PRE-SCHOOL OPPORTUNITY AND SEX DIFFERENCES AS FACTORS AFFECTING EDUCATIONAL PROGRESS

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FOREWORD

The papers reproduced here were originally prepared as part of a series of six public lectures presented by the Faculty of Education early in 1973.

Once the series was completed it became apparent that the papers which follow were even more closely linked than was originally intended, in that they all attempted to focus attention on some educational base lines. The main purpose of each paper was to stress the fact that there is a vital need to look realistically at some of the assumptions made about the pupil in school to see whether what is provided for him is really in accordance with his needs, both present and future.

The chosen assumptions vary slightly from paper to paper but the conclusions reached by all three of the contributors may be summarised as follows:

> The child in school is much more, and much less, than he appears to be. It is necessary to investigate the real pupil and his circumstances, past and present, in order to be able to make effective educational provision. Such investigation must be as rigorously empirical as possible so that broad principles as well as specific difficulties may be identified. But it will be necessary sometimes to take action even before all the evidence is in, if future educational and developmental problems are to be minimised.

It is hoped, then, that this publication, while pointing, perhaps rather diffidently, at some possible answers in limited, even specialised, fields, will encourage more people to look at the educational processes, both formal and informal, and at the validity of the assumptions on which they are based in the light of present and future empirical findings.

ELIZABETH HENDRIKZ

SEX DIFFERENCES IN SCIENTIFIC AND MATHEMATICAL COMPETENCE AT ADOLESCENCE

Elizabeth Hendrikz

The principal purpose of this paper is not to identify and explain sex differences in scientific and mathematical competence for their own sake. The real aim is to increase our understanding of some of the factors which appear to be related to the development of such fundamental cognitive abilities as efficient concept formation, spatial reasoning, identifying and testing hypotheses, deduction and induction, etc. It was thought that an examination of the comparative performances, in selected areas, of boys and girls from different educational and cultural backgrounds would enable us not only to identify limiting factors but also to provide pointers to ways of modifying some of the circumstances apparently affecting the development of these sorts of cognitive competence. The specific topic of scientific and mathematical abilities is chiefly a vehicle for this study and not an end in itself. If, as a result, it becomes possible to propose practical ways of overcoming specific problems in this sphere, so much the better, but that must be looked on as a bonus rather than as a major aim.

The title of this paper implies that there are measurable sex differences in scientific and mathematical abilities at adolescence but it does not suggest in which direction the differences lie. There is, in fact, plenty of research evidence that by this stage girls on the whole are inferior to boys in both these areas, though the best of the girls are as good as the best of the boys (see, for example, Maccoby, 1963; Heim, 1970 and McFarlane Smith, 1964). The research confirms the more subjective opinion of high school and university teachers. Confirmation of the existence of such sex differences was also obtained from research undertaken by the writer in Rhodesia (Hendrikz, 1973).

The research was aimed at investigating some of the factors which might have an influence on the development of mathematical and scientific concepts and the logical abilities fundamental to competence in these fields. Everything possible was done to reduce the influence of formal schooling and tests were selected or devised which seemed to measure the more fundamental cognitive skills without which real scientific and mathematical competence are unlikely to be established. For example, two of the group tests sought evidence of the pupils' understanding of such basic concepts as friction, inertia, scientific as opposed to animistic causality, scale and proportion, density, constancy of weight and so on. The questions were designed to give evidence of the level of conceptual development in these spheres rather than of rote or formal learning. As an illustration, the writer sought to distinguish between the mere ability to define density as "weight per unit volume" and the correct use of the concept of density to understand and explain why some common objects float and some sink.

Another group test was aimed at evaluating the pupils' ability to visualise, compare and mentally manipulate shapes in two- and threedimensional space. This sort of spatial ability has been widely shown, for example by Vernon (1968) and by McFarlane Smith (*op. cit.*) to correlate significantly with mathematical and scientific competence. In line with this, the research showed that results on test items involving this sort of spatial ability also correlated significantly with competence on the more specifically conceptual tests, which suggests that they are at least related abilities, though the nature of the relationship is not clearly understood. This is not the place to describe all the tests in detail but it is worth mentioning that, in addition to a number of group tests, individual practical problem-solving tests were given to a substantial proportion of the original sample, tests which were aimed at evaluating the sort of scientific logic used in solving the set problems, for example how far trial-and-error was used, or relatively haphazard instead of orderly and progressive hypothesis-testing. The subjects included academic secondary school boys and girls from each of the four major ethnic groups in Rhodesia. They included Form I and Form III pupils from both day and boarding schools, so that it can be seen that a number of cultural, educational and other variables were involved, which formed a useful experimental setting for the original research purpose. In this paper, however, it is intended to limit the discussion to the apparent effects of the sex variable. Below are tables which show a few of the comparative results of the different sexes in only two of the major groups studied. It is worth noting the results cross-culturally, too, but only because they demonstrate that, despite the often obvious sex differences in performance, factors other than sex also enter into the picture. The suggestion arises that differential performance in these tests cannot be solely attributed to biological differences, an important suggestion because of its corollary that, if environmental factors are also influential, they ought to be modifiable if the right procedures are adopted.

TABLE 1

Mean raw scores on the Mathematical Insights Test (14+) (N.F.E.R.)
Maximum: 77

GROUP	*FORM I*		*FORM III*	
	N	*mean score*	*N*	*mean score*
European boys	60	55	63	64
European girls	61	55	59	60
African boys	150	49	53	60
African girls	51	51	21	55

TABLE II

Mean raw scores on the Syllogistic Reasoning Test (Hendrikz)
Maximum: 60

GROUP	*FORM I*		*FORM III*	
	N	*mean score*	*N*	*mean score*
European boys	60	31	63	42
European girls	61	28	59	34
African boys	150	23	53	26
African girls	51	21	21	22

TABLE III

Mean raw scores on Science Concepts Test A (Hendrikz)
Maximum: 90

GROUP	*FORM I*		*FORM III*	
	N	*mean score*	*N*	*mean score*
European boys	60	61	63	66
European girls	61	48	59	53
African boys	150	44	53	57
African girls	51	34	21	42

TABLE IV

Mean raw scores on Science Concepts Test B (King)
Maximum: 20

GROUP	*FORM I*		*FORM III*	
	N	*mean score*	*N*	*mean score*
European boys	60	14	63	17
European girls	61	12	59	14
African boys	150	12	53	13
African girls	51	8	21	11

TABLE V

Mean Percentiles on the Spatial Reasoning Test (Thurstone)

GROUP	*FORM I*		*FORM III*	
	N	*mean score*	*N*	*mean score*
European boys	60	49	63	58
European girls	61	41	59	40
African boys	150	27	53	33
African girls	51	18	21	17

The tables demonstrate both a consistent sex difference and a general increase in the gap in performance at the Form III level. The deficit for European girls was relatively less at the Form I than at the Form III level. Notice also that in the Mathematical Insights Test (Table I), which inevitably has a higher formal content, the discrepancies, especially at the Form I level, are negligible. Two interesting facts not visible from the tables are worth mentioning. Firstly, in the European girls' group studied, only 25 per cent. continued with physics-with-chemistry after Form II. The rest had given it up, most of them, according to themselves, because they were "not good at it". The second point to make is that the best of the girls were at least as good on each of the tests as the best of the boys, but the distribution of numbers at the tail end was heavily dominated by girls.

So much then, for some of the evidence from tests designed to assess what may be called a capacity to function competently in the fields of mathematics and science. It does seem that girls at the secondary-school level, looked at as a whole, have a less secure basis than do boys, and the insecurity seems to increase with time, paralleling what has been observed in many educational situations at these ages. The next question to ask ourselves is how far the increasing deficit is biologically based and how far is it the result of a complexity of factors, both experiential and motivational, which have influenced girls rather than boys. For obvious reasons it is not possible to be dogmatic about the extent to which psycho-sexual differentiation in these sorts of cognitive functioning is genetically determined. Certainly the sex discrepancy in such important things as spatial reasoning, convincingly shown to be an essential for the sorts of mental activity with which we are concerned, is a widespread phenomenon. Heim (*op. cit.*) includes a chapter, entitled the "Mediocrity of Women", in which she argues for a significant biological foundation to sex differences in abilities. A very good survey of the theoretical position to date is Hutt's *Males and Females* (1972). She discusses, among other things, the theory that the Y chromosome, which determines the development of a fertilised ovum into a boy, has the effect first of all of speeding up cell division, resulting in the formation of otherwise neutral cells into embryonic male organs. For the first six weeks after fertilisation both sexes develop in the same manner. If the male testis fails to develop at that stage because it has received no instruction from the Y chromosome, then the same neutral cells will develop two weeks later into ovaries and the foetus becomes female. Probably as a secondary result of the different hormones produced by the sex organs, further physiological differentation takes place, including eventually, some structural differentation in parts of the brain, especially the hypothalamus. After the early speedy development of maleness, the general developmental process in boys slows down, girls maturing physiologically, emotionally and possibly mentally quicker than do boys. Hutt argues that, because of the longer immaturity (and hence potential plasticity) of boys, many sex differences, including emotional and intellectual ones, are biologically based though not necessarily directly genetically determined.

So far all this does not appear to have direct relevance for the scientific and mathematical abilities with which we are concerned, though McFarlane Smith (*op cit.*), in contrast to Vernon (*op. cit.*), Skemp (1970), and others, holds that spatial ability is innate and hence states that the differences are inborn and not acquired. There is one piece of genetic evidence for this which cannot be overlooked. There is a rare genetic abnormality called Turner's syndrome, in which the individual receives at conception only one X chromosome, instead of the normal X + X which makes a female or X + Y which makes a male. Such an individual, because it does not have the Y instruction to develop male characteristics, becomes clearly female, though immaturely so, and is normally brought up as a girl. Although shortish of stature, her intelligence is by most standards perfectly normal and her behaviour feminine, perhaps even "ultra-feminine". But there is a noticeable cognitive deficiency in her poorly developed spatial ability, reflected in problems with mathematical and scientific reasoning. So it looks as though, both from its universality and from the little direct evidence that we have, that there could be a biological basis to sex differences in mathematical and scientific ability. One must remember, of course, that the overlap between the sexes is extensive, many girls being highly competent and many boys highly incompetent.

Before we finally accept or reject the primacy of biology in this field we must look at the evidence related to non-biological factors which also seems convincingly significant. For example, Maccoby *(op. cit.)* quotes research which demonstrates a relationship between the way an individual has been brought up and his or her competence at mathematics and science. Girls who have been brought up to be independent and to solve their own problems tend to be better at mathematics and science than do others and, conversely, boys brought up to be dependent, especially on their mothers, and who have been overprotected, tend to be linguistically well-developed but mathematically poor. Girls who identify with their fathers rather than their mothers, who are tomboys and who reject authority, tend to be scientifically and mathematically more competent than others. In fact there is a correlation for both boys and girls between their position on a masculinity/feminity scale and their bias towards linguistic or scientific ability. But all this evidence still does not exclude a biologically sex-linked basis to these abilities, since individual differences in the secretion of male and female hormones may well be genetically determined and hence a determinant of cognitive abilities.

The foregoing, however, does not complete the evidence. In the 1950's and the subsequent decade Witkin (1962), Wober (1967) and others studied different modes of intellectual functioning in many different culture-groups. Witkin developed ways of measuring whether an individual habitually sees and analyses problems in their global context or whether he tends to observe and analyse the details instead. He argued that there is a consistency of approach in most individuals, though a continuum exists from very global to very atomistic. He named two categories, "field-dependence" for those not concerned with details but with the total situation (including emotional and aesthetic aspects) and "field-independence" for those who ignore the apparent irrelevancies of context and concentrate on analysing internal facts and relationships. Basically the subject is shown a simple geometric figure on a card and then, after the removal of the first card, is shown a complex figure which includes the simple one within it. The time taken to identify the embedded figures is one of the measures of field-dependence or -independence. There is a strong spatial element in this, and indeed results are significantly correlated with those on other spatial tests, including those which in turn relate to mathematical and scientific aptitude. Witkin used other tests to re-inforce the results of the embedded figures test and found an interesting consistency of approach in most people measured.

Witkin's overall results showed women on the average to be less able than men to disregard the visual field in which the figure is embedded, though there is, again, substantial overlap between the sexes. Other aspects of his investigations showed that "analytic" mothers tend to produce independence in problem solving in their children of both sexes and hence field independence, spatial ability and scientific and mathematical competence. Dawson (1967) and others, using Witkin's tests, found a significant ethnic (or rather, cultural) correlation with field dependence and independence in groups of people, both men and women, in West Africa. For example, those who had been brought up in a conformist and authoritarian rather than an independent and analytic manner, tended to be field dependent. Similar groups of people were discovered by Beard (1968), Vernon (*op. cit.*), and others to be relatively poor at spatial tests and also at scientific and mathematical reasoning, though the sex discrepancies still existed. There could still be a genetic causality even here, perhaps this time ethnically linked, though an increasing amount of evidence militates against this latter because of the close relationship between traditional child-rearing and educational processes and spatial ability, even within the same ethnic group. A final piece of evidence comes from McArthur (1967) replicating work by Berry (1966) who discovered groups of western Eskimos in which, at least till puberty, there was virtually no difference in the upbringing of boys and girls in their games, toys, dress, responsibilities, etc. While individual differences in spatial ability, field-dependence and independence existed within such groups, they were not dichotomised on sex lines.

The story, then, is not as clear-cut as one would like. The safest thing is to conclude that, while biological and genetic influences probably contribute to sex differences in field-dependence and independence and spatial ability, both of which are widely accepted to be basic to mathematical and scientific competence, it seems as though environmental influences are also important, especially those which determine habitual approaches to the analysis and solution of logical problems, perception of relationships and so on.

It seems appropriate to bring this particular line of reasoning together by coming back again to the measures of spatial ability derived from the local research (Table V). Both sex and ethnic differences were noted, with a different pattern for boys and girls, both African and European. The scores given are in the form of percentiles, which give a placing for each individual in relation to a large group of testees; age differences have been taken into account so that one is able to make a direct comparison between Form I and Form III results. One can see that the sex and ethnic differences are substantial; in both Forms Europeans scored more than the Africans and boys more than girls. The test used was one developed by the Thurstones (1947; 1958), on the theoretical assumption that spatial ability is inborn and not influenced by experience, an assumption, you will remember, which was also made by McFarlane Smith (*op. cit.*) author of the classic work on the subject of spatial ability. If that assumption is justified, the Form III pupils ought to score much the same as they did at Form I. The percentile norms from which the figures were derived are now over twenty years old and were established for Western European children, not for people from different ethnic groups in Rhodesia in the 1970's. However, they still have value, especially when one looks at the comparative figures for Forms I and III. In both boys' groups the Form III score is significantly higher than the Form I score, ($p = < .05$), but in both girls' groups there is a very close relationship indeed.

Interpretation of these scores has, it seems, relevance in helping us to decide the extent to which spatial ability is modifiable. For European boys, and to a less but still significant extent for African boys, the years between Forms I and III are physically active years in this country, with much more opportunity to explore their environment and a vastly increased opportunity now than 20 years ago for investigating all sorts of mechanical gadgets, old motor cars, electrical implements and so on. Much of this activity involves manipulating spatial and practical rather than verbal relationships, and hence, if one can accept an environmental contribution to spatial ability, it seems only logical that an increment in experience in the adolescent years should show on a good test of spatial ability. The superior performance of European boys over African boys can be accounted for environmentally if one compares the traditional early upbringing of boys in a European culture with that of boys in an African culture. Different travel opportunities, toys, attitudes to authority, different traditional beliefs about the physical world and many other factors could well contribute to the difference. We are not really getting away from the theme of this paper since it seems at least possible that sex differences in spatial ability may to some extent be brought about by some of the same sorts of influences at work cross-culturally. The girls' scores shown on Table V stay almost identical but, if one considers the differing interests of boys and girls at this age, it seems a predictable result for most of them, since if anything girls, at least in this country, are rather less active at this age than earlier in practical, mechanical and even independent geographical movement. Nothing extra has been added to their lives to stimulate an increase in spatial ability. Similarly the sex discrepancy *vis-à-vis* their male counterparts, genetics aside, can also be accounted for at least partially in long-term experiential ways, in which right from the early weeks of life girls are usually (unless they happen to be western Eskimos) treated differently from boys, especially in spheres related to spatial, exploratory, practical and mechanical activities. African girls usually lead a much more circumscribed existence than do their brothers and this could be reflected in their much lower scores.

An aspect worth looking at in addition to the directly experiential one is that of self-expectation, and hence motivation. The general and specific culture in which one is brought up builds up over the years a picture of what is appropriate and what inappropriate, what is masculine and what feminine behaviour and so on. All teachers know that children tend to produce, within obvious limits, what is expected of them and what they expect of themselves, both of which concepts they develop over the years. It is possible that many girls have been "brainwashed" into believing that mathematics and science are not their province. As a result, even when they have not been environmentally handicapped in the development of the spatial and other abilities basic to scientific competence, they still may not achieve what they are potentially capable of because of motivational limitations. Perhaps the fact that only 25 per cent. of the European girls studied continued with the physical sciences after Form II is a reflection of this. In addition, many of them, when asked what "O-level" science subject they were taking, said "None", until they were reminded that biology is a science!

There is plenty more empirical evidence to support the cultural, experimental and motivational contributions to scientific and mathematical abilities but enough has been given for our purposes. A few interesting pointers about local conditions were found in which, for example, African boarding school girls, whose lives are much less circumscribed than those of day-school girls, scored fractionally better on spatial and conceptual tests than did the latter. African day-school boys, on the other hand, were slightly better than their boarding-school counterparts, which may reflect the wider urban out-of-school environmental experiences such boys have.

To summarise, we have seen evidence that, in several abilities related to mathematical and scientific competence, girls are widely found to be inferior to boys, though the overlap is extensive, the best of the girls being as good as the best of the boys. Because of the widespread existence of the discrepancy and from the as yet limited direct evidence, one may safely conclude that there is a biological, both genetic and hormonal, contribution to the discrepancy. However, we have also examined evidence which suggests that this is not the whole of the picture, because even within an ethnic group there are variations in the pattern which coincide with general cultural norms and expectations and specific upbringing patterns and experiences. Discrepancies, at least locally, appear to increase in early and mid-adolescence, when motivation and cultural expectations are becoming defined and also more sexually differentiated, providing further evidence of the potential modifiability of the basic abilities. It does seem as though, genetics apart, it should be possible so to arrange the school, if not the home environment to modify some of the limiting factors and enable girls as well as boys to become scientifically and mathematically more competent than many of them presently are.

It could be argued that there is no ethical or moral justification for planning for such a modification. This is not an argument to go into here in any depth, except perhaps to say that, while not necessarily wanting to produce large numbers of scientific and mathematical specialists among women, there is at present a lot of wasted talent which will become increasingly valuable in an increasingly technological world. If scientifically-minded people could be produced, both men and women, who had some of the holistic and human perspective of the field-dependents as well as the analytic insight of the field-independents, the world might be a pleasanter and safer place. Modification of factors limiting the development of the abilities which we have been examining involves the home and pre-school educational opportunities as well as approaches in the formal school. A great deal more research will be necessary before one can be sure which methods will most effectively and economically achieve the purpose. But at least a start has been made in unravelling some of the mysteries of the interaction of genetics and environment in the development of human abilities.

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