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PRIORITIES IN SCIENCE IN UNDERDEVELOPED COUNTRIES

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Introductory remarks

These are rough notes which were written from the point of view that the object of advancement of science in its comprehensive sense is the promotion of national development including economic, social and cultural progress, and that priorities in science have to be decided in order to ensure the most rapid advancement of the nation as a whole and not merely of particular sections of the people. The intention was to use these rough notes for an article for the Pugwash Conference at Udaipur in January 1964. I had also intended to participate in the discussions in the working group on priorities in science and technology. Owing to unforeseen reasons I did not have time to write the article. As I am also unable to attend the Conference, I am sending these notes in a rough form in the hope that they may be of some help in drawing attention to certain aspects of the problem.

A.1.0. *Terminology :* It will be convenient to state the sense in which the following phrases are being used in this note.[1]

A.1.1. *Scientific research :* Efforts to know nature more adequately.

A.1.2. *Technological research :* Efforts to use scientific knowledge to do something more efficiently.

A.1.3. *Surveys :* Collection of information for purposes of either scientific or technological research.

A.2.0. Two phrases are useful for purposes of description.

A.2.1. *Pioneering research* in which there is an attempt to break fresh ground.[2]

A.2.2. *Incremental research*[3] in which the attempt is to achieve its purpose by step by step advances from well established position ; such research is of the greatest importance in both science and technology.[4]

A.3.0. *Size of research effort :* It is useful to have some descriptive phrases relating to the size or magnitude of any research project or organisation in the form of a cell, unit, section, division, department, faculty etc., or an institute or institution as a whole. Three different approaches are possible.

A.3.1. Number of staff or professional workers engaged in the research effort, on the basis of a conventional scale, such as scale 1 from one up to 5 or 10 research workers ; scale 2 from 5 or 10 to 25 workers ; scale 3 from 25 to 100 etc.

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[1] The terminology is partly based on the ideas of W.F.C. Hessenberg, *New Scientist*, 6 December 1962.

[2] C.T.R. Wilson's cloud chamber, semi-conductor theory, genetic code cracking etc. in science or reinforced plastics, hovercraft in technology.

[3] The word 'incremental' seems more suitable than 'marginal' used in the same sense by Hessenberg.

[4] The distinction between 'pioneering' and 'incremental' research is to some extent arbitrary and depends on subjective value judgements ; however, a consensus of opinion is likely to be achieved in most cases.

A.3.2. Capital expenditure relating to land, buildings, equipment as measured on a conventional scale.

A.3.3. Current expenditure comprising staff pay stores, contingent and maintenance charges etc., measured on a conventional scale.

A.3.4. In any given subject field, there would be high association between three different measures of size, and it would be often possible to adopt a single conventional scale representative of all three aspects. This would be also possible for wider fields of research by using broader ranges for each scale.

A.4.1. *Science :* For brevity, it is sometimes convenient to use the single word 'science' in a wider sense to include 'science', 'technology', and 'surveys' (when these three fields are not being distinguished in the sense of para 2 above).

A.4.2. *Research* may be used in a comprehensive sense to include both pioneering and incremental research in science, technology, and surveys.

A.4.3. *Education* refers to teaching of both contents and methods of sciences, technology, and surveys.

A.4.4. *Science research* may be used to include all types of research in all fields of science, technology and surveys, and science education to cover education in all three fields.

1.1. *Head of science for economic development :* The only way to improve the level of living of underdeveloped countries is to increase the per capita production of goods and services by an increasing use of machinery driven by steam or electricity as a substitute for human or animal labour. This can be done only through industrialisation on its broadest sense including manufacture, agriculture, transport, communication, marketing etc.

1.2. Industrialisation would be possible only with the help of a rapidly increasing number of semi-skilled and skilled workers, technicians, engineers, technologists, physicians and scientists. A strong base of science education is indispensable for this purpose. (This point is widely appreciated).

1.3. Industrialisation together with an expansion of both imports and exports (with an increasingly larger content of semi-manufactured or manufactured articles) would be possible only through the most effective utilisation of domestic resources. To do this, it would be necessary to develop and expand technological research. (This point is usually appreciated when it is realised that even most advanced countries like USA and UK, in order to hold their position in the world market, have to devote a third or more of their non-military research to improve the quality of products already in use).

1.4. To sustain an adequate base of technological and applied research, it is essential to establish and foster the tradition of scientific research by creating facilities for free communication and exchange of views and criticisms among research scientists. It is, therefore, necessary to give special attention to the promotion of pioneering research, so that a sufficient number of research scientists become available to function as the eyes and ears of the nation in the field of science to foster the growth of the scientific tradition with the country and to maintain contact with the progress of science abroad.

1.5. An important aim of science education must be to supply an increasing number of qualified students for admission to technical, technological and scientific institutions at all levels and for centres for both scientific and technological research. These are essentially the utilitarian aspects of science education and research.

2.1. *The need of science for social transformation:* There is also a deeper need of science which is the heart of the problem of "modernisation" of underdeveloped countries. The emergence of science during the last four hundred years, at first slowly and then at a rapidly increasing pace, is a turning point in the history of civilisation. Before the emergence of science, there were only two broad domains of human decisions. In one domain, there was always some freedom of choice for individuals in food, clothes, recreations, creative activities in art, literature, music, etc., within, of course, the limits permitted by society or of supplies and facilities available to the individuals concerned.

2.2. The second domain of all organised human activities was (and must always continue to be) regulated by the principle of authority' in which sanction depends on the status or level of the authority. This is true in primitive or present day communities all over the world ; in organised churches and religions ; in all military, police or administrative systems ; in public and private enterprises, and in any regime of law. The decision of a court of law may be upheld or reversed by a higher court of appeal ; the second decision also would be subject to confirmation or reversal by a higher court, and so on. The decision of the highest court to which a case has been (or can be) referred must be accepted ; but there is no guarantee that such a verdict would not have been reversed if an appeal to a higher court had been made or were possible. This principle of authority must be accepted for the very existence of society itself.

2.3. The same principle of authority must, however, be completely rejected in the field of science. Cause and effect must have been the subject of enquiry from time immemorial but only in respect of events in isolation. That natural phenomenon amenable to rational and unified explanation is the great break through of the human intellect which occurred only with the emergence of science and is the characteristic mark of the present age. Modern science consists of a patient accumulation of facts and observations and a critical study of their inter-relations based on the uniformity of nature which can be discovered by the human mind. Science thus introduced for the first time the concept of principle of objective validity which has its foundation in nature itself and cannot be changed or upset by any authority however high.

2.4. Authority based on status is irrelevant to science. The transformation of all the advanced or the rapidly advancing countries has been brought about by the acceptance, slowly at first, and now in an increasing measure, of a scientific and rational view of life and nature. This is the foundation of the modern age.

2.5. In the underdeveloped countries there is an urgent need to establish and develop the outlook of science, and the experimental attitude of mind to acquire knowledge of natural and social forces and to use such knowledge to invent new techniques for intimating material and social changes. This is the only way in which decisions can be made in an increasingly rational manner and in accordance with the principles of scientific or objective validity, based on relevant data and correct reasoning. This is the only way to replace superstition, out-dated custom or dogma, and to bring about a structural change of society to make conditions suitable for rapid economic and national development by removing all barriers to the effective utilisation of all productive forces and all available resources for the benefit of all the people of the country.

2.6. The advancement of science and the growth of the scientific and rational outlook is an essential condition for the modernisation of the less advanced countries. It is necessary for each country, however backward or small, to have as quickly as possible a

sufficient number of men with the scientific outlook who would be able increasingly to influence the thinking of the nation and of persons who make policy decisions at the national level. How to attract a sufficient number of persons to the field of science is thus the crucial problem of national development. This can be achieved only through an increasing appreciation of science and scientists by the general public.

3.1. *Scientific tradition and scientific personnel:* The basic task is to establish the scientific tradition. This has two aspects, one is science research and the other is science education on a country-wide scale. Both to be pursued vigorously.

3.2. A community of research workers with facilities for frank exchange of views and criticisms is indispensable for the establishment and maintenance of the scientific tradition. To build up the scientific personnel in an underdeveloped country it is necessary to offer adequate scales of pay, and social status comparable with that of the administrative personnel and other professions. It is necessary to have a pay structure and service conditions which would facilitate movement from one scientific post to another. It is essential to secure equality of status in discussions at a scientific level for all scientists.

4.1. *Priorities in research:* Fortunately, pioneering research in science, technology and surveys can be conducted very often on a small scale at low cost. On the other hand, incremental research (in science, technology and surveys) tends to require a rapidly increasing scale of operations and expenditure with rapidly diminishing returns.[5] It is now possible to formulate certain basic priorities.

4.2. Pioneering research on a small scale and at low cost in science, technology, and surveys should be promoted in every possible way and preferably in independent research units (in the form explained later) all over the country.

4.3. Incremental research in science, technology and surveys should be initiated and continued only in relation to needs of economic development especially the exploitation of domestic resources.

4.4. As an adequate supply of scientists, technologists, and technicians at different levels is essential for the promotion of both pioneering and incremental research in science, technology and surveys, priority must be given to the training of appropriate man-power at all levels.

4.5. To secure an adequate supply of suitable candidates for training as scientists, technologists, technicians etc., priority must be given to a rapid expansion of science education in schools.

4.6. The above programme would also be of help in bringing about a gradual spread of the scientific outlook among the general public and among persons who make decisions for the country at different levels.

5.1. *Simultaneous expansion of science education and research:* The point to be stressed is the need of expansion of science education and research at the same time. The personnel needs of research determine the minimum rate of growth of science education.

5.2. On the other hand, an expansion of science education can proceed for its own sake with a view to accelerating the growth of the scientific outlook among the general public.

[5] Studies of invention in the industrial research laboratory indicate that "with few exceptions, the large industrial laboratories are likely to be minor sources of major (radically new or commercially or militarily important) inventions ; rather they are likely to be major sources of "improvement" inventions. *Journal of Political Economy*, Vol. LXXXI, April 1963, 95-115.

5.3. The rate of progress of science education is determined by the supply of teachers and of teaching side. High priority must be given to the training of science teachers in rapidly increasing numbers spread over the whole country.

5.4. High priority must also be given to increase the supply of teaching side and to the development of science courses adapted to local conditions.

6.1. *Pioneering research in science:* Pioneering research in science can be developed most effectively by promoting the establishment of small research units associated, wherever possible, with universities and scientific institutions.

6.2. Even in the same subject field, it is of advantage to establish independent research units. The size of each research unit (in terms of number of professional workers and staff, capital and current expenditure) should be kept as small as possible and each research unit should function as independently as possible in scientific matters to reduce to a minimum the administrative overheads (and to prevent the growth of a hierarchical system of authorities).

6.3. Every possible effort should, however, be made for initiating and encouraging research on a "thematic programme" by cooperation between scientists working in the same unit or between different research units in the same centre or locality or in different centres or regions of the country. In a thematic programme, each research scientist or unit would be concerned with a particular topic connected with a central problem. In this plan, each research paper may be independent, but the results would be capable of being integrated to supply a comprehensive picture of different aspects of a central theme.

6.4. The concept of an individual programme for each research unit would be also useful in preventing the growth of large units with a hierarchical level of authorities and large administrative overheads in staff and expenditure.[6]

6.5. A thematic approach would have special advantages for underdeveloped countries. In such countries when scientists in faculties or departments of universities and institutions work on different and unrelated topics, there is no possibility of communication or exchange of views among them. On the other hand, when scientists in one or more research units are working on a related group of subjects, they can communicate with one another; a miniature scientific cell can then become established with the possibility of free exchange of views and criticisms. These scientific cells can then gradually form a scientific community in the country as a whole.

6.6. In the advanced countries, the scientific community is already established and facilities for communication, in the form of publications, scientific meetings and conferences are highly developed and available to all scientists. Any scientist working on any particular topic anywhere is not isolated but can maintain continuing touch with other research scientists working in the same field in the country or in other countries. The position is entirely different in underdeveloped countries; a thematic approach would be particularly useful in such countries.

6.7. Sharing of equipment, library and other facilities is particularly important in underdeveloped countries where resources are meagre (but where, unfortunately, there is a tendency of monopolistic hoarding of such resources even when these are not being fully utilised). Encouraging cooperative research on related topics is likely to be useful in fuller utilisation of meagre resources of research facilities.

[6] Large divisions may be necessary in national laboratories dealing particularly with incremental research or in big universities with large teaching loads; but even in such institutions it would be of advantage to establish associated research units with a 'horizontal' rather 'pyramidal' organisation chart.

7.1. *Pioneering research in technology and surveys:* Practically all the points made above in connexion with pioneering research in science would be equally valid for technology and surveys. A few additional observations may be useful. In technology and certain branches of surveys, it is particularly important to promote acquisition of technical skills; deliberate attention and priority would have to be given to develop suitable training centres and institution for this purpose.

7.2. It is also of great importance to promote and encourage inventiveness and improvement of equipment and instrumentation.

7.3. While the widest possible freedom should be given in deciding topics and subjects for pioneering research (within the limits of available resource) a more selective approach is essential in even pioneering research in technology and surveys. It is obvious that only such subjects should be selected as are already important from the point of view of industrial and economic development or are likely to be relevant in near future. To do anything else would lead to waste of resources.

8.1. *Incremental research :* In an underdeveloped country it is of the utmost importance to select suitable fields for incremental research in science, technology or surveys as such research would inevitably tend to become increasingly large in magnitude and would call for an increasing supply of resources (in terms of men, material equipment and money) which may soon become beyond the means of the underdeveloped country.

8.2. It is most important to refrain from taking up any incremental research without a reasonable expectation of being able to carry it to a point where the results are likely to be truly fruitful. The danger to be carefully guarded against is selecting subjects for incremental research in a superficial imitation of advanced countries at too early a stage. To have to stop incremental research at an intermediate level for lack of resources would be extremely wasteful which underdeveloped countries cannot possibly afford.

9.1. *Priorities in science education :* The most fundamental aim of science education must be to help in the building up of a community of scientific workers and to promote the social appreciation of science among the general public. It is, therefore, necessary to lay the foundations, with as wide a base as possible, of a countrywide system of school education oriented to science and at the same time to promote advanced studies and technology and research at the highest level.

9.2. School science must fit into the economic life of the general masses of the people and have its roots in the villages in the underdeveloped countries. At higher levels, facilities must be provided for the training of technicians and technologists and also of candidates of outstanding ability for admission to higher scientific and technological institutions.

9.3. It would be a fatal mistake to establish an expensive system of science education on the model of the advanced countries which would be beyond the means of the nation as a whole. It is necessary to evolve, through experimentation and research, a system which can be made increasingly available to the people of the country as a whole.

9.4. The approach must be to use teaching aids which would be easily available or can be made available at a low cost all over the country. As most of the pupils will be living in villages, it would be advisable to use agriculture and rural industries as a general base for the teaching of science. The programme should consist largely of nature studies, observations, measurements and experiments which can be done with the help of simple articles, specimens, etc., which are locally available, or which can be constructed with local materials in the villages.

9.5. At the secondary stage, it would be necessary to introduce scientific instruments and equipment but these should be of the simplest type, preferably such as can be manufactured increasingly within the country out of domestic resources.

9.6. At all levels, the main object would be to stimulate the spirit of enquiry, the desire to make observations and measurements or carry out experiments to find out some thing which is not known. It is essential deliberately to refrain from asking the students simply to acquire knowledge of facts or to perform set exercises in the form of practical work. In underdeveloped countries where the scientific tradition has not yet been established, an approach would tend to make the students look upon science as something like magic, or make them accept the facts on the authority of the teachers, and thus frustrate real purpose of the teaching of science.

9.7. It would be of great advantage if scientists from advanced countries can help by experimentation and study in underdeveloped countries, in the development of suitable teaching programmes and aids for science education. The number of scientists required for such work would be comparatively small; much of the experience gained in one country would be capable of being transferred to other countries; projects in this field would be, therefore, extremely economic.

10.1. *Scientific personnel:* There are two somewhat distinct but connected aspects of the problem of an adequate supply of scientific personnel. Firstly, there is need of providing facilities for education and training at all levels. Such facilities would have to be necessarily integrated to a large extent with the general educational system of the country upto the university level. In addition, training in research would have to be provided essentially in research units, wherever these may be located in universities or other institutions.

10.2. The second aspect relates to terms and conditions of service which are particularly important at the research level. In underdeveloped countries the growth of the scientific community and the scientific tradition would depend essentially on the ability to attract a sufficient number of persons of talent to science in its broadest sense. It is, of course, necessary to offer adequate scales of pay, leave, pension etc., which would not be unfavourable compared with those open to the higher administrative and management staff in government agencies and enterprises or upper levels of professional personnel.

10.3. It is also necessary to provide adequate facilities for research. There is usually no overall shortage of buildings and accommodation; sometimes these are even much too lavish. Lack of equipment is a greater difficulty; in many countries there is also an acute shortage of imported articles, especially of stores and supplies. Even when there is enough buildings, equipments, and imported stores and supplies in a country there is sometimes great inequalities of distribution as between government and non-government agencies or between different research centres. Concentration of grants and facilities may easily lead to a psychological situation unfavourable for the growth of a scientific community in the nation as a whole (and may also have adverse effects on national solidarity in the long run).

10.4. Adequate pay and economic incentives and facilities for research even when well distributed are necessary but not sufficient. A most important requirement is to create social conditions of equality of status in scientific matters with freedom for participation in exchange of views and criticisms for all research workers which is essential for the very existence of a scientific community. This is usually the most difficult thing to achieve in a society based on the principle of levels of authority from time immemorial.

10.5. Measures to achieve equality of status would have to be devised no doubt to suit the special needs of the country. A professional organisation of scientific workers with a number of levels based on competence and ability (with equal or approximately equal scales of pay and economic incentives at each level) together with freedom of movement from one position to another and guaranteed rights of publication of research papers (of non-military significance) would have very great advantages compared to a service type of organisation which tends to become dominated by the principle of authority based on seniority of service.[7]

11.1. *Need of planning research:* The variety and complexity of problems connected with science education and research (some of which have been mentioned in the present note) point to the need of giving special attention to the planning of science in the underdeveloped countries. Research is the most slowly maturing sector in national development; the planning of research must have a time horizon of 25 or 30 years, and has to be given the highest priority.

11.2. A first requirement is a continuing flow of information relating to scientific personnel of various types and at various levels, and to expenditure on science research and education with suitable breakdowns by subject fields, agencies, geographical regions etc., (capital, recurring including staff salary, imports etc.).

11.3. The basic economic planning would relate primarily to the allocation of resources (manpower, training facilities, buildings, equipment, current expenditure, imports and other facilities) by broad subject fields, agencies, regions etc.

11.4. A second aspect would be the programmes of education and research which have to be formulated essentially at a scientific level.

11.5. A third aspect would deal with institutional matters relating to scales of pay, incentives, organisation and structure of scientific manpower, mobility, rights of publication etc. All three aspects of planning would have to be completely integrated.

12.1. *Help from advanced countries:* Help from advanced countries is indispensable, and may and would have to take many forms. Perhaps the most important task is to make respectable correct ideas on the advancement of science education and research including the need of long term planning. Equally important is to discourage a superficial imitation of advanced countries at too early a stage, which is, of course, the other side of the same problem.

12.2. It is necessary to recognise that programmes of technical assistance or financial aid for science education and research (on bilateral, multilateral or international basis) have been often wasteful and, in any case, have not yet had enough impact. A great deal of rethinking is urgently needed.[8]

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[7] It is of interest to note that an essentially professional organisation of scientific workers with almost unrestricted freedom of movement has developed in entirely different ways in the U.S.A. and the U.S.S.R., while the more rigid service system of the administrative type has been adopted in many underdeveloped countries.

[8] I made some observation in this connexion in an article on "The Scientific Base of Economic Development" in 1962 and have pointed out the advantages of collaboration in establishing small research units under the leadership of scientists of advanced countries who would visit and revisit the underdeveloped countries, of direct gifts of equipment from advanced countries, or of help in developing effective methods of science education and some other programmes which can be initiated at low cost in terms of both personnel and expenditure, but which, if successful, would have an enduring influence in the growth of science in underdeveloped countries.

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