results are very clear; male artists have much higher P scores than male non-artists and female artists have much higher P scores than female non-artists. As Götz & Götz point out, these results suggest that certainly many artists may be more tough-minded than nonartists. "Some traits mentioned by Eysenck & Eysenck may also be typical for artists, as for instance they are often solitary, troublesome and aggressive, and they like odd and unusual things" (p. 332).

The work of Götz & Götz (1979a, b) thus offers important support for the results of Woody and Claridge, and the other authors cited above, in that this more recent work uses actual artistic achievement as a criterion for the measurement of creativity and originality. In doing so they give credence to the validity of divergent thinking tests as measures of creativity and originality and the fact that, both in the artistic and in the non-artistic populations studied by other investigators significant correlations are found between psychoticism and creativity and originality, very much strengthens the hypothetical link between the personality trait and the behavioural pattern. We may thus be justified in concluding that originality and creativity are the outcome of certain personality traits, rather than being cognitive variables or abilities. This is an important conclusion which is somewhat in contrast with assumptions usually made in this field.

The Götz & Götz study is the only one which actually used the Psychoticism scale, but other studies implicated traits in creative people which are clearly part of the P syndrome. Thus work of the Institute for Personality Assessment and Research at Berkeley, under the direction of MacKinnon (1962), was concerned with creativity in architects, writers and mathematicians. As described by MacKinnon *et al.* (1961) and Barron (1969), creative people showed traits of individualism and independence, lack of social conformity, unconventionality, and lack of suggestibility (Crutchfield, 1962); they were also below par in sociability and self control. Responses on tests like word association were odd and unusual, almost like those of schizophrenics.

Most important, the creative group studied by the I.P.A.R. group consistently showed greater psychopathology on the Minnesota Multiphasic Personality Inventory depression, hypochondriasis, hysteria, psychopathy and paranoia scales than did the controls. Lytton (1971) concludes that: "It is difficult... to deny that there is more than a chance association between psychiatric difficulties and creative powers" (p. 63). This psychopathology is countered, however, by greater 'ego-strength', as also shown on the MMPI scales.

The position of Introversion and Neuroticism in the creativity field needs a little further discussion. Introversion seems to be implicated both for artists and for scientists (Götz & Götz, 1979a, b; Cattell & Drevdahl, 1955; Roe, 1952, 1953; Andreani & Orio, 1972), although perhaps more for scientists than for artists (Hudson, 1966). Neuroticism, however, is clearly more associated with the arts than the sciences (Wankowski, 1973; Eysenck, 1978). It is unfortunate that most empirical studies have used interviewing techniques and tests which do not always enable the reader to make clear distinctions between P, E and N; the use of standard tests like the EPQ would seem to make strict comparisons between studies possible, in a way that the random use of different inventories does not. Nevertheless, the major trends are unmistakeable.

(8) Conclusions

Many conclusions would seem to follow from the fact that genetic factors play an important part in determining differences in temperament and ability between children, as far as their education is concerned. It is possible to argue about some of these, depending on one's social values and political beliefs; one conclusion, however, seems to me to be inescapable and that is that prospective teachers, and even more lecturers in educational colleges, etc., should be thoroughly familiar with the facts outlined in this article, as well as with the general theory of intelligence and personality (Eysenck, 1981, 1982). At present it cannot be said that there is an adequate degree of teaching or understanding of the problems, methods, and results of work in this field among teachers or educationalists generally. This makes impossible the application of such knowledge to the teaching process and hence renders abortive the full use of knowledge acquired over the years. Education is, and always must be, an applied science and if the practitioners are ignorant of the results of scientific research, clearly it must remain in a suboptimal state of development.

In particular I would suggest that it is now possible to make full use of regular tests of temperament and ability in the classroom. Such tests should be carried out regularly once a year and should give information on the major dimensions of temperament, as well as on general ability and the various special abilities which are of interest in education, such as verbal ability, numerical ability, visuo-spatial ability, etc. Each pupil should be accompanied through his school career by a folder containing the results of these yearly tests, to show not only his standing on these various dimensions, but also his development, possible incongruities and even possible errors in testing, etc. Such a folder could be of invaluable importance in guiding him towards areas of prospective excellence, helping him to overcome temperamental and other difficulties and guiding him and teaching him in the optimal manner possible. Without proper training teachers would, of course, not be able to make full use of this information or even to administer and score the tests properly; without the information provided by the tests, even well-informed teachers would be unable to gain sufficient knowledge of the temperament and abilities of their pupils to apply such knowledge as they might have.

My major conclusion would, therefore, be that we now have far more information in these fields than we had even a few years ago and that teachers who are ignorant of these facts lack an essential degree of knowledge important for their work. It can hardly be said that the results of our system of education are so outstanding that no improvement is possible; here is an area where knowledge now exists to make possible such improvements on a very large scale. Obviously this should be accompanied by further detailed research of a practical and applied kind, such as that referred to above in the work of Leith, Wakefield and others. However, enough is already known to make ignorance of these developments on the part of teachers a crime against the rightful demands of their pupils.

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REFERENCES

- ANDREANI, O. & ORIO, S. (1972) Le Radici Psicologiche del Talento (Bologna, Societa Editrice il Mulino). BARON, J. (1982) Personality and intelligence, in: STERNBERG, R.J. (Ed.) Handbook of Human Intelligence, pp. 308-351 (Cambridge, Cambridge University Press).
- BARRON, F. (1969) The Creative Person and the Creative Process (New York, Holt).
- BARRON, F. (1972) Artists in the Making (New York, Seminar Press).
- CANTER, S. (1973) Some aspects of cognitive function in twins, in: CLARIDGE, G.S., CANTER, S. & HUME, W.I. (Eds) Personality Differences and Biological Variation: A study of twins (Oxford, Pergamon).
- CATTELL, R.B. & DREVDAHL, J.G.A. (1955) Comparison of the personality profile (16PF) of eminent researchers with that of eminent teachers and administrators and of the general public, *British Journal of Psychology*, 46, 248-261.
- CRONBACH, L.J. & SNOW, R.E. (1973) Aptitudes and Instructional Methods (New York, Irvington).
- CRUTCHFIELD, R.S. (1962) Conformity and creative thinking, in: GRUBER, H.E., TERRELL, G. & WERKHEIMER, M. (Eds) Contemporary Approaches to Creative Thinking (New York, Etherton Press).
- CSIKSZENTMIHALYI, M. & GETZELS, J.W. (1973) The personality of young artists: an empirical and theoretical exploration, *British Journal of Psychology*, 64, 91–104.
- DREVDAHL, J.E. (1956) Factors of importance for creativity, Journal of Clinical Psychology, 12, 21-26.
- ESTES, W.K. (1982) Learning, memory, and intelligence, in: STERNBERG, R.J. (Ed.) Handbook of Human Intelligence (London, Cambridge University Press).
- EYSENCK, H.J. (1972) Personal preferences, aesthetic sensitivity and personality in trained and untrained subjects, *Journal of Personality*, 40, 544-557.
- EYSENCK, H.J. (1978) Personality and learning, in: MURRAY-SMITH, S. (Ed.) Melbourne Studies in Education, pp. 134-181 (Melbourne: Melbourne University Press).
- EYSENCK, H.J. (1979) The Structure and Measurement of Intelligence (New York, Springer).
- EYSENCK, H.J. (1981) A Model for Personality (New York, Springer).
- EYSENCK, H.J. (1982) A Model for Intelligence (New York, Springer).
- EYSENCK, H.J. & CASTLE, M. (1970) Training in art as a factor in the determination of preference judgments for polygons, *British Journal of Psychology*, 61, 65-81.
- EYSENCK, H.J. & EYSENCK, S.B.G. (1975) Manual of the Eysenck Personality Questionnaire (San Diego, Edits).
- EYSENCK, H.J. & EYSENCK, S.B.G. (1976) Psychoticism as a Dimension of Personality (London, Hodder & Stoughton).
- EYSENCK, M.W. (1977) Human Memory (London, Pergamon).
- GETZELS, J.W. & JACKSON, P.Q. (1962) Creativity and Intelligence (New York, Wiley).
- GÖTZ, K.O. & GÖTZ, K. (1979a) Personality characteristics of professional artists, Perceptual and Motor Skills, 49, 327–334.
- GOTZ, K.O. & GÖTZ, K. (1979b) Personality characteristics of successful artists, Perceptual and Motor Skills, 49, 919–924.
- HAMMER, M. & ZUBIN, J. (1968) Evolution, culture and psychopathology, *Journal of General Psychology*, 78, 154–175.
- HESTON, L.L. (1966) Psychiatric disorders in foster home reared children of schizophrenic mothers, British Journal of Psychiatry, 112, 819-825.
- HIMWICH, H.E. & FAZEKAS, J.F. (1940) Cerebral metabolism in mongolian idiocy and phenylpyruvic oligophrenia, Archives of Neurology and Psychiatry, 44, 1213–1218.
- HUDSON, L. (1966) Contrary Imaginations (London, Methuen).

- HUDSON, L. (1968) Frames of Mind: Ability, perception and self-perception in the arts and sciences (London, Methuen).
- HUGHES, K.R. & ZUBEK, J.P. (1956) Effect of glutamic acid on the learning ability of bright and dull rats: I. Administration during infancy, *Canadian Journal of Psychology*, 10, 132–138.
- JARVIK, L.F. & CHADWICK, S.B. (1973) Schizophrenia and survival, in: HAMMER, M., SALZINGER, K. & SUTTON, S. (Eds) *Psychopathology* (New York, Wiley).
- KARLSSON, J.L. (1968) Generalogic studies of schizophrenia, in: ROSENTHAL, D. & KETY, S.S. (Eds) The Transmission of Schizophrenia (Oxford, Pergamon).
- KARLSSON, J.L. (1970) Genetic association of giftedness and creativity with schizophrenia, *Hereditory*, 66, 177-182.
- LEITH, G.O. (1974) Individual differences in learning: interactions of personality and teaching methods, in: Conference Proceedings, Personality and Academic Progress (London, Association of Educational Psychologists).
- LEITH, G.O. & TROWN, E.A. (1970) The influence of personality and task conditions on learning and transfer, *Programmed Learning*, 7, 181-188.
- LEOHLIN, J.C. & NICHOLS, R.C. (1976) Heredity, Environment and Personality (London, University of Texas Press).
- LYTTON, H. (1971) Creativity and Education (London, Routledge & Kegan Paul).
- MACKINNON, D.W. (1962) The nature and nurture of creative talent, American Psychologist, 17, 484-495. MACKINNON, D.W. et al. (1961) Proceedings of the Conference on 'The Creative Person', University of
- California Alumni Centre, Lake Tahoe. MCCORD, R.R. & WAKEFIELD, J.A. (1981) Arithmetic achievement as a function of introversion-
- extraversion and teacher-presented reward and punishment, *Personality and Individual Differences*, 2, 145–152.
- MCNEIL, T.F. (1971) Prebirth and postbirth influence on the relationship between creative ability and recorded mental illness, *Journal of Personality*, 39, 391-406.
- NEWMAN, H.H., FREEMAN, F.N. & HOLZINGER, K.J. (1937) Twins: A study of heredity and environment (Chicago, Chicago University Press).
- Rose, A. (1952) A psychologist examines sixty-four eminent scientists, Scientific American, 187, 21-25.
- ROE, A. (1953) A psychological study of eminent psychologists and anthropologists and a comparison with biologists and physicists, *Psychological Monographs*, 61 (whole no. 352).
- SPEARMAN, C. (1927) The Abilities of Man (London, Macmillan).
- TORRANCE, E.P. (1962) Guiding Creative Talent (Englewood Cliffs, N.J., Prentice Hall).
- TROWN, E.A. & LEITH, G.O. (1975) Decision rules for teaching strategies in primary schools: personalitytreatment interaction, *British Journal of Educational Psychology*, 45, 130–140.
- WAREFIELD, J.A. (1979) Using Personality to Individualize Instruction (San Diego, Edits).
- WALLACH, M.A. & KOGAN, N. (1965) Modes of Thinking in Young Children (New York, Holt, Rinehart & Winston).
- WANKOWSKI, J.A. (1973) Temperament, Motivation and Academic Achievement (Birmingham, University of Birmingham Educational Survey and Counselling Unit).
- WEISS, V. (1982) Psychogenetik (Jena, Gustav Fischer Verlag).
- WOODY, E. & CLARIDGE, G. (1977) Psychoticism and thinking, British Journal of Social and Clinical Psychology, 16, 241-248.
- ZIMMERMAN, F.T., BURGERMEISTER, B.B. & PUTMAN, T.J. (1949) Effect of glutamanic acid on the intelligence of patients, Archives of Neurology and Psychiatry, 61, 275-287.