RESEARCH FUNDING PATTERNS IN THE UK:
WITH SPECIAL REFERENCE TO ANALYTICAL SCIENCE

by

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Index

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

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ABSTRACT

This work considers the nature of research in Arts and Sciences generally in terms of funding inputs and publication output. The funding is described as broadly 'peer review' or 'customer-contractor', the definitions for which are described.

The data base which has been assembled for the study consists of publications from 20 Institutions of Higher Education (10 Universities and 10 Polytechnics of similar size but wide geographical distribution) over the period 1970 - 79. This constitutes 65,110 publications from within 593 academic units.

Comparisons are made between numbers of publications in the Arts and Sciences. In the chosen Polytechnics 42.2% of the publications are in the Arts whereas in the chosen Universities 41.5% are in the Arts. The number of publications in the Sciences divide between 32,728 science and 5,272 engineering publications which provides a base for comparing funding and traditions in various areas.

Within science, publications are considered within chemistry and physics and the general processes leading to the emergence of new disciplines are analysed with special reference to perceptions of analytical science as a new area which, in the present work, is deemed to be associated with those publications appearing in 103 journals which come into library classifications related to analytical chemistry and optical physics and which account for 419 papers within the data base.

Detailed analysis of the 419 analytical science publications has produced information on authorship, equipment and patterns of funding. Further information was gained from questionnaires returned by 82 selected authors and from reports and summaries from the SERC. It is estimated that 63 - 79% of the equipment and 61 - 66% of the manpower is funded by the 'peer review' rather than by the 'customer-contractor' process. The 'excellence' and 'usefulness' in terms of the work carried out and the location or destination of the co-authors in industry, government and education is discussed.

CHAPTER 1

Introduction

1.1 Research Funding Patterns

1.2 The Peer Review System

1.3 The Customer- Contractor Principle

1.4 Measurement of Research

1.5 Research Publications

CHAPTER 1

Introduction

1.1 Research Funding Patterns

People perceive research in different ways. Benjamin Jowett, Master of Balliol in the late nineteenth century considered the emergence of research, as a major academic preoccupation, to be a threat to university education. Logan Pearsall Smith said that the Master described research as 'a mere excuse for idleness'(1). Some people have even seen research as a leisure activity. In some spheres research is seen as a vocation for life. Leaving such comments aside, research makes an important contribution to man's understanding of the world around him.

The question arises - what is research? According to the Concise Oxford Dictionary it is 'Careful search or inquiry after or for or into; endeavour to discover new or collate old facts etc. by scientific study of a subject, course of critical investigation'(2). Norris and Vaizey define research as 'the process of adding to the total, or advancing the limits, of scientific knowledge'(3). Simply, research is a scientific study into a specific area in order to obtain new information.

Some areas of research are concerned with the storage and transmission of knowledge. Other areas are devoted to new investigation. There is a continuous spectrum of research from pure or basic research through to applied research. Nevertheless it is convenient to catalogue research as pure/basic and applied research. Government sources define basic or fundamental research as 'work undertaken primarily for the advancement of scientific knowledge without a specific practical application in view'(4). And applied research as 'research undertaken with either a general or a particular application in view'(5).

According to standard accounting practice research expenditure means expenditure falling into one or both of the following two categories:
'(a) Pure (or basic) research: original investigation undertaken in order to gain new scientific or technical knowledge and understanding. Basic research is not primarily directed towards any specific aim or application.
(b) Applied research: original investigation undertaken in order to gain new scientific or technical knowledge and directed towards a specific aim or objective'(6). The criteria in Table 1 illustrate how basic and applied research can be distinguished(7).

For research to be undertaken it needs to be paid for. When formulating a research project, cost needs to be considered. There are criteria such as the benefits of successful research, together with estimates of the probability of success which can be used to determine feasibility(8). With increasing costs of research economic factors need to be taken into account. By considering the probable cost of research it is possible to decide whether a project can be justified.

Although there may be no estimate of absolute monetary value, relative cost estimates still enter as one of the factors in deciding between alternatives. Cost estimates include not only direct expenditures for materials but also salaries and overheads, though these may not be directly charged to the project. Overheads include the cost of running a laboratory. Cost also enters into the decision whether to buy or build apparatus.

For the cost of a research project to be met there needs to be money. In this sense a fund, which is a 'stock of money, especially one set apart for

TABLE 1

DISTINGUISHING CRITERIA OF RESEARCH

		TYPE	
		Basic, Experimental, Exploratory, Fundamental and Pure Research	Applied, Technological Research
CRITERIA	Manpower	Researchers motivated by scientific tradition	Researchers externally influenced by market requirements
	Location	University, Polytechnic, College, Government Laboratory, Industrial Laboratory, Non- Profit Foundation	Industrial, Government, Commercial, University, Polytechnic, and College, Laboratories
	Aim	To resolve scientific problems and create new understanding	Creation of new products and processes
	Means	Investigation of new scientific phenomena, discovery of nature's unknowns, verification of physical world theories.	Creation, invention and discovery. New applications.
	Results	Knowledge presented and distributed by peer review evaluation	Theories and knowledge of materials, industrial processes and products.

a purpose'(9) is required. Once allocated to a specific research project funds can be seen as 'pecuniary resources'(10).

In order to determine the amount of money to be set aside for research the patterns of research funding need to be known. De Bono states that a pattern has order, predictability, recognition and repetition (11). He says 'a pattern exists when the probability of one specified state succeeding another specified state is greater than chance'(12). He also says the degree of predictability indicates the strength of the pattern (13). From past research funding patterns it is possible to see the trends and, therefore, determine priorities accordingly.

Most research in the UK, especially basic research, is undertaken in universities and polytechnics. This ranges from academic studies, through investigations of useful applications showing long term promise to the study of problems requiring urgent practical solutions.

The University Grants Committee (UGC), the Research Councils (dual support system) and Local Education Authorities finance university and polytechnic research respectively. The UGC's main grant to universities contains an unearmarked proportion for research and the UGC equipment grant provides for both undergraduate teaching and research, whereas the research councils support specific projects in particular fields. The Science and Engineering Research Council (SERC) tries to support all those research projects it considers to be of first rank. Funding obtained from these sources is peer review type funding.

Universities and polytechnics also receive support for research from government departments, industry and charitable institutions. This is usually customer-contractor type funding.

A fundamental problem that these funding agencies have is to determine the value of research. The value of applied research may be easy to recognise in the medium to long term since it can take the form of new products and processes. Whereas justification of fundamental research is more difficult. It makes a contribution to intellectual and cultural activity of society, it provides new useful ideas and it stimulates the education of students at both the postgraduate and undergraduate levels. The timescale to realise benefits from basic research is , therefore, much longer than for applied research.

Researchers are responsible for maintaining and understanding past knowledge and experience making it available for the future as well as the present. In this sense research is important for cultural development. Research into fundamental issues often provides results of immense practical value for the future. It is this view of research that needs to be borne in mind by funding agencies when being presented with grant applications of a fundamental and intricate nature. This is especially the case for peer review type funding.

1.2 The Peer Review System

In order to determine the funding of research in the UK, universities, polytechnics and research councils use the peer review system. This is the system whereby academics determine what grants to give to their fellow researchers. Participation by such 'panels of peers'(14) results in the 'gatekeeper role'(15). They recommend and determine research fellowships, grants and awards due to their competence in the field in question.

Peer review systems that have a committee structure, which review many proposals at the same time, are usually effective in overcoming over concentration of research effort in popular areas. The research committee is seen as the principal mechanism for determining the approval of grant applications. Appointed members of research committees have the responsibility for granting or refusing research applications. They need the requisite information on which to base their decisions. Criteria provide a means for doing this.

Criteria for scientific choice are used by funding agencies when there is not enough money to fund all the 'worthwhile' applications sent to them. Hilary and Steven Rose have said that 'most agencies, at least in Britain and the US, seem to have funds to cover only some thirty to sixty per cent of the total grant applications made to them'(16).

Since 1960 four principal approaches to the criteria for scientific choice have been explicated. In 1962 Polanyi when describing the advancement of science by independent initiatives said that the scientist assesses a problem by the standards of scientific merit accepted by the scientific community (17). He said that scientific merit for a contribution to science depends on a number of criteria which are: a sufficient degree of plausibility; its scientific value composed of the three coefficients of its accuracy, its systematic importance and the intrinsic interest of its subject-matter; and originality (18).

A year later in 1963 Weinberg identified internal and external criteria (19). He described internal criteria as being generated within the scientific field itself answering the question how well it is done. Whereas, he said external criteria are generated outside the scientific field and answer the question as to why this particular science is pursued. The two internal criteria he identified were whether the field is ready for exploitation and whether the scientists in the field are really competent (20). His three external criteria were technological merit, scientific merit and social merit (21).

In March 1970 the Council for Scientific Policy (CSP) set up a working group headed by Professor (later Sir) Frederick Stewart to establish criteria to determine priorities in science policy (22). The working group published its report in October 1972 and was highly critical of Polanyi's view that the scientist should restrict his view to judgements of scientific merit. Its criteria fell into the three main groups of intrinsic (excellence of the study field and of the research workers, pervasiveness or promise of impetus to advances in other and related fields of science, cultural value, and relationships with similar research in the field), external (short-term and long-term economic benefit, social benefit, educational benefit, national prestige and scientific reputation, and other national goals), and resource implications (demand on capital and demand on manpower) (23). It recognised that there was nothing new in its criteria and realised that they were already tacitly taken into account in decisions taken about research. The group thought that it was worth making them explicit so that existing programmes and new proposals could be assessed.

In 1975 the Advisory Board for the Research Councils (ABRC) again led by Sir Frederick Stewart amended the categories of criteria (24). The two principal criteria were scientific policy criteria (excellence of study field and research workers, pervasiveness of the activity with respect to other fields, social and/or economic importance, significance for the training of scientific manpower, educational importance, and significance in maintaining national scientific prestige) and management criteria (improvement in the efficiency of the organisation and/or plant, the obsolescence of a major item of equipment without support, the criticality of the timing of the activity, dependence on the Science Budget, availability of the necessary manpower, and the scope that exists for redeployment of resources allocated to the activity) (25).

How these criteria are applied in practice is not known due to lack of information. But, in the end, whether a research proposal is accepted or not rests with the research committee members themselves.

Committee members are often hard pressed to cope with the flood of researct applications. Several important implications follow from this. First, there is the danger that decisions will be given which are 'wrong', which do not accord with committee objectives. Second, good relationships with unsuccessful applicants are difficult to attain. Third, this lack of time corroborates the view of many unsuccessful applicants that their case did not have adequate consideration. The unsuccessful applicant may suspect that his case was considered in general terms rather than in the particular detail which he thinks is important in his case.

An advantage of the peer review system is that it can be used to indicate new disciplinary areas that show promise. If, for example, money is given to a new field and the quality of research proposals is low it can create caution to providing further funds even if the field is politically popular. Alternatively, emerging new areas can be found as a result of original and imaginative proposals by researchers with good records in adjacent areas.

A problem that may arise is that if there is an announcement that there is money available for certain kinds of research it will attract a large number of proposals, and if funds are only available for a limited number of areas, it will result in many gaps.

General observations of the peer review system are that it favours safe proposals rather than highly original projects that do not fall within accepted paradigms, that it favours experimental work with well-developed theory instead of theoretically unfavoured work, and that it favours research projects that produce fast results that are published against work that takes longer to filter through as public knowledge.

Another problem with the peer review system, associated with the above observations, is that it can suffer from the art of 'grantmanship'(26). A researcher might design a proposal by basing it on a fashionable model (27). As a result he may collect several grants from outside bodies to give good support to badly formulated research. He may, therefore, undeservedly win a peer adjudicated grant on the basis of his other grants.

A similar situation to the above is where a researcher who has published many papers will find it easy to obtain funding due to this recognition resulting in him being able to publish even more. This has been called the 'Matthew effect'(28). Simply, those who have already received grants receive more. This favours the eminent researcher with many grants at the expense of the little known researcher with new ideas.

In recent years the peer review system has come under much criticism. This has been due to researchers complaining that they have not received a fair share of the scarce resources, involving funding, manpower and equipment, that they should have had (29).

It has been said that the peer review system is a constraint on academic research and because of this what has been called its 'elitism' has been attacked (30). This is because peer review when distributing funds produces a concentration of grants to a limited number of researchers. Instead of funds being distributed on a geographical basis they are provided for according to 'excellence'. This sort of argument puts into question the basis upon which peer review was founded - that of being judged only by those with competence to judge in that they are one's equals.

It has been said, on the one hand, that the peer review system is good at providing project grants within the limits of a given number of universities and other institutions of higher education, and is good at creating a given balance of support among scientific disciplines. Whereas, on the other hand, it has been said that it is no good at dealing with broader issues such as the support between universities or how much money should go to one discipline compared with another (31).

Another criticism against peer review is what Nelson has called 'proposal pressure'(32). This is that funds allocated by the SERC to its committees seem to depend upon the volume of proposals received by each committee in previous years (as well as on the basis of funds used in the preceding session). Very often the scientific community has already decided what is worth doing, by weighting the researchers involved and the quality of their ideas in specific proposals, before adjudication is made.

Some observers of the peer review system have said that it should be more open in order to overcome the comments of critics who have viewed it as an 'old boy' system that perpetuates established institutional ideals (33). This could be overcome by allowing younger researchers and those who represent lesser known concepts to be included in the process. This would allow peer review to become a more open process and mechanism for determining proposals, instead of the closed and academic exercise that exists. This is met to some extent by the Science Board system of using younger researchers as sub-committee members.

The peer review system allows grants to be made to academic researchers on the basis of 'timeliness and promise'(34) of their proposals. Members of review panels are allocated from similar 'invisible colleges' of research colleagues, which allows the researcher to be adjudicated by his or her research community opinion. As a result support by peer review procedures usually gives more standing to 'internal' criteria, such as the advancement of expertise within a particular research area, rather than 'external' factors such as the possible use of what might be found. This means that 'excellence' tends to be the fundamental criterion for support (35). As a result the peer review system is directed towards the allocation of funds for pure research.

It needs to be remembered that peer review is the best system the academic world has for providing grants on as fair a basis as possible. If replaced by another system, as has been suggested, it could result in something far worse. The best way to overcome the problems is by improving the way in which peer review is carried out. This would be by creating a more open system, that would be accountable to the academic community, and including more representation within it. In essence what one is saying is that there should be improvement of the system rather than destruction and replacement. If more emphasis was placed on 'external' criteria it might enhance its ability to provide a fairer share of funding and perhaps bring it more in line with the customer-contractor process. (This, of course, does not mean equal shares for all, since this would destroy the selectivity of the research council system).

1.3 The Customer-Contractor Principle

According to the customer-contractor principle the customer says what he wants, the contractor does it, and the customer pays (36). This was stated in Lord Rothschild's report in 1971 which referred to applied research that has practical application as its objective (37). Scientific back-up was required on the customer side because the customer-contractor principle could not work in isolation (38). A strong distinction was made between basic and applied research. Research that is basic was seen as principally taking place within research councils and universities and directed towards the 'discovery of rational correlations and principles'(39), whereas applied research has 'a practical application as its objective'(40). A named customer was required to fund applied research which is distinguished by its objectives. In its purest form the customer-contractor principle gave government departments responsibility to formulate policy for applied research to be implemented by their contractors (41). Examples of these were research councils, in-house research establishments and others. In this model on the customer side are government departments and on the contractor side are research councils. It has been said that there needs to be development of the customer role in the customer-contractor relationship (42). Seen in this light the metaphors of customer and contractor show that the customer metaphor or the government needs to have explicit objectives 'before entering the marketplace to purchase knowledge from researchers'(43) and the contractor metaphor requires an autonomous scientific community. In real life the relationship for both sides show many epistemologies, functions, goals and power bases (44). And there is probably a better chance of it succeeding when the research product is easily recognised (45).

When the Rothschild report was published it created a great debate. This took place in various forms. Much comment was given in Nature and New Scientist. In the Times 4 editorials and 45 letters were published on the subject (46).

By those opposing Rothschild it was stressed that science should have autonomy, that there were dangers in state control and that the style of Lord Rothschild's report was irritating (47). Also the validity of the distinction between pure and applied research was questioned (48). It was said that such a strong distinction missed the possible spin-offs and interactions (49).

Those who supported Rothschild said that the proposals were a step in the right direction (50). Although some people felt he had not gone far enough (51).

This work considers the customer-contractor principle in its broadest sense. That is, anyone who commissions research and all those undertaking the research are acting according to the principle. This principally includes government, industry and charities on the customer side. By taking this approach it is possible to measure funding provided on this basis.

1.4 Measurement of Research

The three principal stages at which research can be measured are at the input stage, during the research process and at the output stage. Table 2 shows the measurement of research at these three stages for preferred and non preferred measures.

For the input stage the most used measure of research is the amount of funding. The best known example of this is the Science Budget. The amount of funding is also used by the research councils for their annual research reports. The number of research grants is not used as much but does find acceptance by those undertaking policy analysis studies as a contributing factor to statistical measures. A good example of this is Farina and Gibbons' study of peer-adjudicated research grants awarded by the then Science Research Council (SRC) between 1964 and 1974 (52, 53). They used a statistical measure of the concentration of resources by grant-awarding committee to see whether the SRC's policy of 'Selectivity and Concentration' (54) had taken effect. From close analysis of the pattern of grant distribution adopted by the Council they found little change between the time the policy was adopted and the last year of their study in 1974.

TABLE 2

MEASUREMENT OF RESEARCH

		STAGES		
		INPUT	PROCESS	OUTPUT
MEASURES	Preferred Measures	Amount of Funding Number of Grants	Number of Scientific Personnel, Use of Equipment	Research Publications, Citations
	Non-Preferred Measures	Gifts	Research Period	Patents

Another measure of input is the number of gifts of equipment and money. But this only forms a small amount of the resources that are provided for research and is, therefore, of no great significance.

The measurement of the actual research process has had minimal study. This is because it is difficult to measure something that is constantly changing. It is possible, though, to measure the number of scientific personnel in the research process who are actively taking part in research. This has been done by measuring the number of Qualified Scientists and Engineers (QSE's). Studies that have measured QSE's have taken place in both the academic world and industry. An example of the measurement of the activities of scientists in universities and industry was the study by Cotgrove and Box (55).

An easier way of measuring the activity of scientists in the research process has been by studying awards and membership of learned societies. But this has only been applicable to indications of scientists of real eminence. Examples of this are awards like Nobel prizes and membership of learned societies like the Royal Society. de Solla Price studied the listings of scientists in a biographical compilation of the American Men of Science. The numbers listed increased from 4,000 in 1903 to 96,000 in 1960 (56).

Another measure of the research process is the amount of equipment used. By doing this it is possible to make comparisons between disciplines.

It is also possible to measure the time taken to undertake research but this has found little use because of difficulties in obtaining such data. Even if obtained there may be problems due to inaccuracies arising from varying time periods, undetermined starting and finishing dates and extensions of cut-off points.

The most popular way of measuring research is by quantification of its outputs. The problem with output measurements, though, is one of accuracy. This is because measurement of the flow of information containing the results of research can involve problems of what is actually being measured.

The best measure of output, in terms of the flow of information, is the number of published scientific papers. By doing this one is at least able to measure part of the research activity.

There has been quite a lot of empirical investigation into the use of published research papers as a means of measuring research. The average output of papers by Indian researchers has been estimated by Rangarao (57) which was found to be approximately equivalent to one paper every ten to twelve scientist-years. de Solla Price (58) roughly estimated an output of one paper every two scientist-years for the world. The output of Russian research scientists was roughly estimated by Kapitza (59) to be only half that of United States research scientists.

In a pioneering article in the 1920's Lotka (60) showed that for some branches of the natural sciences for every 100 authors who produce one paper during a certain period, the number of authors producing 'n' papers is about '1/n squared'.

The output of the most eminent men of science was investigated by Wayne Dennis and others (61) in the 1950's. It was shown that the most outstanding scientists are usually prolific in their volume of output.

Concerning the degree of concentration in research output Rangarao (62) showed that in India 8 universities out of 68 accounted for 50% of university research papers. He also found that 44 institutions out of 2,000 contributed 50% of all papers. 17 institutes with the biggest output of papers provided 30% of all papers to Indian journals and 50% of all papers in foreign journals.

Published papers can be used not only to show characteristics about researchers, disciplines, institutions and countries, but also about publication practices themselves. An example of this is the increasing 'multiplicity' of authorship. By studying chemical abstracts it was found that single author papers had by 1960 declined to account for less than 50%, and papers with four or more authors were increasing faster than papers with less authors (63). As a result there seems to be an increasing number of co-authors who support elite researchers who lead teams and groups.

Another preferred method of measuring research output has been by citation analysis. This has been established by Eugene Garfield through the Science Citation Index (64, 65). By using the Science Citation Index one can undertake citation counts for all papers published by an author, a research group or an institute. Although citation analysis can measure the productivity of work it cannot measure its merit. An example of the use of citation analysis is the indication of likely Nobel prize winners. Harriet Zuckerman found that the average winner in the 1960's received at least 200 citations during the year before receiving the honour (66, 67). Another use of citation analysis has been for tracing the emergence of scientific disciplines.

A non-preferred method of measuring research output is by using patent statistics. The principal disadvantage with patents is that they are not as easy to obtain information from due to secrecy, but they do show the practical value of research.

Although many policy studies use only one of the different methods of research measurement some studies use several. An example of this was an attempt to measure research output of university staff in chemistry by Blume and Sinclair (68). They used five output indicators which were the number of publications measured by counting papers published and awaiting publication over a five year period; doctorate awards to students over five years; relevance according to the number of co-operative awards in pure science, number of patents held and the days spent on consultancy each year; peer group judgement according to recognition measured by honours and medals; peer group assessment by asking respondents to name individuals whom they considered to be pacemakers in their own area in the UK and abroad.

Another example of several research measures being used in a study was the investigation by Verry into the planning of higher education at the sectoral level: with special reference to higher education costs in Britain (69). Research output was measured in two alternative ways. The first method counted the number of books and articles published by department's staff over two years. This was then averaged to give an annual publications measure of the research output of departments. The second method took as an index of the research output of a department the annual hours of personal research by academic staff. This was taken from a survey of the use of academic staff time.

Although research measures do not give completely accurate accounts of research activity they do give a good indication of what is happening. Out of the different measures that have been used publication counts in their various forms are probably the most useful.

1.5 Research Publications

The amount of research undertaken by a non-random sample of universities and polytechnics was measured to illustrate research activity on both sides of the binary divide. This was achieved by choosing a sample of twenty institutions comprising an equal number of universities and polytechnics from a total population of one hundred institutions of higher education in the UK.

The data for the sample were obtained from research reports usually published annually at the end of an academic year by an institution. The period under consideration was the ten years from 1970 to 1979. The reports were obtained by the institutions response to being asked if they would participate in the survey.

The measurement of research was by 'publication'. A publication in this sense is defined as 'making publicly known'(70) in the form of a book or a periodical. The view of a publication expressed by J. M. Ziman (71) as being in the form of a paper in a journal or abstract journal, a book or review article was also deemed relevant to this work, therefore, allowing for a wide definition. This was to allow for the slightly different approach of institutions towards what a publication was in their research reports. All the different types of publication (72) were included. No judgement was made as to what constituted a publication, the judgement of the institution concerned being taken as the determination.

In the preliminary analysis all subjects were taken into account to provide an overall view of publication practices. For the specific view, for the characteristics of science publication, the number of physics and chemistry publications were found, to give an indication of the nature of analytical science publication. Table 3 shows the number of publications produced by academic units (departments, schools, research units and institutes) in institutions for the sample.

Although the number of academic units is of doubtful validity since departments evolve, split and change their name, the number does indicate the structure and size of an institution. (A department is a traditional unit which can be identified in most institutions although some depart from this organisational structure in order to attempt to overcome perceived difficulties of internal communication and management).

The total number of academic units in the sample was 593. This gave an institution average of 30 units. The number of university units was 386 and polytechnic units was 207. This gave average figures of 39 and 21 respectively.

The total number of publications produced by academic units by all 20 institutions was 65,110. This gave an institution average of 3,256. For universities the total was 52,589 with an average of 5,259 publications per institution. For polytechnics the total was 12,521 with an average of 1,252 publications per institution. The number of university to polytechnic publications was approximately 4:1.

The figures of 1.8 times as many academic units in universities as in polytechnics and 4:1 as many publications being produced for 1970-1979 in the sample gave an overall figure of twice as many publications being produced by university units as by polytechnic units. When comparing physics with chemistry for each institution it was apparent that

TABLE 3

NUMBER OF PUBLICATIONS AND ACADEMIC UNITS

Institution		Number of Publications	Number of Academic Units
University			
1.	University College, Bangor	4,736	32
2.	University of Bath	4,222	22
3.	The Queen's University of Belfast	8,550	92
4.	University of Durham	5,505	44
5.	University of Kent at Canterbury	3,540	15
6.	University of Leicester	7,654	53
7.	The University of Salford	5,502	27
8.	University of Stirling	3,087	26
9.	University of Warwick	4,918	42
10.	University of York	4,875	33
	Total	52,589	386
Polytechnic			
11.	The Hatfield Polytechnic	859	25
12.	The Polytechnic, Huddersfield	1,777	42
13.	Kingston Polytechnic	1,627	20
14.	The Polytechnic of Central London	1,152	21
15.	Oxford Polytechnic	1,475	21
16.	Paisley College of Technology	899	11
17.	Plymouth Polytechnic	1,497	16
18.	Sunderland Polytechnic	1,440	20
19.	The Polytechnic of Wales	1,115	14
20.	The Polytechnic of Wolverhampton	680	17
	Total	12,521	207
	Sample Total	65,110	593

there were more chemistry publications resulting in higher percentages for this subject. In fact chemistry was the most productive subject for both universities and polytechnics.

Out of the 65,110 publications in the sample the 3,980 physics publications and 7,275 chemistry publications accounted for 6.1 per cent and 11.2 per cent of the sample respectively. There were 1.8 times as many publications in chemistry as in physics.

The numeric growth of publications for the whole sample in Figure 1 shows that there was a fairly constant increase in the number of publications in the sample. This increase became greater towards the end of the 1970's, and this growth was probably related to the increase in the funding over the 1970's. 1979-80 might be an upper limit, with constraints on funding since 1980 there could be a future reduction in the growth of publications.

The rate of growth for publications is graphically illustrated in Figure 2. It can be seen that the rate of growth progresses in a 'wave-like' pattern. The peaks and troughs occur every 4 years. From Figure 2 it is apparent that there is a 'publication cycle' with the peaks becoming stronger with time.

The 'publication cycle' has an important bearing on the publication characteristics of the sample. It illustrates the way in which the number of publications grow over a period of time. The factor probably creating this cycle is the impact of new researchers on the rate of growth of publications at various points in time.

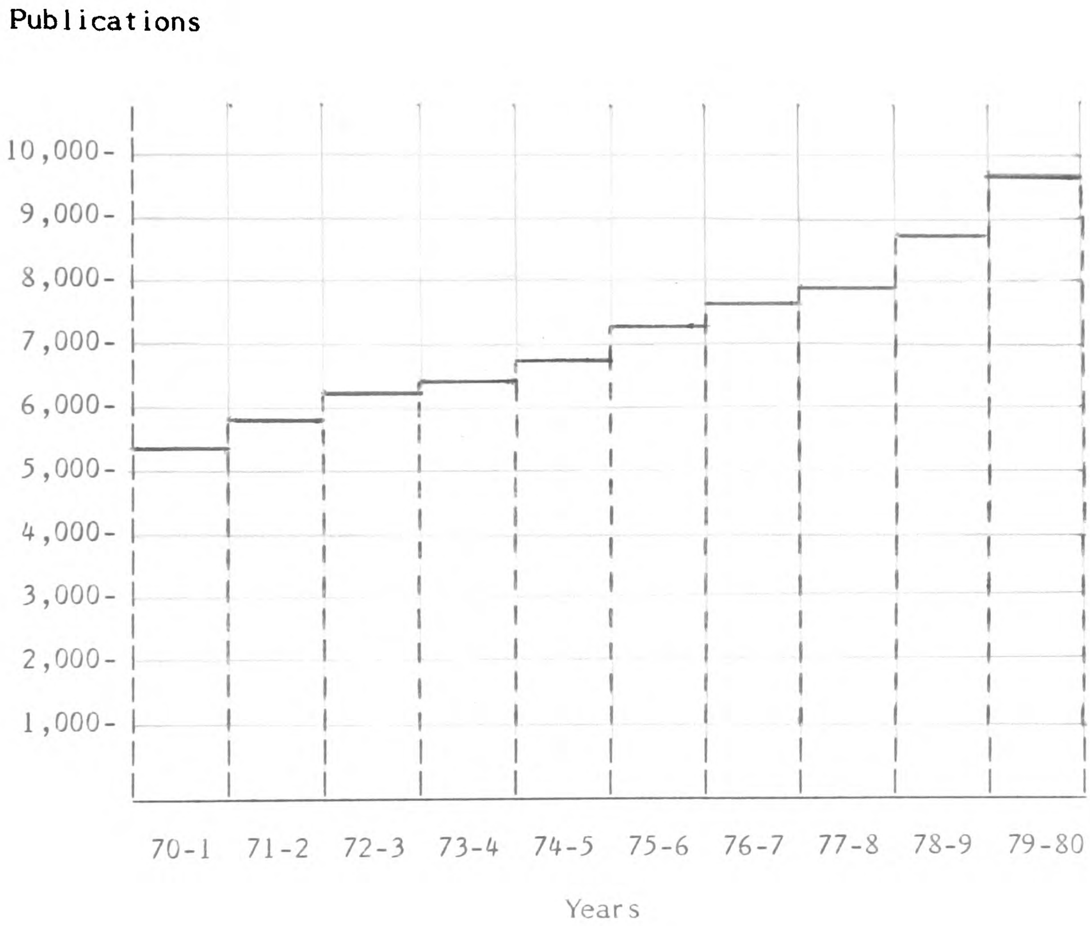

FIGURE 1

PUBLICATION GROWTH

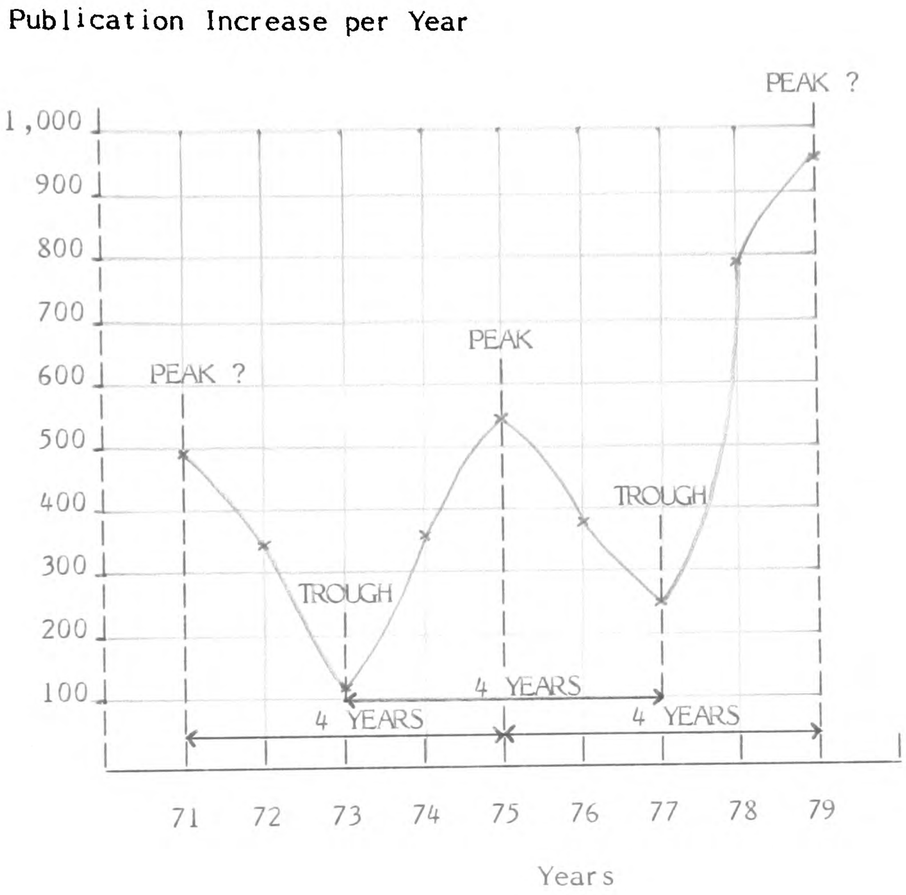

FIGURE 2

PUBLICATION GROWTH RATE

There was a fairly high rate of growth of publications at the start of the 1970's following the creation of the polytechnics and expansion of the universities, which then reduced, possibly as a result of the re-organisation of departments in many institutions, to produce the 1973 trough. The new researchers introduced in the re-organisation re-established the rate of growth giving the 1975 peak. The dilution of available funds over the increased number of researchers probably caused the 1977 trough. However, the creation of new research units increased the rate of publication growth to produce the 1979 peak.

For the sample the publications have grown from 5,369 in 1970-1 to 9,665 in 1979-80. This shows an approximate doubling time of between 10 and 15 years if such growth continues. de Solla Price (73) has referred to this doubling of publications every 10 to 15 years when describing the exponential growth (74) of publications as the First Law of Research on Research (75):

> 'The size of Science as a function of time exhibits a regular exponential rate of growth, holding for periods as long as 200 years with a doubling every 10 to 15 years. One gets about the same rate whether you count men or scientific journals, or the papers published in them. Rates vary only a little from field to field of science, from country to country'(76).

The growth of publications over the ten year period in the sample shows agreement with this. And the 'publication cycle' for the rate of growth of publications from year to year is an important observation on the way such growth occurs. It is evident that this work corroborates de Solla Price's although here analysis has been made of the reason for the rate of exponential growth.

This work also indicates that the rate of growth of publications increases in a 'wave-like' pattern of expanding magnitude. This is due to pressures on research that cause a greater increase in some years than in others. This results in the doubling of publications every ten to fifteen years.

The positive pressure exerted by the introduction of new researchers driven by the funding of their research to publish as much as they can 'publish or perish'(77) causes an increase in the rate of growth in some years. Other than by constraints already mentioned this positive pressure may be partly opposed by the peer-adjudication of journals which acts as an opposite pressure in other years, so reducing the potential rate of growth.

This 'see saw effect' of positive pressure from the funding of researchers and sometimes negative pressure from peer-adjudication for journals in the 'publication process' probably produces this in-built 'up and down' movement in the rate of growth of publications, resulting in the doubling time of no more than 15 years and no less than 10 years.

To find the approximate doubling time of the publications in the sample the total growth can be described as Pn-Pi where Pn is the number of publications in the nth or last year and Pi is the number of publications in the first year. The growth per year can be described as $\frac{Pn-Pi}{(n-1)}$,

where n - 1 is the nth or last year -1.

Noting these two expressions the doubling time approximation can be expressed as follows :

Let N be the number of years in excess of n required to double the number of publications in the first year, then as an approximation

$$\left[Pn + \frac{(Pn - Pi)N}{(n - 1)} \right] = 2Pi$$

$$\text{giving } N = \frac{(2Pi - Pn)\ (n - 1)}{(Pn - Pi)} \text{ ------ } (1)$$

Hence if D is the doubling time

$$D = n + N \text{ ------ } (2)$$

Applying equation (1) to the number of publications in the sample for the 10 years from 1970 to 1979 for Pi = 5,369 and Pn = 9,665 gives

$$N = \frac{[(2 \times 5{,}369) - 9{,}665] \times 9}{(9{,}665 - 5{,}369)} = 2.248$$

Hence if D is the doubling time

$$D = n + N \text{ ------ } (2)$$

$$= 12.248$$

Taking the doubling time as occurring within 10 to 15 years (according to de Solla Price) the mid point will be 12.5 years in the 13th year. The result of 12.248 for D (being in the 13th year) shows good agreement with this. Accordingly, the publication distribution over the ten years in the sample must be fairly accurate.

Whether the pattern of exponential growth continues in the future as has been apparent in the historical progression of science through the ages to the development of modern science is yet to be seen, especially with the publication practices of the contemporary scientist being affected by a world of limited resources, and therefore a levelling off (78). Further to this, E. J. Hobsbawm (79) has stated that in terms of a modest global increase in scientific research papers, there is a relative decline of British scientific output. However, this statement has been questioned by P. V. Dankwerts (80) who has criticised the way in which the scientific output in such an exercise is defined.

To obtain a closer look at the way in which the growth of research activity occurs in terms of different areas in higher education the funding of the arts and sciences each side of the binary line can be investigated.

CHAPTER 2

The Arts and Sciences each side of the Binary Line

CHAPTER 2

The Arts and Sciences each side of the Binary Line

2.1 Two Cultures and Within

There has been much debate on the proper balance and level of endeavour between the two broad cultures (81) encompassed within higher education. Many subjects are not easily separated into these distinctive categories due to components of intuitive skill and quantitative rigour. Higher Education Institutions (HEI's) are composed of departments and faculties which teach, research and practise arts (including humanities, social studies, business, education, art and design) and sciences (including scientific, technological and engineering subjects).

Arts are those branches of study serving as preparation for life involving languages, literature and history. Whereas, sciences are those branches of knowledge conducted on scientific principles. Table 4 shows how these research areas are defined by the Council for National Academic Awards (CNAA), Advisory Board for the Research Councils (ABRC) and the present work in terms of Arts and Social Sciences (A & S) and Science and Technology (S & T).

Variations in terminology are due to academic boundaries being drawn between the fundamental traditional sciences and practical or applied subjects in engineering or other technological areas. Science and engineering are often treated under the same title such as the 'Science Museum', 'Department of Education and Science' and 'Science Parks' on university campuses. The Finniston report (82) makes a strong case for a

TABLE 4

DESCRIPTION OF RESEARCH AREAS

CNAA 1984 Policy	ABRC (including actual allocations for 1983 - 84)	Present Work
1. Art and Design 2. Arts and Humanities 4. Creative and Performing Arts 5. Education 3. Business and Management Studies 7. Social Sciences	1. ESRC £ 22.4 M (formerly SSRC) Total £ 22.4 M	1. Arts and Social Sciences (A & S)
6. Science and Technology	2. AFRC £ 46.0 M (formerly ARC) 3. MRC £113.7 M 4. NERC £ 62.5 M 5. SERC £254.5 M (formerly SRC) Total £476.7 M	2. Science and Technology (S & T)

distinction. This led to a change in title from the 'Science Research Council' to the 'Science and Engineering Research Council'. Science has and will continue to define a general area for organized knowledge involving tangible materials.

Academic areas like geography and architecture have roots in both the arts and sciences. This poses a problem of classification especially when evaluating the forces leading to growth and decline. These forces are likely to proceed at greater pace in the future than in recent decades. The decade of the 1970's illustrates this and has been studied in order to determine the growth of areas in terms of academic activity.

2.2 A Comparison of Publications

The twenty HEI's in the sample were selected for comparison of the number of publications for the ten years from 1970 to 1979 in the two academic areas of A & S and S & T. The HEI's were equally divided between universities and polytechnics and were of similar size. They represented a wide geographical selection from the south west of England to the north east coast of Scotland and from London and the Home Counties to Northern Ireland. In Scotland because there are no formal polytechnics Paisley College of Technology, which is a Scottish Central Institution, was selected as one of the institutions with polytechnic characteristics.

For the total number of publications in A & S and S & T shown in Table 5 and the growth of publications in each area the most striking feature is the close similarity in the relative numbers in universities and polytechnics and the parallel growth patterns between these two areas.

TABLE 5

NUMBER OF A & S AND S & T PUBLICATIONS 1970 - 1979

H.E.I.		A & S Publications	S & T Publications
University			
1.	Bangor	2,161	2,575
2.	Bath	1,638	2,584
3.	Belfast	2,445	6,105
4.	Durham	2,720	2,785
5.	Kent	1,950	1,590
6.	Leicester	3,077	4,577
7.	Salford	834	4,668
8.	Stirling	1,632	1,455
9.	Warwick	2,457	2,461
10.	York	2,919	1,956
	Total	21,833	30,756
	Average	2,183 (41.5%)	3,076 (58.5%)
Polytechnic			
11.	Hatfield	209	650
12.	Huddersfield	1,188	589
13.	Kingston	707	920
14.	Central London	488	664
15.	Oxford	803	672
16.	Paisley	213	686
17.	Plymouth	407	1,090
18.	Sunderland	492	948
19.	Wales	364	751
20.	Wolverhampton	406	274
	Total	5,277	7,244
	Average	528 (42.2%)	724 (57.8%)
	Sample Total	27,110	38,000
	Sample Average	1,356	1,900

Contrary to certain conventional wisdom the proportion of A & S to S & T is higher in the polytechnics (42.2 per cent) than in the universities (41.5 per cent). Although there are substantial differences between institutions Table 5 represents a large amount of the total academic output of the 1970's in the UK.

Obvious pitfalls are accrued to simply counting publications. A publication is the result of a piece of work which has reached a level of acceptability by a publisher or journal for subsequent peer review assessment of its contribution to knowledge. It is, therefore, not a measure of achievement in itself. Also, for the timescale covered by successive reports variations arise resulting in publications being counted more than once in some institutions. For research, different areas vary in tradition, style and resources. Worth consideration, therefore, is the relative number in A & S and S & T between universities and polytechnics. In Table 5 the data given havebeen taken from institutional reports for the period 1970 - 1979. These are the subject of some editorial control over the criteria for inclusion showing the different practices between A & S and S & T. The proportion of reviews of single works or of general areas is thus found to be generally higher in A & S whereas the proportion of publications of completely new information is generally higher in S & T. Detailed analysis shows that the proportion of different categories of work are similar for A & S and S & T in different institutions. The way in which A & S and S & T is subdivided in institutions was found from the number of departments in these two areas. This is shown in Table 6.

TABLE 6

NUMBER OF A & S AND S & T DEPARTMENTS

H.E.I.		A & S Departments	S & T Departments
University			
1.	Bangor	19	13
2.	Bath	11	11
3.	Belfast	37	55
4.	Durham	31	13
5.	Kent	8	7
6.	Leicester	27	26
7.	Salford	10	17
8.	Stirling	16	10
9.	Warwick	32	10
10.	York	21	12
	Total	212	174
	Average	21	17
Polytechnic			
11.	Hatfield	8	17
12.	Huddersfield	27	15
13.	Kingston	13	7
14.	Central London	8	13
15.	Oxford	14	7
16.	Paisley	3	8
17.	Plymouth	5	11
18.	Sunderland	10	10
19.	Wales	5	9
20.	Wolverhampton	11	6
	Total	104	103
	Average	10	10
	Sample Total	316	277
	Sample Average	16	14

2.3 Funding the Arts and Sciences

Funding particularly for studentships and equipment associated with higher degree work dominates the style of research between A & S and S & T. The two principal agencies are the Science and Engineering Research Council, and the Economic and Social Research Council (ESRC) formerly the Social Sciences Research Council (SSRC) with respective current budgets of £254.5M and £22.4M.

Also heavily weighted on the side of S & T is other public and private funding. The view of successive governments that the growth of national wealth is fostered by funding based on a mix of potential serendipity and dirigisme in the areas of science and engineering is reflected in this weighting. The Advisory Board for the Research Councils, which is the body advising the Government on this balance, has become more open in its considerations recently (83, 84). It has, therefore, become more amenable to public representations on the relative merits of all the different forms of research.

Successive annual reports of the SERC have revealed that the distribution of its budget shows that the biology and chemistry committees allocate the largest number of grants and studentships among the 20 or more committees. Highly developed communities for judging excellence by peer review processes are apparent in these areas. Of significance is that the proportion of these resources allocated to polytechnics over the years is 1 - 2 per cent. Areas designated in terms of judgement on national need rather than a community demand that have been funded by the SERC is the province of a directorate rather than a committee. The Teaching Company

Directorate allocating about two thirds of its funds to universities and one third to polytechnics in recent years is an example.

It seems certain that funding which is proactive to work identified by industry or government is easier to win than funding which is reactive to work the scientific community finds necessary. A recent report on improved links between higher education and industry, by the Advisory Council for Applied Research and Development (ACARD) (85), argues for a better balance between pure and applied research. It says this should be achieved by the reallocation of work which is less urgent, interesting or in worked out areas rather than by undermining excellent work or scholarship.

This apparent classification of research into a first division of pure work and a second division of potentially applied work is seen by some overseas academics as a peculiarly British attitude. Problems have arisen in identifying which of the publications listed in Table 5 (Page 35), are representative of work worth perpetuating because of intrinsic excellence and other than by forces of supply and demand of resources, should be replaced by more applied work. This raises the question on the extent to which policy is led by the peer review process or the customer-contractor principle and the forces which influence these two processes.

2.4 A Comparison of Universities with Polytechnics

Between universities and polytechnics two aspects of comparison need comment. Firstly, it is generally believed that polytechnics are relatively stronger in S & T than A & S for the proportion of work between these two areas. This was a feature of their parent colleges, which were originally technical colleges, and was written into their raison d'etre as a result of the Robbins report (86). It is also a firmly held belief of many members of the Board of the Council for National Academic Awards (CNAA) on both sides of the cultural divide. This is highlighted by a policy statement on research and related activities published by the CNAA in 1984 (87).

A larger rigour gap may be in evidence between A & S and S & T in publication reports in polytechnics than in universities but a careful and painstaking study of the respective publications would be needed to support this view. Of greater likelihood is that the strength of university S & T hardened by strong competition for research council funds has been underestimated by those people in the maintained sector who have believed that research achievements are fairly even across an institution.

Secondly, the general observation that universities report many more publications than polytechnics is not surprising in view of some of the relevant factors.

One factor is that the comparison of courses and departments reveal some material which is similar but a lot more that is different and lacking identity with research funding and higher degree work in the way established subject areas are shown in universities.

Another is that the dual funding policy of the University Grants Committee allows similar undergraduate unit cost in universities as in polytechnics but allows about an extra 25 per cent for research being the seed corn for further funding from the research councils and other sources. The last factor is concern with the distinctive style of universities and polytechnics and is partly described in terms of the establishment and role of Senior Academic Staff (SAS).

2.5 The Contribution of Senior Academic Staff

In conventional subjects such as biology and chemistry most universities have separate departments each usually with a number of professors who are appointed in terms of academic ability.

In polytechnics, on the other hand, there are relatively few separate biology and chemistry departments and the proportion of SAS is required to be much smaller in number and salary by the respective negotiating machineries. More than one post at the head of department level within a department has been permitted on the Burnham scale. But very few such appointments have been made.

Managerial and administrative duties within university professorial ranks such as head of department, dean, vice principal or pro-vice chancellor are usually shared by rotation for short-term periods with the managerial role being secondary to the academic role in most cases. Typically all academic staff under principal/vice chancellor have a teaching and/or research role.

A different ethos is produced by the factors operating on polytechnics in which SAS are head of department, school or research unit, dean, assistant director and deputy director. A course also has an important identity with responsibility being placed on a course leader. Definition of these posts is largely in management or academic leadership terms for which teaching and research is secondary to responsiveness to many agencies.

There are a large number of agencies through which local authority maintained education operates. These generate greater numbers of planning and policy issues than on the university side of the binary line. Universities can afford a greater emphasis on academic activity resulting in an evaluation of the type of material students receive and the way in which they receive it.

The average number of SAS from a sub sample of 10 selected institutions of similar size were 52 in universities and 25 in polytechnics for the year 1979-80. They each published an average of 15 and 22 publications respectively in the university A & S and S & T areas over the decade of the 1970's and in polytechnics 6 and 4 publications in the A & S and S & T areas.

The comparisons of SAS show differences in style of institutions relating to the institutional balance between the roles of academic work and management. In universities SAS tend to be concerned with academic work whereas in polytechnics they are concerned with management.

These factors affect the ethos of an institution which in turn influences the abilities of students who determine the nature of future society. Amongst these are science and engineering students.

CHAPTER 3

A Comparison of Funding in Engineering and Science

3.1 Science compared with Engineering
3.2 Science and Engineering Publications
3.3 Funding Science and Engineering
3.4 The Development of Science and Engineering

CHAPTER 3

A Comparison of Funding in Engineering and Science

3.1 Science compared with Engineering

Engineering and science show both similarities and differences. Similarities arise on a logical and systematic basis, whereas differences occur due to practice and application.

There are many definitions of science ranging from dictionary to textbook locations. T. H. Savory's definition is that: 'Science consists of organized knowledge in which the facts have been obtained by observation and progress has been directed by hypothesis' (88). Lachman has said that 'Science is a knowledge-generating activity. It is a continuous, creative, and cumulative process' (89).

For science policy purposes the Dainton report (90) subdivided science into three principal categories which were:

'(a) tactical science - the science and its application and development needed by departments of state and by industry to further their immediate executive or commercial functions ...
(b) strategic science - the broad spread of more general scientific effort which is needed as a foundation for this tactical science. It is no less relevant in terms of practical objectives ..., but more wide ranging ...
(c) basic science - research and training which have no specific application in view but which are necessary to ensure the advance of scientific knowledge and the maintenance of a corps of capable scientists.' (91)

The principal areas of science can still be broken down into physics, chemistry, biology and mathematics. The main societies for science in the UK are the Royal Society of London for the Promotion of Natural

Knowledge, The Royal Institution of Great Britain and the British Association for the Advancement of Science. For the four main areas of science the Institute of Physics is the main society in physics, The Royal Society of Chemistry in chemistry, the Institute of Biology for the biological sciences, and the London Mathematical Society for the mathematical sciences.

This model of the organisation of the scientific community in the UK has been developed over several centuries and has been used as a forebear for the development of similar organisational structures in many other countries.

Scientific societies in the UK make important contributions to the understanding of the requirements of the funding of scientific disciplines. They do this by having representation on policy making bodies. They also very often take up the initiative of providing policy for the development of ideas concerning the funding of new areas in their respective disciplines.

Engineering, although similar to science in the way it is segregated into principal disciplinary areas, is different due to the fact that these areas conform to industrial practice. Engineering can be defined as 'the art of directing and controlling physical forces towards either economic or military ends' (92). Because the ends and studies are various engineering is an eclectic combination of the principles of the sciences and business.

The main branches of engineering include civil, electrical, mechanical, chemical, mining, production and marine. These categories are not mutually exclusive and there is a certain amount of cross-disciplinary activity. A rational division can be made between civil engineering (concerned with equilibria between static and dynamic loads and statical reactions) and mechanical and electrical engineering (concerned with the transfer of energy). Production engineering can then be defined as 'repetitive performance of both mechanical and chemical actions for purposes of manufacture' (93).

The principal engineering institutions follow the main branches of engineering which are the institutions of Civil, Structural, Electrical, Mechanical, Chemical, Mining and Marine. These are overviewed by the Council of Engineering Institutions. Due to the fact that these institutions are directed towards the industrial setting of their disciplines they tend not to partake in or influence policy on the funding of engineering disciplines.

The very nature of the difference between science and engineering can be seen by comparing the scientist with the engineer. Whereas, a scientist is an investigator in a laboratory, an engineer 'combines scientific with other knowledge and skills for the purpose of planning and directing constructional works or industrial production' (94). Whether a scientist's research is basic or applied his first concern with his work is an understanding of the material universe. For an engineer it is to create physical constructs by controlling forces efficiently. As a result of this, in the academic world the scientist sees funding in terms of the development of ideas in his discipline. Whereas an engineer sees funding in terms of developing ideas that can be used in practice. Perhaps one of the best distinctions between science and engineering was written by Sir Richard Gregory, for many years editor of Nature who said :

> 'Science has done its part when it has made a new discovery; constructive engineering renders good service when it shows how the discovery may be chained to the chariot of industrial advance. To foresee the possibilities of a discovery, to transform a laboratory experiment into a mechanical plant of a large works or to apply it to the needs of ordinary life, require aptitudes not commonly possessed by the scientific investigator. The engineer .... seeks not so much to know Nature as to circumvent her.' (95)

Whereas a scientist needs to be an individualist an engineer needs to be practical. The engineer needs to combine science with empiricism in circumstances where science is not established. This dependence of engineering on science was illustrated by the annual James Forrest Lecture at the Institution of Civil Engineers which had 'the interdependence of abstract science and engineering' as its theme (96).

The above critique of the similarities and differences between science and engineering, which illustrates the dissimilar funding provision, can be expanded by stating their common and special characteristics. These are shown in Table 7 which illustrates the basis for funding.

The common characteristics in Table 7 arise due to there being no basic philosophical difference between science and engineering. This is because the scientist and engineer have a similar philosophical outlook by endeavouring to confirm theories. There is also no strong logical distinction. The methods of both science and engineering involve the origin of theories according to conjecture, experiments to test the theories and acceptance or refutation of these theories (97). By doing this they follow Popper's schema for the logic of scientific discovery by testing theories according to corroboration (98).

The aesthetic choice of the engineer can be compared with the choice of basic 'elementary' systems of the scientist by comparing design skill

TABLE 7

SCIENCE AND ENGINEERING

COMMON AND SPECIAL CHARACTERISTICS

	Common Characteristics	Special Characteristics	Funding Basis
Science	Philosophy Logic Testing theories	Main branches based on disciplinary areas associated with theory. Studies directed towards laboratory work	Funds principally obtained for the internal development of disciplines
Engineering		Main branches based on disciplinary areas associated with practice. Studies directed towards field work	Funds mainly obtained for the development of ideas for practical uses

with intellectual skill. Therefore, the strategy of approach to scientific problems is comparable with design and strategy in engineering. Differences that arise between science and engineering concern emphasis, motives for theorizing and experimenting, and differences in the scale of operation and experiment. The scientist's motives involve curiosity and the desire to relate previously unrelated phenomena by a simplifying pattern. An engineer's motive is to have satisfactory operation. This results in the engineer being less able to choose simple intellectual systems but he has the advantage of being able to make things operate according to good aesthetic design.

Accordingly, the special characteristics of theory and practice show the scientist to be a 'theoretician' and the engineer to be a 'practician'. It is this fundamental difference that results in funds being obtained for the intellectual development of disciplines on the one hand and for ideas of practical value on the other.

Science is learnt by science students as an introduction to the techniques they will use in later life. Students of engineering learn science in order to apply it to practical problems. Whereas, scientists very often can be considered to be fully equipped for their profession by higher education alone this is not applicable to engineers. Once educated, engineers then require professional training and experience and membership of a professional engineering body.

The standing of engineering and science in higher education can be assessed from comparative study of the distribution and patterns of their research funding and publications.

3.2 Science and Engineering Publications

From the sample of 20 institutions the number of science and engineering publications were measured for the period 1970 to 1979. The general pattern was one of predominance by science over engineering. The number of engineering and science publications produced by institutions is shown in Table 8.

The 32,728 science publications, with an average of 1,636 per institution, is six times larger than the 5,272 engineering publications, which has an average of 264 per institution. This results from the total of 26,922 science publications for universities, whose average is 2,692, being seven times larger than the engineering total of 3,834, having an average of 383 per institution. And the polytechnic total of 5,806 science publications, average 581, being four times greater than the engineering total of 1,438, giving an average of 144.

In 19 institutions there were more science than engineering publications. The only institution with more engineering than science publications was a polytechnic. Three universities had no engineering publications. Polytechnics had a greater proportion of engineering publications than universities being 20% compared with 12%. This is as one might expect due to polytechnics being more directed towards engineering and technology.

For science and engineering together 86% of the publications were science and 14% were engineering. This greater pattern of activity for science publications compared with engineering publications is qualified by the larger amount of funding received by science.

TABLE 8

SCIENCE AND ENGINEERING PUBLICATIONS

H.E.I.		Science Publications	Engineering Publications
University			
1.	Bangor	2,308	267
2.	Bath	2,056	528
3.	Belfast	5,575	530
4.	Durham	2,629	156
5.	Kent	1,590	0
6.	Leicester	4,430	147
7.	Salford	2,792	1,876
8.	Stirling	1,455	0
9.	Warwick	2,131	330
10.	York	1,956	0
	Total	26,922 (88%)	3,834 (12%)
Polytechnic			
11.	Hatfield	524	126
12.	Huddersfield	513	76
13.	Kingston	758	162
14.	Central London	505	159
15.	Oxford	638	34
16.	Paisley	480	206
17.	Plymouth	964	126
18.	Sunderland	808	140
19.	Wales	369	382
20.	Wolverhampton	247	27
	Total	5,806 (80%)	1,438 (20%)
	Sample Total	32,728	5,272

3.3 Funding Science and Engineering

Although science and engineering are funded together at national level by being incorporated in the Science and Engineering Research Council (SERC) they are separately funded within it. The principal Science Board Committees in the SERC are Biological Sciences, Chemistry, Mathematics and Physics, and the main Engineering Board Committees are Engineering Processes, Environment, Information Engineering, Materials, and Machines and Power (99).

For science and engineering together a total of £42.4m was spent by the then Science Research Council (SRC), excluding post graduate training, in 1978 (100). Of this total £17.4m (41%) was spent on engineering and £25.0m (59%) on science. This shows that science due to its distinctive divisions into a number of main disciplinary areas received more funding across the board than engineering. Out of the science total, physics received the largest amount of funding (£12.5m) due to provision for 'big' science facilities. Biology had £4.0m and Chemistry £8.0m. Mathematics received least (£0.5m) because of its theoretical character.

The distribution of the total value of research grants by the Biological Sciences, Chemistry, Mathematics and Physics SRC Science Board Committees for 1973, 1976 and 1979 to the institutions in the sample is shown in Table 9. The committees increased their contribution for 1976 to 1979 to these institutions except for Physics which reduced its contribution to the polytechnics in 1976 and universities in 1979, and Mathematics which decreased its contribution to polytechnics in 1979. For the sample total only Physics decreased in 1979.

TABLE 9

TOTAL VALUE (£,000) OF SRC RESEARCH GRANTS BY BIOLOGICAL SCIENCES (BS), CHEMISTRY (C), MATHEMATICS (M) AND PHYSICS (P) SCIENCE BOARD COMMITTEES AT EACH INSTITUTION IN THE SAMPLE (101)

H.E.I.		1973				1976				1979			
University		BS	C	M	P	BS	C	M	P	BS	C	M	P
1.	Bangor	48	58	-	48	44	77	-	58	144	35	13	22
2.	Bath	32	-	8	-	50	-	-	5	115	-	9	29
3.	Belfast	15	49	4	238	81	72	11	129	29	130	-	196
4.	Durham	42	111	7	30	27	76	5	40	37	73	11	61
5.	Kent	53	60	-	36	68	53	7	49	124	124	-	15
6.	Leicester	275	84	-	61	210	173	-	92	369	155	-	70
7.	Salford	-	20	-	150	-	69	-	112	58	53	18	57
8.	Stirling	5	32	-	40	51	82	6	80	76	31	-	87
9.	Warwick	71	109	17	99	116	94	21	266	189	181	13	192
10.	York	65	23	7	163	140	91	7	176	148	94	11	158
	Total	606	546	43	865	787	787	57	1007	1289	876	75	887
Polytechnic													
11.	Hatfield	-	-	3	-	-	-	11	-	-	-	-	-
12.	Huddersfield	-	-	-	-	-	4	-	-	-	3	-	-
13.	Kingston	-	-	-	-	-	9	-	-	-	14	-	-
14.	Central London	8	-	-	3	8	-	-	2	24	-	-	-
15.	Oxford	-	-	-	-	-	-	-	-	-	-	-	-
16.	Paisley	-	-	-	-	2	4	-	-	-	-	-	15
17.	Plymouth	-	-	-	-	-	-	-	-	10	1	-	-
18.	Sunderland	-	-	-	-	-	-	-	-	33	17	-	-
19.	Wales	-	-	-	-	-	-	-	-	-	-	-	-
20.	Wolverhampton	-	-	-	-	11	-	-	-	16	-	-	-
	Total	8	-	3	3	21	17	11	2	83	35	-	15
	Sample Total	614	546	46	868	808	804	68	1009	1372	911	75	902

The figures corresponding to the SRC Science Board Committees for a number of SRC Engineering Board Committees are shown in Table 10. Aeronautical and Mechanical Engineering, Control Engineering, and Electrical and Systems Engineering all increased their contributions in 1976 compared with 1973 but decreased their contributions in 1979 compared with 1976. Also Chemical Engineering and Technology, and Civil and Transport Engineering increased their contributions for both 1976 and 1979. Excluded from these figures is Polymer Engineering Management which only had figures for 1979 due to it being formed in 1978.

Table 11 shows the total value of grants provided by the SRC Board or Committee to the institutions in the sample. For the three years concerned it shows an increase, although the rate of increase is reduced for 1979 due to the universities growth being reduced.

3.4 The Development of Science and Engineering

Due to the 'conceptual' nature of science there is constant change in the perception of its disciplinary constructs. As a result new areas emerge resulting in the development of new disciplines. Engineering, on the other hand has a 'professional' nature, due to its practical orientation. Because of this, science tends to attract funding for new ideological developments with the result that it receives extra provision for this. Coupled with this the large cost of certain scientific facilities means that science receives greater support than engineering in the academic world. The greater activity that results is apparent from the larger number of science publications.

TABLE 10

TOTAL VALUE (£,000) OF SRC RESEARCH GRANTS BY AERONAUTICAL AND MECHANICAL ENGINEERING (AME), CHEMICAL ENGINEERING AND TECHNOLOGY (CET) CIVIL AND TRANSPORT ENGINEERING (CTE), CONTROL ENGINEERING (CE) AND ELECTRICAL AND SYSTEMS ENGINEERING (ESE) SCIENCE BOARD COMMITTEES (102)

H.E.I.	1973					1976					1979				
University	AME	CET	CTE	CE	ESE	AME	CET	CTE	CE	ESE	AME	CET	CTE	CE	ESE
1. Bangor	-	21	-	18	41	-	10	-	-	103	-	-	-	-	18
2. Bath	51	28	2	18	-	71	41	-	-	6	132	-	24	-	14
3. Belfast	36	-	-	-	19	101	5	6	-	43	39	5	9	-	23
4. Durham	18	13	-	-	20	59	-	-	-	-	47	7	-	22	5
5. Kent	10	-	-	-	22	-	-	-	-	36	-	47	-	46	47
6. Leicester	90	7	-	-	1	316	32	-	-	10	75	-	-	-	-
7. Salford	81	35	73	-	-	91	51	50	-	28	18	41	-	-	2
8. Stirling	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9. Warwick	19	-	36	228	20	18	-	87	200	82	237	-	-	14	31
10. York	-	-	-	-	-	-	-	6	-	-	-	34	-	-	-
Total	305	104	111	264	123	656	139	149	200	308	548	134	33	82	140
Polytechnic															
11. Hatfield	10	9	-	-	-	20	9	-	-	10	-	12	100	-	-
12. Huddersfield	-	1	-	-	-	-	-	-	-	-	12	-	-	-	-
13. Kingston	-	-	10	-	-	-	-	10	-	-	-	-	-	18	-
14. Central London	-	-	33	-	-	21	5	30	-	54	-	5	29	-	21
15. Oxford	-	-	-	-	-	-	6	13	-	-	-	-	18	-	-
16. Paisley	-	-	-	-	-	-	-	2	-	10	23	-	25	-	-
17. Plymouth	-	-	-	-	-	3	-	-	-	8	-	-	18	-	-
18. Sunderland	-	-	-	15	-	10	-	-	-	-	-	-	-	25	-
19. Wales	-	-	-	-	-	-	16	-	-	-	-	26	-	-	-
20. Wolverhampton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	10	10	43	15	0	54	36	55	0	82	35	43	190	43	21
Sample Total	315	114	154	279	123	710	175	204	200	390	583	177	223	125	161

TABLE 11

TOTAL VALUE (£,000) OF SRC GRANTS, BY BOARD OR COMMITTEE AT EACH INSTITUTION IN THE SAMPLE (103)

H.E.I.		1973	1976	1979	Total
University					
1.	Bangor	268	344	414	1,026
2.	Bath	185	208	655	1,048
3.	Belfast	590	615	652	1,857
4.	Durham	438	469	901	1,808
5.	Kent	245	317	594	1,156
6.	Leicester	819	1,453	1,119	3,391
7.	Salford	486	557	632	1,675
8.	Stirling	130	235	199	564
9.	Warwick	777	1,039	1,230	3,046
10.	York	286	528	590	1,404
	Total	4,224	5,765	6,986	16,975
Polytechnic					
11.	Hatfield	22	59	184	265
12.	Huddersfield	1	4	27	32
13.	Kingston	10	39	81	130
14.	Central London	43	139	79	261
15.	Oxford	0	19	18	37
16.	Paisley	0	19	82	101
17.	Plymouth	3	18	53	74
18.	Sunderland	15	26	106	147
19.	Wales	0	18	49	67
20.	Wolverhampton	1	11	16	28
	Total	95	352	695	1,142
	Sample Total	4,319	6,117	7,681	18,117

Science and engineering are funded together at national level due not only to evolutionary connections but also due to engineering having a smaller associated research activity. The possibility of having separate engineering provision for funding as proposed in the Finniston report (104) in the form of an autonomous engineering authority does not appear to be applicable to the present situation.

The question arises whether engineering, like science, can be measured in terms of numbers of publications, grants awarded or higher degrees. This stems from the fact that engineers are forced into playing the game by rules made by scientists by being subjected to criteria which may not be relevant to engineering.

If in the future engineering evolves at a greater pace in line with science it might become necessary to develop engineering funding on an individual basis using its own criteria.

CHAPTER 4

The General Theory of how Scientific Disciplines Develop: A Sociological View

4.1 The General Theory

4.2 Development Factors

4.3 Mechanism of Development

4.4 Instigators of the Development

4.5 Study of the Development

4.6 Funding the Development

CHAPTER 4

The General Theory of how Scientific Disciplines Develop: A Sociological View

4.1 The General Theory

A sociologist's view is that the development of a scientific discipline is studied by its history, which in the form of a systematic case study may be used for comparison with other case studies. A typical historical case study focuses on the concept of the 'specialty', 'research area', 'field' or the 'network' - the main institutional and intellectual orientation for scientific research. In this way they emphasise the structure and function of disciplines which reveals essential social characteristics of scientific activity, mechanisms of communication, recognition and reward, thus providing access to cognitive features distinguishing one area from another.

Knowledge of the ways in which scientific disciplines develop and the factors which determine their growth is still incomplete. This is principally due to the fact that their development is a complicated process.

Sociologists conclude principally that they develop as a result of the growth of science as a social and intellectual activity, and evolve by means of movement into new areas.

Two popular areas for the study of the development of scientific disciplines have been those of Chemistry and Astronomy. This has resulted in the writing of a number of case studies in these areas.

The sociologist considers that the development begins when a scientist working in an existing area perceives a new problem or observation, pursuit of which is outside his present field. Development is often started by a process of scientific migration, and once established the discipline will grow. Eventually it will become saturated and interest will shift elsewhere. This is usually illustrated by the sequence of preliminary exploration, exponential growth and levelling off (105).

Setting aside the introductory theoretic, it is the thesis of this work that the general theory of the development of scientific disciplines is characterised by the following empirical common formulations.

Firstly, there are discernable development factors.
Secondly, there is a mechanism of development.
And thirdly, there are instigators of the development.

4.2 Development Factors

To begin with, factors involved in the development of a scientific discipline can be broken down into the following :

(i) Social features.
(ii) Cultural phenomena.
(iii) Organisational aspects.
(iv) Economic and political influences.

These influence development by affecting its rate, direction and intellectual content.

Social features exist through social relationships in which scientists are variously implicated. Hagstrom (106) has highlighted three principal roles/statuses that determine relationships. These are the scientist's academic role as an explorer/theoretician, his professional role as a chemist, physicist, biologist, etc., and his organisational employee role as university lecturer, technologist, laboratory technician, etc. The most important role in terms of the development of scientific disciplines is the academic role. It is from this role as an explorer and theoretician that new ideas which generate the development of scientific disciplines arise.

This idea of role being important is developed by Gilbert who talks of 'role hybridisation' as a general mechanism (107). He cites Ben-David and Collins who say the process is a result of 'fitting the methods and techniques of an old role to the materials of a new one, with the deliberate purpose of creating a new role' (108). According to Mullins they state that 'role hybridisation' is the means by which a new role is established (109).

Normative values which govern the behaviour of science are important social features, and are common to members of scientific groups. Barber (110) has defined institutional scientific values as rationality, utilitarianism, progress and meliorism. Further to this, Merton (111) has defined the institutional norms of science as universalism, organised scepticism, communality and disinterestedness. According to Law norms are held to bind the scientists together in a specialty, research front, or invisible college (112).

Cultural phenomena are best described by the division of intellectual labour in science into the knowledge aspect (113) (fragmentation of science into different parts) and the social stratification aspect (114) (the division of labour within the scientific community) which causes cultural roles and psychological effects (cognition). This in turn results in cognitive dissonance which leads scientists to break away from traditional disciplines resulting in the formation of new areas.

There are many more disciplines in science now than there were forty years ago. This is due to the scientific division of labour causing scientists to look at new areas. In the nineteenth century knowledge became specialised, professionalised and institutionalised (115). It was about the middle of the nineteenth century that specialisation in science occurred. For example, Physiology originated in the 1860's due to competition between universities which was an external factor in contradistinction to internal factors. This was the beginning of the expert in one discipline causing a fragmentation of knowledge into many disciplines such as Physics, Chemistry and Biology.

Hagstrom has highlighted the phenomena of segmentation and differentiation of different disciplines (116). Segmentation begins with cultural change. This is the appearance of new goals within the scientific community. These do not spontaneously appear and scientists actively seek them out. Those who discover important new problems upon which few others are engaged are less likely to be anticipated and more likely to be rewarded with recognition. Thus scientists tend to disperse themselves over the range of possible problems. This in turn results in deviance from the traditional or established disciplines. Where this is seen as a deviation from a traditional discipline efforts may be made to try to change it. As viewed by the scientific community it may lead to overt conflict. An example of a breakaway group is Biochemistry from Biology and Chemistry.

Another situation where an emerging discipline is linked to two existing disciplines is where according to Ben-David and Collins one has 'idea hybridisation'(117). They define this as 'the combination of ideas taken from different fields into a new intellectual synthesis'(118). An example of this is Biogeochemistry being formed by Botany and Surface Geology. A new discipline is always linked to an existing discipline or disciplines. This takes place by intellectual migration. A good example of scientists moving from existing disciplines to a new area is the case of Watson and Crick in their work on DNA (119).

An important organisational aspect is that communication channels need to be created for new scientific disciplines. This is linked to the development of a disciplinary utopia which requires leadership. Disciplinary utopia is a futuristic state of science that deviates from the existing state. As a result structural change occurs and charismatic individuals come to the fore of the scientific deviance that results causing a new discipline eventually.

Establishment of communication channels and the development of a new utopia allow scientists to associate with the developing scientific discipline and to establish and claim legitimacy for their point of view. This is especially so when presenting their case to university bodies or other groups in society. The acceptance of this new point of view is essential in the establishment of a new scientific discipline.

At first structural change, that does not involve strong commitments by organisations, will evolve after the development of a new utopia. At this point incomplete differentiation stops. Once structural change involving strong organisational commitments has evolved it results in formal socialisation and direct ties between the new scientific discipline and the larger community.

The organisational aspect of differentiation for the development of a scientific discipline (based on Hagstrom) (120) is shown in Figure 3.

For a scientific discipline to become established it needs to have separate departments, research units or institutes from those already in existence. It needs to be marginal to at least two existing scientific disciplines for structural change in the form of departmental differentiation to occur. If the development is confined only to one existing scientific discipline, it will be hard for it to attain appeals outside the disciplinary community, especially those requiring structural change.

Economic and political influences mainly occur through research funding which is determined by science policy. This occurs at individual, group, departmental, institution and national levels. An example of this at the individual and group level is Mulkay's study of Radio Astronomy groups in Britain whose scientists were responsible for maintaining the groups' financial support (121). The departmental and institutional levels are determined by the national level which is teleological. At the national level government science policy controls and regulates science in line with political demands. This is external direction. van den Daele and Weingart observe that in the recent past there have been many attempts to regulate

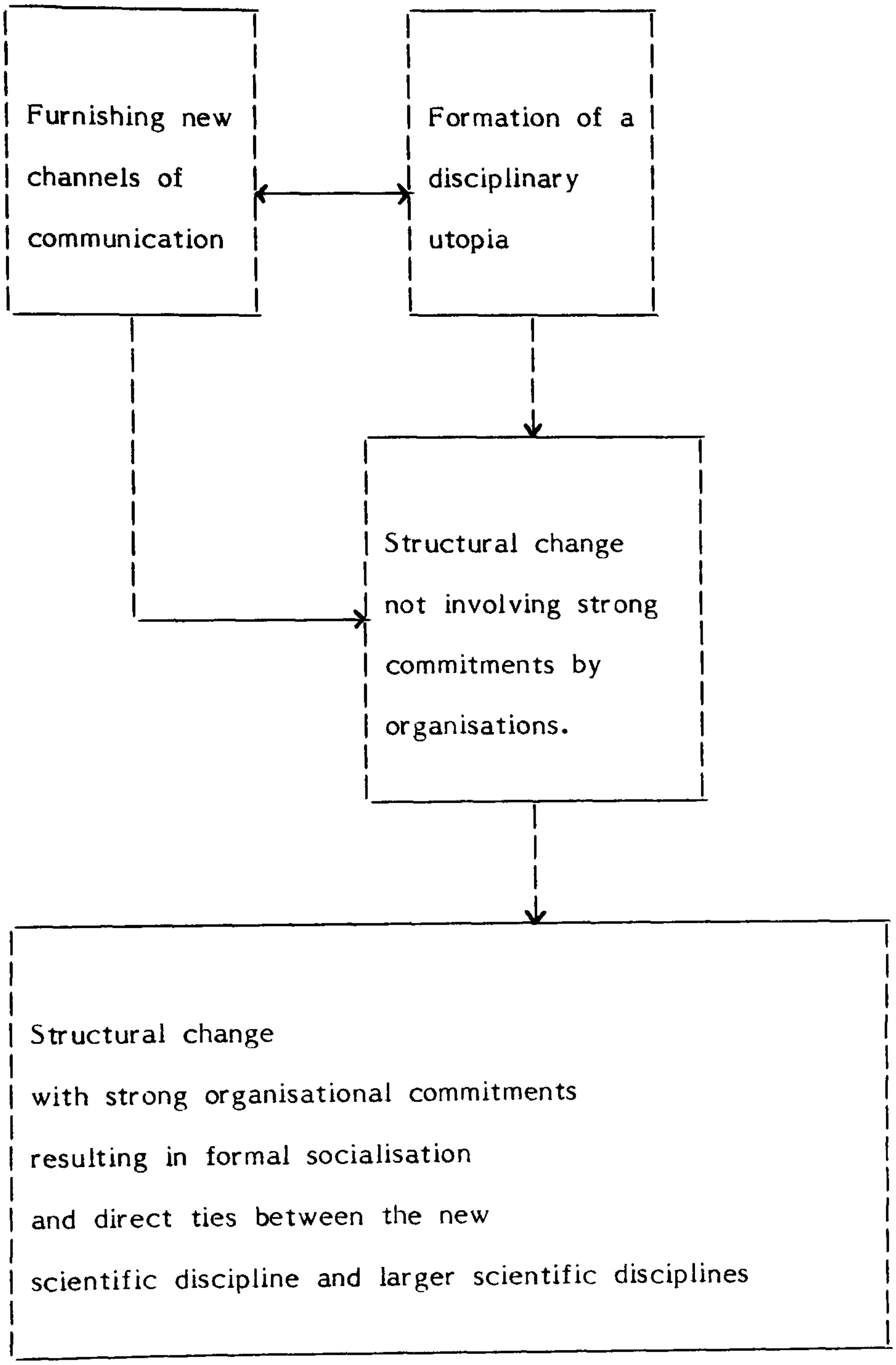

FIGURE 3.

ORGANISATIONAL ASPECT OF DIFFERENTIATION FOR THE DEVELOPMENT OF A SCIENTIFIC DISCIPLINE the development of scientific specialties according to politically defined goals (122). The science policy objectives here may, for example, be the desire for a medical cure or a new weapons system. In such cases the new type of scientific specialty envisaged for developing a cure or weapon will have as its focus of development political goals. This is the utilisation of science for policy-making, which corresponds to what van den Daele and Weingart call 'means-ends rationalisation'(123).

It is, therefore, possible to determine the structure and the development of a discipline or specialty. This may be done through science policy directives as in Table 12. Here the distinction is made between strategic and tactical development. For strategic development, an efficient interdisciplinary research strategy is required. According to van den Daele and Weingart this kind of strategy is one by which gaps in knowledge are identified and related to the competence of the various disciplines (124).

In cases where there is total government control of the development of a scientific discipline one finds stable specialty formation (125). An example of this are government or industrial laboratories with different mechanisms regarding the financing and organisation of research to the academic world. (State financed laboratories were established as long ago as the eighteenth century and analysed gun powder, water and minerals).

van den Daele and Weingart consider that the financial circumstances existing during the development of a specialty may influence its stability (126). The stability is likely to be affected if the necessary resources are allocated by a centralised or decentralised funding agency

TABLE 12

DEVELOPMENT OF A SCIENTIFIC DISCIPLINE BY SCIENCE POLICY DIRECTIVES

Type of Directive	Method of Directive	Desired Result of Directive
Strategic Development of Discipline	To achieve the desired ends by direction on a planned level	Formation of a Stable Discipline
Tactical Development of Discipline	Immediate support to implement at an operational level	Means by which a Stable Discipline can be developed

'if such allocations are made to depend on changeable political goals or on the agencies of scientific self-management, and if funding is made within the frame of a regular and formal system of allocations' (127).

Where there is total government control one will find a dependent development of scientific disciplines whereas in the academic world one will find independent development. On the one hand one may have a scientific discipline directed towards the solution of 'external' problems and on the other scientific disciplines which are developed according to their own logic.

The feasibility of science policy programmes is important in the government funding context. van den Daele and Weingart say that rational science policy should be founded on the possible rather than upon the unpredictable and surprising result (serendipity) or upon the perceived difficulty (anomaly) (128). They sum up their views on science policy by saying that it has to rely on an assessment of the cognitive and institutional conditions of science relative to the objectives of political control (129).

For the above, social features, cultural phenomena and organisational aspects, have all had substantial study by sociologists. Only economic and political influences have not been properly developed. It is here that work needs to be done. This can be seen in Table 13 which is a general matrix of the factors involved in the development of scientific disciplines and shows that social, cultural and organisational aspects are more refined

TABLE 13

GENERAL MATRIX OF THE FACTORS INVOLVED IN THE DEVELOPMENT OF SCIENTIFIC DISCIPLINES

Factors Case Study	Social Features	Cultural Phenomena	Organisational Aspects	Economic and Political Influences
W. Krohn and W. Schafer (Agricultural Chemistry)	Social goal-orientation	Cognitive structure	Strategic institutionalisation	Research planning
R. G. A. Dolby (Physical Chemistry)	External social pressure	Conceptual distinctions	Specialist facilities and organisations	Reform and growth
M. Worboys (Tropical Medicine)	Social conditions, change, identity, pressures and goals.	Cognitive status	Socio-institutional aspects	Policies and finance
J. Law (X-ray Protein Crystallography)	Social distinctions	Cultural/Intellectual change	Community	None
M. J. Mulkay and D.O. Edge (Radio Astronomy)	Social structure	Intellectual development	International research community	Allocation of funds
G. N. Gilbert (Radar Meteor Research)	Web of social relationships	Growth of knowledge	Institutionalised procedures	Research funds and grant giving
J. Ben-David and R. Collins (Psychology)	Social factors	Intellectual content	Institutionally-based movement	None
N. C. Mullins (Molecular Biology)	Social variables	Intellectual processes	Social organisation	None

than economic and political. Table 14 shows the predominance of factors being internal or external according to their nature. A greater understanding of how these factors come into play in the development of a scientific discipline can be obtained from study of the mechanism of development.

4.3 Mechanism of Development

When constructing a general mechanism for the development of scientific disciplines the epistemological significance of the growth of an idea into a recognised area needs to be made. This is reflected in the way a discipline develops through metamorphosis into an established body of knowledge.

Table 15 shows the stages of development for scientific disciplines in various case studies. Table 16 defines the sequential mechanisms that are identifiable in these case studies. The mechanism of development in all these case studies involves mutation which is the process by which scientific disciplines develop.

From Tables 15 and 16 it is possible to deduce a general mechanism describing the development of scientific disciplines. This is shown in Table 17. It shows progression from stages 1 to 6 as origins, emergence, growth and development, establishment, maturity and decline.

TABLE 14

PREDOMINANCE OF FACTORS BEING INTERNAL OR EXTERNAL

Nature of Factors / Factors	Predominantly Internal/External
Social Features	Internal
Cultural Phenomena	Internal
Organisational Aspects	Internal/ External
Economic and Political Influences	External

TABLE 15

SEQUENTIAL STAGES FOR A SELECTION OF CASE STUDIES ON THE DEVELOPMENT OF SCIENTIFIC DISCIPLINES

Case Study	Stage			
	First	Second	Third	Fourth
W. Krohn and W. Schafer (Agricultural Chemistry)	Rise of subject	Special development	Development of theories	Strategic institutionalisation
R.G.A. Dolby (Physical Chemistry)	New idea	Idea development	Geographical diffusion	Institutional status
M. Worboys (Tropical Medicine)	Origins	Early development	Emergence	Recognition
J. Law (X-ray Protein Chrystallography)	Sub-set of a discipline	Development of techniques and methods	Specialty development	Subject Community
M.J. Mulkay and D.O. Edge (Radio Astronomy)	Emergence	Early growth	Cumulative growth	Formation of a distinct discipline
G.N. Gilbert (Radar Meteor Research)	Proliferation of lines of enquiry into research	Development of research	Growth in the number of problem areas	Emergence of research area
J. Ben-David and R. Collins (Psychology)	Necessary ideas	Emergence	Growth	Existence of a distinct discipline
N.C. Mullins (Molecular Biology)	Paradigm Group	Network	Cluster	Specialty

TABLE 16

SEQUENTIAL MECHANISMS FOR THE DEVELOPMENT OF SCIENTIFIC DISCIPLINES

Case Study	Sequential Mechanism
W. Krohn and W. Schafer (Agricultural Chemistry)	Structure formation
R. G. A. Dolby (Physical Chemistry)	Idea evolution
M. Worboys (Tropical Medicine)	Specialty emergence
J. Law (X-ray Protein Crystallography)	Specialty development
M. J. Mulkay and D. O. Edge (Radio Astronomy)	Discipline growth
G. N. Gilbert (Radar Meteor Research)	Subject development
J. Ben-David and R. Collins (Psychology)	Role-hybridisation
N. C. Mullins (Molecular Biology)	Structure development

TABLE 17

GENERAL MECHANISM DESCRIBING THE DEVELOPMENT OF SCIENTIFIC DISCIPLINES

Stage 1	Origins
Stage 2	Emergence
Stage 3	Growth and Development
Stage 4	Establishment
Stage 5	Maturity
Stage 6	Decline

Ben-David and Collins have identified the importance of the origin and growth of scientific disciplines in their study of the emergence of Psychology (130). Gilbert notes that disciplines are established in growing university systems (131). Mullins has studied the emergence and growth of Phage research as a precursor of Molecular Biology (132). He focuses on the research network (133). According to Woolgar it is a relatively intensive concentration of interest ties and because of this has no boundary (134). Here one has participants marginal to the field. Importance is attached to 'core' members of the network (135). Dolby makes the distinction between a focal and peripheral topic (136). He describes a focal topic as one that receives much attention attracting many research papers and eventually text book summaries. A peripheral topic is on the fringes of scientific interest in a field only attracting attention of a few isolated individuals. Woolgar talks about the processes of growth and development when looking at a scientific collectivity as what actually constitutes a particular area of scientific endeavour (137). The network helps in what he calls the location of scientific collectivities (138).

Many sociologists see the development mechanism for scientific disciplines following Kuhnian theory which involves paradigms, normal science and revolutionary science. According to Kuhn the actions of scientists in mature sciences are determined by a 'paradigm' (139). Law observes that a paradigm is 'a scientific achievement that has been accepted by a substantial group of scientists, and is used by them as a basis for their scientific work'(140).

Further to this Ben-David and Collins see a 'paradigm' as a model of scientific reality, which has implied methodology and research directions

(141). According to Mullins paradigm development occurs when a group of scientists, separately or together, undertake a 'Gestalt shift' which changes their perception of the topic or topics they are analysing (142).

Kuhn calls the articulation of a paradigm 'normal science'(143). Whereas normal science is characterised by orthodoxy, consensus and tradition, revolutionary science is characterised by incommensurability, schisms and controversy (144). According to Law normal science is interrupted by important conceptual revolutions, examples of which are the Copernican revolution, and the development of the quantum theory, when old theoretical frameworks are removed by new ones being brought in (145). Worboys sees the establishment of 'normal science' and the connected notion of a 'shared paradigm' as similar to the emergence of a mature specialty (146).

van den Daele and Weingart define normal science as the exhaustion and occasional modification of a paradigm, 'cleaning up' after the decisive breakthrough (147). They link this to the idea of 'finalisation' which is a particular kind of theoretical development of externally determined problem areas on the basis of accepted general theories (148). They perceive 'finalisation' as strategic theory development according to externally set goals (149). Krohn and Schafer also talk about 'finalisation' in their study of the origins and structure of Agricultural Chemistry (150).

Mulkay talks of intellectual migration as a way in which new Kuhnian paradigms can be formed (151). Kuhn sees shared paradigms or specialties as essentially theory-based. Law proposes that there are also subject-matter specialties, such as entomology, and technique-based, such as X-ray crystallography (152). Theory-based specialities are defined in terms of a shared formalism. Subject-matter specialties have members working on a particular subject matter or problem. And technique-based specialties have an interacting group of scientists with solidarity on the basis of the development of shared scientific instruments.

Table 18 shows these three types in terms of discipline and their basis of solidarity. The basis of solidarity for technique-based disciplines is technical solidarity. Mechanical and organic solidarity are the basis for theory-based and subject-matter disciplines respectively.

Technical solidarity occurs due to the binding together of scientists through technical problems. According to Law mechanical solidarity is 'the development and maintenance of relationships which depend on shared standards and exemplars, and hence on a relatively high degree of consensus about theory and method'(153). He states that organic solidarity is 'an aspect of the division of labour in which scientists come into relationship with one another because one performs services which the other cannot easily carry out for himself'(154). The way in which technical, mechanical and organic solidarity affect the scientist's choice of research (based on Law) (155) is shown in Figure 4.

The result of a development mechanism is the establishment of a scientific discipline or specialty. van den Daele and Weingart define a 'specialty' as 'an organisational unit of science which differs from the traditional disciplines by its lesser scope and from particular problem areas by a higher degree of cognitive and social institutionalisation'(156). Hagstrom defines 'specialties' as interacting groups at a common research front (157). Mullins defines a specialty as 'an institutionalised cluster which

TABLE 18

SOLIDARITY ASSOCIATED WITH DISCIPLINE TYPE

Discipline Type	Basis of Solidarity
Technique-based	Technical
Theory-based	Mechanical
Subject-matter	Organic

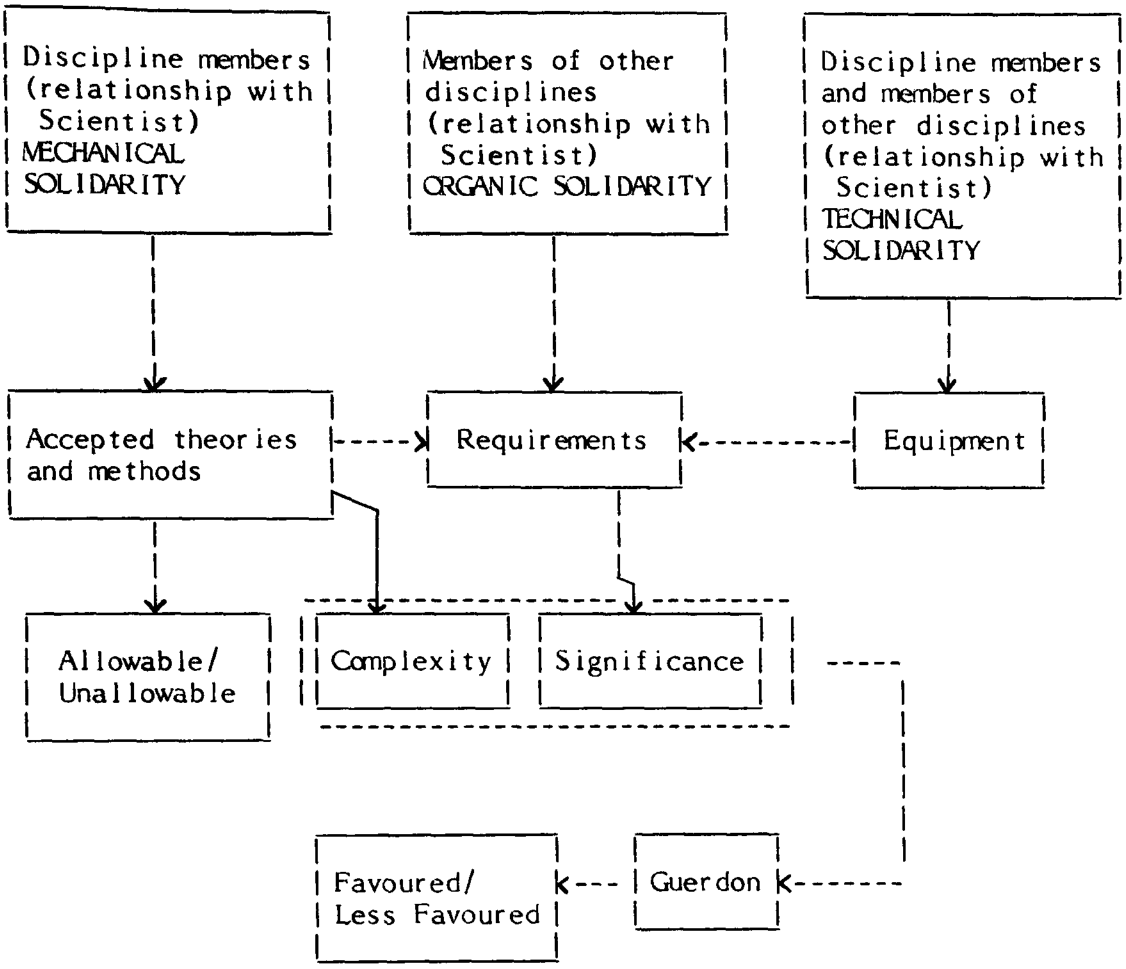

FIGURE 4

FACTORS DETERMINING A SCIENTIST'S CHOICE OF RESEARCH has developed regular processes for training and recruitment into roles which are institutionally defined as belonging to that specialty'(158). He observes that a specialty's problems can be described by Kuhn's concept of puzzle-solving which is the normal activity of science (159). Ravetz states that a 'mature' specialty exists when 'a certain underlying stability, ... persists through all the rapid changes in results, problems, and even objects of inquiry'(160). van den Daele and Weingart note that a stronger functional differentiation of specialties and problem areas is found in mature disciplines than in less developed ones (161).

Worboys describes two types of discipline. 'Applied' specialty with close links to professional practice, and 'pure' or 'basic' scientific specialty (162).

A final point that needs to be made here is that the development of a scientific discipline can eventually result in its decline. A good example of this is Fisher's study of the decline of a mathematical specialty concerned with the theory of invariants (163).

4.4 Instigators of the Development

The way in which the mechanism of the development of a scientific discipline is controlled can be understood by considering who instigates the development. For this there is a dilemma as to whether what Mulkay calls a 'great man'(164) is responsible or what Kuhn calls a 'paradigm group'(165) is the prime mover. Table 19 gives examples of 'great men'. Mulkay infers that it is unlikely that a 'great man' is the principle reason for the development and gives the example of Radio Astronomy where all graduate theses in the Cambridge radio astronomy group continued, until

TABLE 19

EXAMPLES OF 'GREAT MEN' IN THE DEVELOPMENT OF SCIENTIFIC DISCIPLINES

Discipline	'Great Men'
Agricultural Chemistry	Liebig
Physical Chemistry	Ostwald
Experimental Psychology	Wundt
Tropical Medicine	Manson
X-ray Crystallography	W.H. Bragg and W.L. Bragg
Radio Astronomy	Jansky
Radar Meteor Research	Hey and Lovell
Quantum Mechanics	Dirac

the 1950's, to cite Jansky's original contribution (166). Originally it seemed the case that the 'great man' hypothesis prevailed but after further examination of citations Mulkay found that references made to Jansky in early published research reports were negligible (167). Mulkay therefore calls this the 'Jansky myth'(168).

On the other hand it seems unlikely that the reason for the instigation remains with the group. Both seem to play a prominent role and the truth lies somewhere between. It is apparent that the instigation is a progression from a 'great man' and his followers into a paradigm group.

Mullins considers that a paradigm group is a set of individuals, who have moved into a similar cognitive situation with respect to the same, or similar, problems (169). The idea of a group being a 'community' is described by Law as a group of scientists who are interested in a specific scientific area from a certain point of view, and who are in contact with scientists from other disciplinary backgrounds who are also interested in such questions (170).

Ben-David and Collins note that there are three important levels of scientists in the development of a scientific discipline. There are 'forerunners', who are scientific 'dilettantes', 'founders', who form the new discipline and 'followers' who are 'disciples' and are related to 'founders' by means of 'discipleship'(171). According to Mullins 'forerunners' do not actually begin the discipline but work on ideas that are later important to the discipline. 'Founders' have the first students, and 'followers' are the students themselves (172).

Accordingly a new discipline's existence can be measured by the presence of 'followers'(173). According to Gilbert 'founders' have the luck or judgement to find a problem whose solution has ramifications outside its immediate context (174).

In order to determine the importance of 'great men' or 'founders' and the paradigm group their activities need to be measured. Mulkay and Edge observe that leadership is reflected in co-authorship and citation data (175). This can be obtained from published material.

4.5 Study of the Development

The most efficient way sociologists study the development of scientific disciplines is by scrutiny of the data obtained from publications. Woolgar has stated that any scientific area is amenable to a count of its publications and authors (176). He also states that the use of scientific literature appears to be a tool providing standardisation in the identification of research collectivities (177).

The initial objective when dealing with publications is the location of all publications by deciding which types of publications should be considered to form the literature of the collectivity (178). Table 20 lists the different publication types found, based on Woolgar (179). He states that analysis of the growth of a scientific field should only be concerned with those publications in section 1 (180). Membership of a discipline and the nature of its growth can be determined from the observed patterns of publication growth. Woolgar also states that researchers with less than

TABLE 20

LIST OF PUBLICATION TYPES

1.	Articles and Letters submitted to Journals, not including items below.
2.	Books, Theses, Reports.
3.	Papers Presented at Conferences, Meetings, Symposia, Colloquia.
4.	Abstracts of Items in 3.
5.	Reports of Conferences, Meetings, Symposia, Colloquia.
6.	Published Lectures.
7.	Reports issued by Institutes or Company Journals.
8.	News Articles, Editorial Articles, Articles written by journal staff writers.

three publications in an area are not regarded as having made a significant contribution (181).

The publications in section 1 of Table 20 come under the heading of 'scientific paper'. Law perceives scientific papers as 'purist' data and as that most easily available (182). He notes that scientific papers are important because they are relevant accounts about scientific beliefs (183). Scientists in general give special importance and epistemological status to accounts in scientific papers.

According to Mulkay figures on co-authorship can be used to indicate the extent of scientific co-operation (184). He looks at the incidence of co-authorship (185). Co-authorship has an integrating role and illustrates active colleagueship with other scientists. From this comes the idea that it shows how stable research teams are and therefore how stable a scientific discipline is.

Mulkay observes that stable teams lack single author papers (186). When comparing single authorship with co-authorship he states that one should look at co-authorship among group 'veterans' whom he defines as those who have been in their group six or more years (187).

Table 21 shows disciplinary stability based on authorship of papers. An unstable discipline is perceived as having low co-authorship and a stable discipline as having high co-authorship. Due to the fact that there is a greater chance of a discipline being developed as a recognised entity that is stable, co-authorship gives an idea as to the likelihood of a scientific discipline being properly developed.

TABLE 21

DISCIPLINARY STABILITY BASED ON AUTHORSHIP OF PAPERS

Percentage Authorship	Disciplinary Stability
Low percentage of co-author papers	Unstable Discipline
High percentage of single author papers	
High percentage of co-author papers	Stable Discipline
Low percentage of single author papers	

4.6 Funding the Development

Because of the effect that funding has on the development of a scientific discipline, the amount of funding is important in determining whether it will eventually develop into a recognised scientific entity. Since economic and political influences, which occur through funding, have been studied less than the other factors of social features, cultural phenomena and organisational aspects, they need further investigation.

Like the other factors involved, funding influences the rate, direction and intellectual content of the development. Without funds it is impossible for a scientific discipline to become established. Through funding it is possible to construct the organisational structure necessary for it to become fully developed in the form of distinct departments in institutions.

It is because of this dependence on funding that in cases where governments are providing money for certain areas they are able to control the growth of disciplines. This type of development involves external direction according to politically defined goals. It is important to realise, here, that in practice there will not usually be total government control creating a completely dependent development, due to the fact that the discipline will also develop simultaneously according to its own logic.

The factors involved in the development come into play through the development mechanism. In this context, research funds can be seen as the resources that run the mechanism. The instigators of the development control the way these funds are used, and are usually formed into a recognisable group which is then responsible for the success or failure of the development. By forming such a group the participants become leaders in their own area. To join the group scientists usually require credentials that are acceptable to the group as a whole.

In order to try to bring the understanding of economic and political influences to the level of the other factors it is important to study the funding of the development of a scientific discipline. This has been attempted by investigating the funding of Analytical Science as a new scientific area.

Analytical Science shows both similarities and differences when compared with the development of other scientific disciplines. It shows the same features as those outlined by Griffith and Mullins. These are acknowledged intellectual and organisational leaders, a geographical centre, and a brief period of comparatively intense activity (188). In Analytical Science there exists a group of recognised analytical leaders from various academic institutions. Probably the greatest single source of the origins lay within the Department of Chemistry at Birmingham University from which a significant number of the acknowledged leaders of Analytical Chemistry emerged in the post war decades. Amongst these were Belcher, West, Kirkbright, Townshend, Betteridge and Stephens. This led to a period of comparatively intense activity, in the late 1970's and early 1980's, when the SERC investigated the area.

The main difference from other developing disciplines is that it does not have a group that relates to the two main recognisable groups, the 'revolutionary' group and the 'elite' group noted by Griffith and Mullins (189). In Analytical Science a different type of group has arisen. This is because analytical leaders have formed a group that views this area of science in a new and different way. Previously, this area of science was viewed in terms of Physics and Chemistry. However, analytical leaders have changed from this vertical view of science concerning two distinct disciplines, to a horizontal perception across that part of Physics and Chemistry which involves the use of analytical techniques. They have in fact undergone a 'Gestalt shift'. They, therefore, form a new type of group that can be called the 'shift' group. The survival of this analytical 'shift' group, and the development of Analytical Science, will depend on whether it can attract the right sort of funds to this area.

CHAPTER 5

Funding a New Scientific Area: The Case of Analytical Science

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Funding a New Scientific Area: The Case of Analytical Science

5.1 Concept

In recent years a number of scientific areas have been studied by ad hoc groups set up by the SERC. One of these areas is Analytical Science (AS) which has been investigated in response to pressure from professional societies and a small but vocal academic community (190).

Interest arose in AS due to the fact that analytical chemistry had already evolved as a well recognised area of work, albeit more on the practising end than in the academic community. Many instrumental methods arose from discoveries by physicists leading to the solution of problems involving the analysis of materials of a chemical or biological nature. The broad area encompassed may be identified as AS. Two questions arise - how has the perception of this area evolved in recent years, and what are the funding patterns which control the development?

Within the present science policy structure in the UK there are three principal types of establishment that control the funding of AS. These are: (i) Policy Making and Funding Organisations; (ii) Academic Institutions; (iii) Industrial Enterprises.

Policy making and funding organisations determine the analytical areas into which funding will be allocated based on 'excellence' of work and academic institutions deploy this funding into analytical projects. Working alongside these two are industrial enterprises who require the funding of useful projects. These three categories are described below.

The main policy making and funding organisations are: (i) Research Councils - e.g. Science and Engineering Research Council (SERC); (ii) Government Departments - e.g. Department of Industry (DOI); (iii) Professional Bodies - e.g. The Royal Society of Chemistry (RSC). These three types of organisation have played important roles in the identification of AS.

AS was identified as an area of special importance by a panel of industrialists, government scientists and academics (under the chairmanship of Professor L. Crombie) set up by the Chairman of SERC and Chief Scientist of the DOI, who reported in September 1979 - Report of the Analytical Science Panel, 'Crombie Report' (191) - on possible initiatives in the field of post graduate education in AS. The panel described AS as a broader area than analytical chemistry and instrumental methods. Physics and electronics were seen to make a contribution to the subject including microelectronics resulting in the computerisation of analytical instruments, development of new equipment and data handling and in innovative instrumental control of continuous process industry.

The panel emphasised the contrast between the wide use of analytical work in industry, government and public health and the very low level of activity in universities as indicated by the low numbers of chairs and readerships. The panel reported that AS received less emphasis in universities than it deserves and concluded that appointments of analytical scientists should be made.

In response to the report, the SERC set up an Analytical Science Working Group (ASWG) of industrialists and academics under the chairmanship of Professor J. J. Turner. This reported in March, 1981 - Report of the Analytical Science Working Group, 'Turner report' (192).

The ASWG considered the problem of definition and following a survey produced five model job descriptions under the five headings:
'(i) the chemical analyst; (ii) the specialist analyst; (iii) the instrument technologist; (iv) the production analyst; (v) the instructor.'

After the Analytical Science Panel (ASP) reported it would have been thought that some new ideas would have come to light on increasing the awareness by academia of the importance of AS. In fact the ASWG proposed no new initiatives. The conclusions only tended to emphasise the 'usefulness' of high quality analytical work that can be obtained from proper assessment and funding.

The 'Crombie report' noted the extent to which academic chemists identify with inorganic, organic and physical chemistry and few would describe themselves as analytical chemists. Also the Chemistry Committee of the SERC has a structure of sub-committees composed of Inorganic, Organic and Physical. It is also clear that few academics would describe themselves as analytical scientists. This is in contrast with the roles within British industry and also at variance with the academic branches of chemistry and science in other developed countries. It can be argued that analytical work is fully integrated under the activities of teaching and research and does not merit a separate label. For example, the report of the ASWG found the present PhD training in chemistry which largely occurs within the inorganic, organic and physical sub-structure is well regarded by industry and satisfies the requirements in number and subject content.

The two principal industrial enterprises concerned with the funding of AS are:

(i) Instrument manufacturers - Analytical Instrument Firms;

(ii) Industrial Instrument Users - Industrial Research Establishments, Chemical and Petroleum Companies.

Membership of the ASP included scientists from Perkin Elmer Ltd., the Atomic Energy Research Establishment and Laporte Industries Ltd. in order to obtain industrial input. The ASWG included representation from Shell (Thornton) and ICI (Mond).

The 'Crombie report' found that the size and range of activities of companies determines their view of AS. Several large companies see no role for the MSc trained analytical scientist. They tend to appoint first degree or doctoral applicants. The 'Crombie report' also found that many industrialists have to provide analytical training due to the weakness of academic undergraduate training. This is because industry demands a high level of skill in the chemical manipulation of samples.

If AS is to be developed into a scientific entity it needs to become an accepted area of research. To this effect the ASP recommended that research activity be developed in this area. Following this, the report of the ASWG described the uses made by industry of analytical scientists, forms of training and the likely future direction of research. The working group recognised the positive change in attitude by the academic community towards AS and stressed the importance of new chairs and courses.

Because research in AS is multidisciplinary, problems may be caused due to applicants not receiving thorough assessment through peer review. To overcome this, cross-membership between the committees concerned and an understanding by committees of the views of analytical scientists has been advocated.

5.2 Nature

Due to this multidisciplinary nature AS is difficult to define. A broad definition would be that it is a multidisciplinary link between science and engineering, serving to measure materials associated with manufacture or processing industries, or in some environmental situation. A stricter definition is 'chemical or physical methods of determining the composition of substances'(193).

If AS is to be recognised as an important subject area in the future it will need to be accepted by both the academic world and by industry. Although it has found much acceptance in industry its development in the academic world still has a long way to go. This is due to the fact that although analytical techniques have changed more over the period of the last thirty or so years than at any other time there has not been much advancement in the recognition of AS as a concrete subject area. The vast development of analytical techniques has been due to the change from macro to micro analytical techniques which has led subsequently to the automation of much analytical equipment. This period has seen the vast development of chromatography in its various forms and likewise large advances have occurred in spectroscopy. Analytical techniques are constantly growing as new requirements are placed on them from fields as diverse as forensic science and atmospheric pollution to process control and space projects. This illustrates the diversity of techniques that have evolved over the last thirty years including a steady replacement of wet chemical analysis by instrumental analysis creating complex and advanced forms of scientific analysis. In this sense AS can be seen as a central discipline serving other physical, biological and earth sciences, engineering, medicine, the environment, energy, space and nearly every facet of human existence and endeavour, associated with the quality of life. It is basically an experimental science central to which is the need to identify and analyse or measure the quantity of reagents consumed or formed in physical or chemical changes.

Every scientist who undertakes analysis is 'de facto' an analytical scientist, though relatively few specialise in AS per se. AS is concerned with the latest ideas and technologies of many scientific frontiers. Possibly more than any other area of science it has been revolutionised by computers, microprocessors and all that stems from the technological revolution they have caused.

Change has occurred in atomic and molecular spectroscopy including the analysis of surface and interfacial phenomena (194). There has been much development in electro-analytical chemistry, selective-ion probes, flow-injection techniques and in the separation science of chromatography as well as at the beginning of analysis in the selection, handling and storage of the sample (195). There has also been the impact of microprocessors on the whole analytical scene.

The subject-matter of AS is mainly found in physics and chemistry. This has resulted in an 'analytical science interface' being formed between these two principal areas. Intra-subject analytical research activities are found to take place within physics and chemistry, whereas inter-subject research occurs between physics and chemistry. The two principal areas in physics and chemistry are optical physics and analytical chemistry, and these form the hybrid (196) AS. This can be seen in Ulrich's Directory (197) which neatly defines what is subsumed under the rubric of AS.

The activity of AS is best described in terms of a system (198). The fundamental input and output modes of the analytical system are the sample and result respectively. Within the system the analytical apparatus analyses the sample by producing a signal which is processed so creating the required data. There is also feedback from the analytical data processing to the apparatus.

A system boundary can be drawn around the collectivity of the analytical apparatus, signal and data processing, and the feedback. Restricting the analytical system is the time factor which requires the analytical research process (199) to be undertaken within given time limits for beneficial results to be obtained from the activity of the system.

In universities and polytechnics many engineers and scientists are involved with AS but probably few would wear the label. This is an example of a difference between titles of academic areas under which teaching and research takes place and titles applied to activities outside academic institutions, as in many other cases, is multidisciplinary.

Due to this broad multidisciplinary nature AS has an interdisciplinary structure. This results in the contribution of periodicals from other areas to the two principal areas of analytical chemistry and optical physics.

The origins of periodicals from other areas associated with analytical chemistry are biochemistry, organic, inorganic and physical chemistry. Whereas, the origins of periodicals from other areas associated with optical physics are communications science, mechanical physics, medical science and nuclear physics.

The countries of origin for analytical periodicals are shown in Table 22. The United States has more than twice as many analytical periodicals as the United Kingdom which has three times as many as the Netherlands. The other fourteen countries have between one and five periodicals each. By dividing the number of analytical periodicals by the population of each country the figure for the number of periodicals per million population can be computed. The higher the figure the greater is the productivity of analytical periodicals. Accordingly, Switzerland is the most productive country with 0.635 and India is the least productive with 0.002. This relates to the fact that Switzerland is one of the richest countries in the world whereas India is one of the poorest. Within the range 0.2 - 0.7 as well as Switzerland there are the Netherlands with 0.451, the United Kingdom with 0.409, Israel with 0.333 and the United States with 0.203. In this range these countries can be considered to have a good productivity of analytical

TABLE 22

COUNTRIES OF ORIGIN FOR ANALYTICAL PERIODICALS FROM ULRICH'S DIRECTORY

Country	Number of Periodicals (1981)	Population (200) (1980) (M)	Periodicals -------------- Population (M)
1. Canada	2	21.8	0.092
2. Czechoslovakia	2	14.5	0.138
3. France	4	52.6	0.076
4. Hungary	1	10.4	0.096
5. India	1	547.0	0.002
6. Israel	1	3.0	0.333
7. Italy	3	54.4	0.055
8. Japan	3	106.0	0.028
9. Netherlands	6	13.3	0.451
10. Poland	2	33.0	0.060
11. Russia	3	131.4	0.023
12. Spain	1	34.1	0.029
13. Sweden	1	8.1	0.123
14. Switzerland	4	6.3	0.635
15. United Kingdom	22	53.8	0.409
16. United States	42	207.0	0.203
17. West Germany	5	62.0	0.081
Total	103		

periodicals. Those countries that have quite good productivity are in the range 0.1 - 0.2. The medium range can be considered to be 0.05 - 0.1. And low range 0.05 and below.

Some principal analytical techniques in the subfields of analytical chemistry and optical physics are shown in Table 23. This area is highly dynamic with frequent appearances of new techniques or combinations of techniques occasioned by diverse demands and the never ending endeavour to try to acquire new chemical or physical principles for analytical applications. The growth of analytical principles over the last seventy years illustrates a continual progression from gravimetric methods, through volumetric and electrochemical, to instrumental (201). There will probably be large growth in the future if past rates continue.

AS in the future will involve a high degree of automation and data handling, and instrumentation will involve advanced forms of data processing. This will result in advanced quantitative work employing new developments in instrumental and microelectronics techniques.

Although AS has developed over many years it is a newly developing subject entering a critical period of time in the next few years of expansion or contraction. The progress and pace of development in the United Kingdom has been equal to or better than that in many other advanced countries and seems likely to stay this way.

At present a scientific revolution (202) is taking place in AS which in turn is strongly influenced by the 'microelectronics revolution' (203). An important aspect of microelectronics is the application of microprocessors

TABLE 23

ANALYTICAL TECHNIQUES

Analytical Chemistry (Based on T. R. Hooper) (204)	Optical Physics (Based on S. Tolansky) (205)
1. Spectroscopy i. Ultra-violet/visible ii. Infra-red iii. Nuclear magnetic resonance iv. Mass spectrometry v. Atomic absorption/emission vi. X-ray	1. Microscopy i. Ultra-violet microscopy ii. Flying-spot microscopy iii. Phase-constant microscope
2. Chromatography i. Thin layer ii. Gas-liquid iii. High-performance liquid	2. Luminescence i. Infra-red image converters ii. Fluorescence microscopy
3. Electro-analytical chemistry i. Polarography ii. Ion-selective electrodes iii. Non-aqueous titrations	3. Interferometry i. Multiple-beam interferometry ii. Interference microscopes
4. Thermal analysis	4. Electron optics i. Electron microscope ii. Reflection electron microscope iii. Scanning electron microscope iv. Field ion microscope
5. Wet chemical analysis	5. Optical instrumentation i. Schmidt telescopes ii. Light detectors iii. Photomultiplier iv. Image intensifier v. Photo-conductors
6. Analytical instrumentation	6. Laser optics i. Ruby laser ii. Gas laser iii. Solid-state lasers iv. Pulsed lasers
7. Statistical chemical analysis	7. Holography

to instrumentation. A computer chip can provide an instrument with powerful data-processing capacity resulting in easy operation. A microcomputer enables an unskilled person to use a complex instrument. Spectrophotometers and many other scientific instruments now incorporate microcomputers (206). Laboratory analytical equipment can be applied to process control using microcomputers. Particle analysers have been developed that use laser beams to measure particles and microcomputers to determine their size distribution.

Spectrometers and chromatographs are the principal analytical instruments employing microcomputers. The incentive is mainly cost cutting, but instruments are also being created with new capabilities. Spectrum analysers can automatically set themselves up to locate a particular frequency (207).

Whether AS is recognised as a scientific entity is yet to be seen, even so the analytical community will see many changes. A promising future lies ahead if AS is correctly developed with sensible funding.

5.3 Construction

From the above introduction it is apparent that AS has an identity problem. For the purposes of the present work AS is identified in terms of publications listed in the journals coming within the Ulrich Directory under the headings 'Analytical Chemistry' and 'Optical Physics' (Appendix 1). 46 and 57 journals are listed in these areas respectively and their titles suggest these form an analytical base of published AS.

Nevertheless much published work by authors of papers in these journals also appear elsewhere. As a measure of the analytical community with these 103 journals the publications of 6 acknowledged leading analytical workers in the UK were surveyed. The measure of journals in which AS is published is a measure of the problem of identity.

The grants received and the papers written by the six leading analytical workers were determined from Chemical Abstracts and SERC literature over the period 1970 - 79. This is shown in Table 24 by comparing the number and the duration of SERC grants with the total number of periodical papers and analytical papers. The number of grants received varied between one and three with two receiving none. This resulted in funds received varying between £9,953 and £32,142. The grant duration was from 1 to 6 years per author. Total publications were between 41 and 106 giving a range of 25 to 85 for analytical papers. The percentages of AS to total papers were therefore from 46% to 80%. Although these percentages were high they did not relate well to the number of grants received. These authors appeared to receive little SERC funding for the amount of analytical work they undertook.

The database of work and manpower for AS in the present work are those published papers from the 103 identified journals, from 20 institutions comprising 10 polytechnics and 10 universities. These were selected as being of similar size but of wide ranging character and geographical distribution.

The time scale covered was the decade of the 70's and the Research Reports of the 20 institutions listing all publications were obtained over the

TABLE 24

SERC GRANTS RECEIVED AND PAPERS WRITTEN BY LEADING ANALYTICAL AUTHORS DURING 1970 - 79

Author	Institution	SERC Grants	SERC Funding	Yrs.	Periodical Papers		%AS
					Total	AS	
D. Betteridge	Swansea -	2	£25,658	5	43	31	72
G. Kirkbright	Imperial College - UMIST	1	£ 9,953	1	106	85	80
J. Miller	Loughborough	0	0	0	43	28	65
G. Nickless	Bristol	0	0	0	48	25	52
R. Thomas	UWIST	2	£27,000	5	79	36	46
A. Townshend	Birmingham - Hull	3	£32,000	6	63	50	79

period 1970 - 79. From this data base all analytical papers were collected onto individual cards and selected information was obtained from a full study of each paper. By doing this a second data level was made. This is shown in Table 25.

The analytical papers were indexed and categorised on the card index. 419 papers were scrutinized according to a four fold method of content analysis which was used to extract the data on research funding (Appendix 2).

This four fold method consisted of the recognition of the following factors from the scrutiny of papers:

(i) Authorship and Co-authorship Details;
(ii) Principal Equipment Used;
(iii) Funding Information - Equipment,
- Manpower;
(iv) Past References to Analytical Authors.

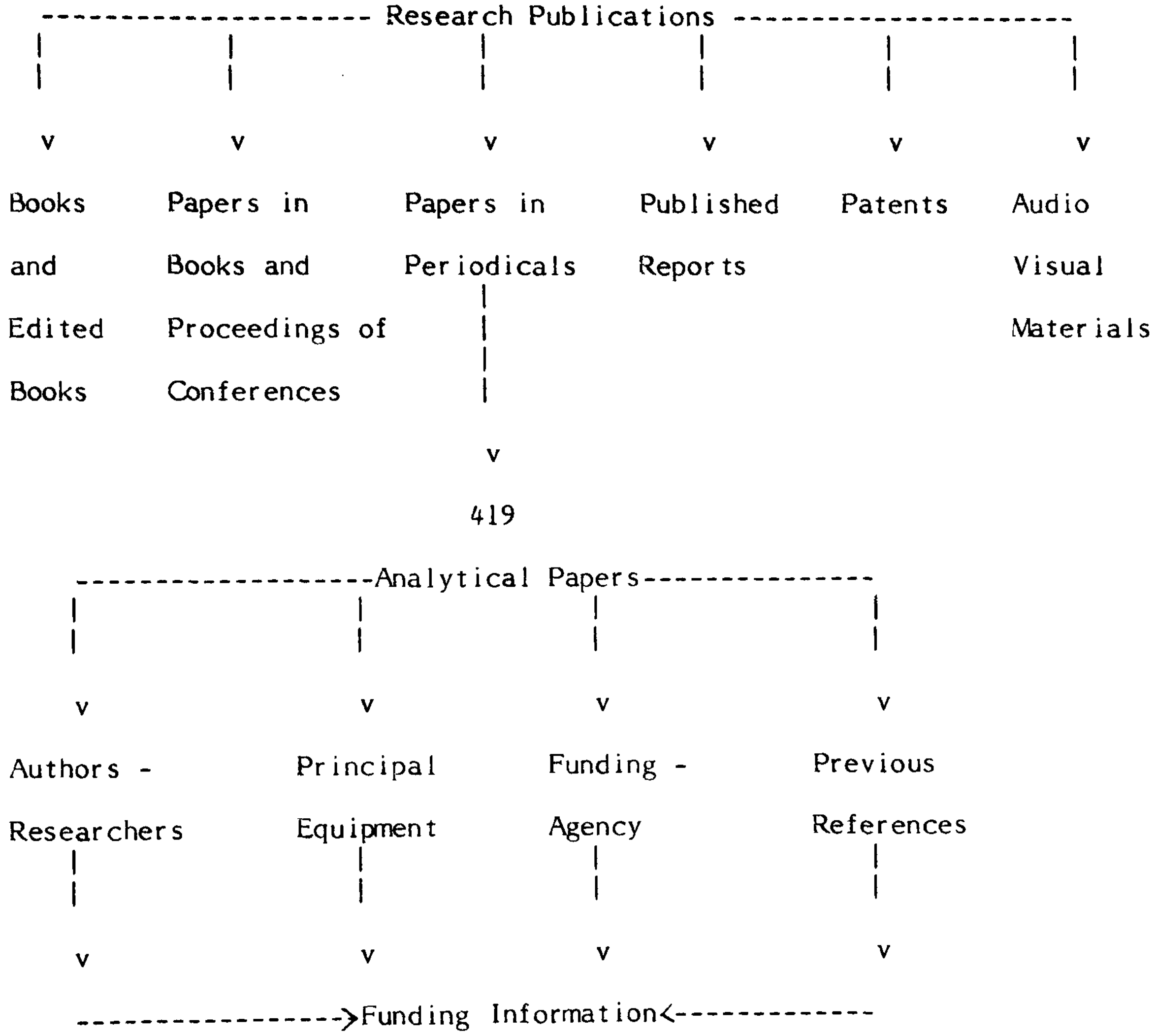
The authors and co-authors of papers, the type of instrumentation used and its funding, the source of funding of the authors involved and any references to other analytical papers by the authors in the period 1970 - 79 (to ascertain the link with previous work stated in the papers) was determined.

To reinforce the above information from the periodicals a questionnaire was constructed (Appendix 3). This was sent to selected authors in the card

TABLE 25

DATA BASE FOR THE CONSTRUCTION OF ANALYTICAL SCIENCE

1. Work Published under the Ulrich Classification



2. Results of Questionnaires to Selected Authors

	Pilot	Questionnaire 1 (Including Pilot)	Questionnaire 2
Date Sent	August 1983	Autumn 1983	June 1984
Number	24	154	82
Returns	19 (79%)	82 (53%)	45 (55%)

index. The questionnaire was in two principal parts - equipment and manpower.

The equipment section had five parts and listed the main types of instrumentation cited in the list of analytical papers that accompanied the questionnaire return. These were arranged in five columns. Parts 1 and 2 (Columns 1 and 2) were the type, make and model of the instrument. These were already completed from information obtained from the card index. If, however, the make and model of the instrument was not known it was asked if the recipient would complete this. For Parts 3, 4 and 5 (Columns 3, 4 and 5) the recipient was asked to complete the location, source of funding and approximate value at the time of purchase (also year of purchase if known) of the instrument.

The manpower section had six parts and listed the co-authors from the information held in the card index obtained from the analytical papers. These were arranged in six columns. Parts 1 and 2 (Columns 1 and 2) were already completed and stated the co-authors name and location indicated by publication. Parts 3, 4, 5 and 6 (Columns 3, 4, 5 and 6) required the recipient to give details on the status, funding body, number of years supported and position at institution/organisation for present location and position (if known).

The status ranks given at the bottom of the questionnaire sheet for the recipient to refer to were: internal permanent member of staff, internal short-term research appointment, post-doctoral research fellow, post-doctoral research assistant, graduate research assistant, graduate research student, technician and technical support staff, and other. The funding body categories also at the bottom of the questionnaire sheet for the recipient to refer to were: Research Council (e.g. SERC, MRC), Government Department (e.g. DOI), Local Education Authority, Nationalised Industry (e.g. CEGB), Private Industry (e.g. Unilever, BP), Charitable Trust or Society, etc., Self Supporting, Other Source.

Each questionnaire return was referenced according to name, department and institution. The two sections of equipment and manpower were related to the list of analytical papers which was the appendix to the letter that accompanied the questionnaire return. The letter outlined the aims of the research which were to determine the amount of funding received by researchers in AS according to source and type and from this to determine the patterns for the funding of manpower and equipment. It also stated that AS is not clearly defined although it emerges in a number of ways in a number of reports. It was asked if the recipient would complete and return in a month if possible in the Stamped Addressed Envelope (SAE) provided. Finally, the recipient was asked if he would comment on the concept of AS as a subject area or community of interest. Alternatively, the recipient was asked if he would comment on any other heading under which it was felt his own work belongs.

A pilot questionnaire survey was sent on 26th August 1983 approximately a month before the main survey was sent so that its results could be studied before the rest of the questionnaires were sent. This involved five polytechnics to see how they would reply. The results of this survey in Table 25 show that there was a good reply resulting in a 79% return. It was inferred from this that the questionnaire was of the right quality to be sent and, therefore, did not need to have any changes made. The main questionnaire survey was sent between 29th September and 14th December 1983 in batches according to institution.

Following the receipt of the questionnaire returns and the analysis of the data obtained, a further questionnaire was constructed and sent. The questionnaire returns were sent between the 4th and 6th June 1984. This supplementary questionnaire referred back to the first questionnaire and was sent to all those selected authors who returned the first questionnaire. A summary of the information that was gained from the first questionnaire was attached, in the form of a spread sheet (Tables 37 and 38), to the letter with the second questionnaire (Appendix 4). In the letter it was asked if the recipient would provide further information on the appended questionnaire form. Again it was asked if the recipient would send the questionnaire return within a month in the SAE if possible.

In the letter it was stated that 'peer review type' funding meant the provision of external funds based on decisions by active researchers in similar fields, who decide on the merit of the work by the internal criteria of their community, typically a Research Council. Whereas, by 'customer-contractor type' funding it was stated that it meant funds provided on the 'Rothschild principle' which are largely made by the organisation who needs the information, typically a government department or industrial enterprise.

The questionnaire sheet asked the recipient to answer two questions by referring to the Publications (1970 - 79) appearing in periodicals identified as publishing AS which were listed in an attached appendix (the same appendix attached to the first questionnaire). The first question asked recipients to estimate the percentage 'peer review type' funding and the percentage 'customer-contractor type' funding for equipment and manpower. The second question asked recipients to provide examples of external measures, or their own judgement, of 'excellence' or 'usefulness' deriving from their work in relation to one or more of the four categories in question 1.

The results of the data from the card index, questionnaire 1 and questionnaire 2 were used to determine the research funding patterns that exist in AS within the context of the sample studied. The extent to which work was funded according to peer review and customer-contractor was found. This was done by determining the number of authors and co-authors (researchers) funded and by the amount of equipment funded. References to other analytical papers by the authors in the period 1970 - 79 showed the relationship to other funding.

5.4 Authorship of Analytical Papers

In order to determine the patterns of research funding in AS as defined in 5.3, the number of analytical scientists, their publication practices, location, equipment and departments were determined. This did not include papers published by those authors outside AS as defined.

The authorship of papers in AS is shown in Table 26, for universities and polytechnics. For the number of authors and the number of papers, there were four times as many in universities as in polytechnics. For single author papers there were twice as many for the former as for the latter. This shows a general pattern of activity of four and two times that of

TABLE 26

AUTHORSHIP OF ANALYTICAL PAPERS

H.E.I.		Authors	Papers	Single Author Papers
University				
1.	Bangor	16	7	0
2.	Bath	49	27	4
3.	Belfast	92	59	5
4.	Durham	27	29	3
5.	Kent	27	19	3
6.	Leicester	36	21	6
7.	Salford	130	112	11
8.	Stirling	9	5	2
9.	Warwick	31	23	1
10.	York	40	29	8
	Total	457	331	43
Polytechnic				
11.	Hatfield	19	20	4
12.	Huddersfield	4	2	0
13.	Kingston	24	17	3
14.	Central London	0	0	0
15.	Oxford	0	0	0
16.	Paisley	7	12	5
17.	Plymouth	8	9	0
18.	Sunderland	12	8	4
19.	Wales	14	10	2
20.	Wolverhampton	18	10	1
	Total	106	88	19
	Sample Total	563	419	62

polytechnics for universities. The two polytechnics, Central London and Oxford, have no figures for AS authors because no analytical papers were found according to the Ulrich Directory. This occurs right through the data. These two institutions are, therefore, considered to have no AS activity. Their inclusion is important due to the need to have information on those institutions that do not explicity partake in AS. Analytical authors identified in the data base were found to be located in the three main areas of Higher Education Institutions, Government Research Laboratories and Industry. The breakdown of these in terms of numbers is shown in Table 27.

The average length of analytical papers, measured in pages, and the average number of analytical authors per paper have been computed to see how analytical authors relate to the number of analytical papers that have been published. Clearly the style and format of different journals creates variations between amount of material and number of pages but these factors tend to average out over a large sample. These calculated values are shown in Table 28.

On average the length of papers, measured in pages, by analytical authors in universities was 8, and 6 in polytechnics. This is probably due to the fact that analytical authors in universities would be more established than in polytechnics and would, therefore, write longer papers. Also they would receive more funding. The average number of authors for analytical papers was 3 for universities and 2 for polytechnics. The same reasons would apply for these figures as for the average length figures. Also the average length would be greater for universities due to the average number

TABLE 27

LOCATION OF ANALYTICAL AUTHORS

H.E.I.		Higher Education Institutions	Government Research Laboratories	Industry	Total
University					
1.	Bangor	14	0	2	16
2.	Bath	43	0	6	49
3.	Belfast	87	1	4	92
4.	Durham	24	2	1	27
5.	Kent	21	1	5	27
6.	Leicester	33	0	3	36
7.	Salford	123	2	5	130
8.	Stirling	8	0	1	9
9.	Warwick	26	2	3	31
10.	York	38	2	0	40
	Total	417	10	30	457
Polytechnic					
11.	Hatfield	12	0	7	19
12.	Huddersfield	4	0	0	4
13.	Kingston	19	2	3	24
14.	Central London	0	0	0	0
15.	Oxford	0	0	0	0
16.	Paisley	7	0	0	7
17.	Plymouth	7	0	1	8
18.	Sunderland	11	0	1	12
19.	Wales	14	0	0	14
20.	Wolverhampton	17	0	1	18
	Total	91	2	13	106
	Sample Total	508	12	43	563

TABLE 28

AVERAGE LENGTH AND NUMBER OF AUTHORS FOR ANALYTICAL PAPERS

H.E.I.		Average Length in Pages		Average Number of Authors	
University					
1.	Bangor	9		3	
2.	Bath	8		3	
3.	Belfast	7		3	
4.	Durham	9		3	
5.	Kent	11		2	
6.	Leicester	7		2	
7.	Salford	7		2	
8.	Stirling	9		2	
9.	Warwick	9		3	
10.	York	7		2	
	Total	83	Av. 8	25	Av. 3
Polytechnic					
11.	Hatfield	5		3	
12.	Huddersfield	10		2	
13.	Kingston	6		2	
14.	Central London	0		0	
15.	Oxford	0		0	
16.	Paisley	6		2	
17.	Plymouth	7		2	
18.	Sunderland	8		2	
19.	Wales	9		3	
20.	Wolverhampton	7		3	
	Total	58	Av. 6	19	Av. 2
	Sample Total	141	Av. 7	44	Av. 2

TABLE 29

STATUS OF ANALYTICAL AUTHORS

H.E.I.	I.R.W.											E.R.W.		
	H	P	R	SL	L	RF	PA	RA	RS	T	S	HR	IC	Total
University														
1. Bangor	1	1	0	3	1	0	0	1	4	0	0	3	2	16
2. Bath	0	3	3	8	11	1	0	0	11	0	0	6	6	49
3. Belfast	1	4	2	4	25	5	4	3	14	1	0	24	5	92
4. Durham	0	2	0	0	6	3	1	0	8	0	0	4	3	27
5. Kent	0	0	3	3	7	1	0	0	3	0	0	4	6	27
6. Leicester	0	1	1	4	5	2	0	0	6	1	0	13	3	36
7. Salford	0	6	5	8	41	4	0	0	25	1	0	33	7	130
8. Stirling	0	0	0	0	6	0	0	0	0	0	0	2	1	9
9. Warwick	0	1	0	0	2	2	4	0	4	0	0	13	5	31
10. York	0	5	2	5	9	1	0	0	8	0	0	8	2	40
Total	2	23	16	35	113	19	9	4	83	3	0	110	40	457
Polytechnic														
11. Hatfield	1	0	0	0	6	0	0	0	1	0	1	3	7	19
12. Huddersfield	0	0	0	0	1	0	0	0	2	0	1	0	0	4
13. Kingston	0	0	1	0	6	0	0	2	4	0	0	6	5	24
14. Central London	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15. Oxford	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16. Paisley	0	0	0	3	1	0	0	0	3	0	0	0	0	7
17. Plymouth	1	0	0	0	1	0	0	0	0	0	0	5	1	8
18. Sunderland	0	0	0	0	6	0	0	0	0	0	0	5	1	12
19. Wales	1	0	0	0	2	0	0	0	0	0	0	11	0	14
20. Wolverhampton	1	0	0	1	8	0	0	0	2	0	0	5	1	18
Total	4	0	1	4	31	0	0	2	12	0	2	35	15	106
Sample Total	6	23	17	39	144	19	9	6	95	3	2	145	55	563

Key to Table 29 :

I.R.W. - Internal Research Worker
E.R.W. - External Research Worker
H - Head of Department
P - Professor
R - Reader
SL - Senior Lecturer
L - Lecturer
RF - Research Fellow
PA - Post Doctoral Research Assistant
RA - Research Assistant
RS - Research Student

T - Technician
S - Student
HR - Higher Education Institution Researcher
IC - Industrial Collaborator

of co-authors being greater.

The status of analytical authors was found according to internal and external location. Table 29 shows that there were approximately four times as many internal research workers as there were external research workers. For universities one quarter of the industrial collaborators were from government establishments, whereas three quarters were from industrial enterprises. For polytechnics one tenth of the industrial collaborators were from government establishments and nine tenths were from industrial enterprises. This shows that universities were more dependent on government establishments for collaboration than polytechnics.

5.5 Equipment described in Analytical Papers

The average number of pieces of equipment per department used by analytical authors is shown in Table 30. Universities had five times as many pieces of equipment as polytechnics within the database, and four times as many departments partaking in AS. This gives average equipment figures per department of 11 for universities and 8 for polytechnics. The reason for universities having five times as many pieces of equipment compared to polytechnics was again due to superior funding in the form of more equipment grants.

The breakdown of these equipment figures into the different types of analytical instruments that were used is shown in Table 31. Universities had more spectrometers, lasers and chromatographs than polytechnics. Whereas polytechnics listed no spectrofluorimeters, oscilloscopes,

TABLE 30

ANALYTICAL EQUIPMENT

H.E.I.		Number of Pieces of Equipment		Number of Departments		Average Equipment	
University							
1.	Bangor	11		1		11	
2.	Bath	67		5		13	
3.	Belfast	110		7		16	
4.	Durham	19		4		5	
5.	Kent	22		3		7	
6.	Leicester	22		4		5	
7.	Salford	119		5		24	
8.	Stirling	12		3		4	
9.	Warwick	22		2		11	
10.	York	38		4		9	
	Total	442	Av. 44	38	Av. 4	105	Av. 11
Polytechnic							
11.	Hatfield	14		1		14	
12.	Huddersfield	9		1		9	
13.	Kingston	22		1		22	
14.	Central London	0		0		0	
15.	Oxford	0		0		0	
16.	Paisley	7		2		3	
17.	Plymouth	6		1		6	
18.	Sunderland	5		1		5	
19.	Wales	11		1		11	
20.	Wolverhampton	12		1		12	
	Total	86	Av. 9	9	Av. 1	82	Av. 8
	Sample Total	528	Av. 26	47	Av. 2	187	Av. 9

TABLE 31

ANALYTICAL INSTRUMENTS

H.E.I.		Sm	Sf	Sg	L	Ch	O	Co	E	M
University										
1.	Bangor	3	0	0	0	1	1	0	0	0
2.	Bath	17	0	0	1	2	0	2	0	0
3.	Belfast	21	3	0	8	4	3	0	0	1
4.	Durham	13	0	0	1	0	0	0	0	0
5.	Kent	7	0	0	1	0	1	0	0	0
6.	Leicester	13	0	0	1	0	0	0	0	0
7.	Salford	27	5	0	3	4	3	6	0	1
8.	Stirling	3	1	0	0	0	0	0	0	0
9.	Warwick	8	0	0	1	0	0	0	0	1
10.	York	13	0	0	3	2	0	2	2	1
	Total	125	9	0	19	13	8	10	2	4
Polytechnic										
11.	Hatfield	4	0	0	0	3	0	0	0	0
12.	Huddersfield	0	0	0	0	0	0	0	0	0
13.	Kingston	15	0	1	2	1	0	0	0	0
14.	Central London	0	0	0	0	0	0	0	0	0
15.	Oxford	0	0	0	0	0	0	0	0	0
16.	Paisley	3	0	0	0	1	0	0	0	0
17.	Plymouth	2	0	0	0	2	0	0	0	0
18.	Sunderland	2	0	0	0	0	0	0	0	0
19.	Wales	5	0	0	3	0	0	0	0	0
20.	Wolverhampton	2	0	0	0	1	0	0	0	0
	Total	33	0	1	5	8	0	0	0	0
	Sample Total	158	9	1	24	21	8	10	2	4

Key to Table 31 :

Sm - Spectrometers

Sf - Spectrofluorimeters

Sg - Spectrographs

L - Lasers

Ch - Chromatographs

O - Oscilloscopes

Co - Computers

E - Electron Microscopes

M - Manochromators

computers, electron microscopes and monochromators, universities did not cite spectrographs.

Having determined the number of analytical authors, their publication practices, location, equipment and departments, their funding according to these criteria was then determined. From this the research funding patterns were found.

5.6 Funding Data from Papers

Two principal types of support were studied. These were pecuniary and non-pecuniary support. Pecuniary support is defined as funding involving the transfer of money. This was categorised under the number of grants that were allocated to institutions for AS. Once the grant money is obtained, the researcher has a certain amount of freedom to use it as he wishes, unless it is provided for a specific purpose such as the purchase of a piece of equipment in the form of an equipment grant. Non-pecuniary support, on the other hand, does not involve the transfer of money to a researcher. Instead an alternative is provided which has monetary value in a capital form. This is usually a piece of equipment that is given, or the gift of a chemical sample.

It was found that three gifts of instruments were listed in two universities. Polytechnics listed no gifts of instruments. Thirteen chemical samples were given to four universities and one chemical sample to a polytechnic. This gave an overall figure of sixteen gifts in the sample. Although these are of no large significance they are worth noting.

Whereas non-pecuniary support is provided informally, pecuniary support is provided on a formal basis. Pecuniary support involves the provision of grants through the mechanisms of funding agencies. The grants can be broken down into six main types. These are the maintenance grant, research fellowship, research studentship, research assistantship, project grant and equipment grant. These six main types are shown in Table 32 for the twenty institutions in the sample.

For these purposes the award of a research studentship is regarded as a grant although this is often regarded as serving a different purpose. A studentship is to provide a training in research, a grant is to achieve a piece of research. In operational terms the distinction between these two categories may become small.

Table 32 shows that there were five times as many maintenance grants received by universities as by polytechnics. Maintenance grants are used to support researchers while they undertake research projects. A similar figure of six times as many grants received by universities to polytechnics was found for research fellowships. Research fellowships are at the post-doctoral level and are usually tenable for three years. There was a larger figure of ten times as many grants received by universities compared with polytechnics for research studentships. Amongst the grants paid for the support of personnel, research studentships were the largest. This is due to the fact that in the provision of stipends for research manpower they are the largest source of funding. It is for this reason that they are actively sought after by research project leaders. Research assistantships were distributed evenly between universities and polytechnics (having one each). These were, therefore, the smallest form of funding. Project grants were of the order of universities having seven times as many as polytechnics. As well as exhibiting the largest difference between these two types of HEI they also produced the largest total amongst the different

TABLE 32

TYPES OF GRANTS OBTAINED BY ANALYTICAL AUTHORS

H.E.I.	MG	RF	RS	RA	PG	EG	Total
University							
1. Bangor	3	1	4	1	1	1	11
2. Bath	2	1	9	0	3	2	17
3. Belfast	6	2	9	0	9	0	26
4. Durham	1	3	6	0	4	1	15
5. Kent	2	1	3	0	3	1	10
6. Leicester	1	0	7	0	6	3	17
7. Salford	6	4	10	0	11	2	33
8. Stirling	2	0	0	0	0	2	4
9. Warwick	3	3	1	0	8	3	18
10. York	7	2	3	0	7	0	19
Total	33	17	52	1	52	15	170
Polytechnic							
11. Hatfield	0	0	1	0	0	0	1
12. Huddersfield	0	0	0	0	0	0	0
13. Kingston	4	0	0	0	1	3	8
14. Central London	0	0	0	0	0	0	0
15. Oxford	0	0	0	0	0	0	0
16. Paisley	1	0	0	0	1	0	2
17. Plymouth	1	0	1	0	0	0	2
18. Sunderland	0	1	1	0	1	1	4
19. Wales	1	2	0	0	3	0	6
20. Wolverhampton	0	0	2	1	1	0	4
Total	7	3	5	1	7	4	27
Sample Total	40	20	57	2	59	19	197

Key to Table 32 :

MG - Maintenance Grants

RF - Research Fellowships

RS - Research Studentships

RA - Research Assistantships

PG - Project Grants

EG - Equipment Grants

types of grant. There was less difference for equipment grants with universities having four times as many as polytechnics. Equipment grants are provided specifically for the funding of scientific instruments usually used for specific research projects. Finally, for the total number of grants, universities had six times as many as polytechnics. This ratio is the same as that for research fellowships showing that they are perhaps a good indication of the general level of funding.

There are nine principal types of funding agency providing grants. These are Higher Education Institutions (i.e. internal funding), Research Councils, Government Departments, Industrial Firms, Public Corporations, Research Organisations, Learned and Professional Associations, International Organisations and Charities. As stated earlier for the purposes of the present work it is assumed that support from Higher Education Institutions and Research Councils are subjected to 'peer review' judgement based on the academic 'excellence' of the proposal whereas support from Industrial Firms, Public Corporations, Research Organisations, Learned and Professional Associations, International Organisations and Charities are assumed to be based on the 'customer-contractor principle'. The number of grants received from these funding agencies by analytical authors is shown in Table 33. Higher Education Institutions (HEI's) are universities, polytechnics and colleges. Research Councils are principally the Science and Engineering Research Council and Medical Research Council in this country, the National Science Foundation in America and the National Research Council for Canada. Government Departments are those that provided grants for research. Industrial firms included privately owned and publicly quoted companies whose principal source of revenue is from manufacturing. They usually provide funds for specific purposes concerning their manufacturing processes.

TABLE 33

NUMBER OF GRANTS PROVIDED BY FUNDING AGENCIES FOR AUTHORS IN THE 419 ANALYTICAL PAPERS

H.E.I.	'Peer Review'			'Customer-Contractor'								Overall
University	H	R	Total	G	F	P	O	L	I	C	Total	Total
1. Bangor	4	7	11	0	0	0	0	0	0	0	0	11
2. Bath	1	10	11	1	3	0	0	2	0	0	6	17
3. Belfast	0	9	9	14	1	0	1	0	0	1	17	26
4. Durham	0	10	10	0	1	1	0	2	1	0	5	15
5. Kent	1	6	7	1	1	0	0	1	0	0	3	10
6. Leicester	1	8	9	3	1	0	0	4	0	0	8	17
7. Salford	4	13	17	3	7	1	0	2	3	0	16	33
8. Stirling	0	3	3	0	1	0	0	0	0	0	1	4
9. Warwick	1	8	9	4	4	0	0	0	1	0	9	18
10. York	0	8	8	5	2	2	0	1	0	1	11	19
Total	12	82	94	31	21	4	1	12	5	2	76	170
Polytechnic												
11. Hatfield	0	0	0	1	0	0	0	0	0	0	1	1
12. Huddersfield	0	0	0	0	0	0	0	0	0	0	0	0
13. Kingston	2	4	6	1	0	0	0	1	0	0	2	8
14. Central London	0	0	0	0	0	0	0	0	0	0	0	0
15. Oxford	0	0	0	0	0	0	0	0	0	0	0	0
16. Paisley	0	0	0	0	0	1	0	1	0	0	2	2
17. Plymouth	0	1	1	0	1	0	0	0	0	0	1	2
18. Sunderland	0	3	3	0	1	0	0	0	0	0	1	4
19. Wales	1	1	2	0	2	0	1	1	0	0	4	6
20. Wolverhampton	0	2	2	0	2	0	0	0	0	0	2	4
Total	3	11	14	2	6	1	1	3	0	0	13	27
Sample Total	15	93	108	33	27	5	2	15	5	2	89	197

Key to Table 33 :

H - Higher Education Institutions

R - Research Councils

G - Government Departments

F - Industrial Firms

P - Public Corporations

O - Research Organisations

L - Learned and Professional Associations

I - International Organisations

C - Charities

Public corporations are those corporations within which the UK government controls 60 per cent or greater of their shares. Research organisations included contract research organisations which receive most of their income from research and development projects, and research associations for specific industries. Learned and professional associations mainly consisted of the major scientific societies. International organisations were those which have operations on a world wide basis. Charities were those groups which have been formed to help remedy specific problems (such as the treatment of cancer).

From Table 33 it can be seen that universities received four times as many grants as polytechnics from HEI's. This is the same as grants received from industrial firms, public corporations and learned and professional societies. From Research Councils universities received seven times as many grants as polytechnics. Government departments provided sixteen times as many grants to universities as to polytechnics. This is the largest individual difference out of all the comparison figures. The only category where there was no difference between universities and polytechnics was for grants provided from research organisations. For grants provided from the two categories of international organisations and charities none were given for polytechnics. For 'peer review type' funding universities received seven times as many grants as polytechnics. A similar figure of six times as many grants received by universities to polytechnics is apparent for grants received on a 'customer-contractor type' funding basis. For the total figures for the number of grants provided by funding agencies for analytical authors, universities again had six times as many grants as polytechnics.

For the grants listed in Tables 32 and 33 the number of analytical authors

TABLE 34

NUMBER OF AUTHORS FUNDED IN THE 419 ANALYTICAL PAPERS

H.E.I. University		Number Funded	H.E.I. Polytechnic		Number Funded
1.	Bangor	9	11.	Hatfield	1
2.	Bath	17	12.	Huddersfield	0
3.	Belfast	24	13.	Kingston	5
4.	Durham	13	14.	Central London	0
5.	Kent	9	15.	Oxford	0
6.	Leicester	13	16.	Paisley	2
7.	Salford	26	17.	Plymouth	1
8.	Stirling	4	18.	Sunderland	4
9.	Warwick	8	19.	Wales	4
10.	York	16	20.	Wolverhampton	3
	Total	139		Total	20
				Sample Total	159

TABLE 35

NUMBER OF ANALYTICAL GRANTS

		Funding Types						
		MG	RF	RS	RA	PG	EG	Total
	H	5	1	7	1	1	0	15
	R	11	12	35	1	22	12	93
Funding	G	10	0	11	0	11	1	33
	F	6	2	2	0	16	1	27
Agency	P	2	1	1	0	1	0	5
	O	1	0	0	0	1	0	2
Types	L	4	1	1	0	4	5	15
	I	1	3	0	0	1	0	5
	C	0	0	0	0	2	0	2
	Total	40	20	57	2	59	19	197

Key to Table 35:

Funding Agency Types

H - Higher Education Institutions

R - Research Councils

G - Government Departments

F - Industrial Firms

P - Public Corporations

O - Research Organisations

L - Learned and Professional Associations
I - International Organisations
C - Charities

Funding Types

MG - Maintenance Grants

RF - Research Fellowships

RS - Research Studentships

RA - Research Assistantships

PG - Project Grants

EG - Equipment Grants

TABLE 36

RESEARCH COUNCIL GRANTS

		Funding Types						
		MG	RF	RS	RA	PG	EG	Total
Research Councils	SERC	7	10	33	1	15	9	75
	MRC	0	0	2	0	4	1	7
	NSF	2	0	0	0	3	2	7
	NRCC	2	2	0	0	0	0	4
	Total	11	12	35	1	22	12	93

Key to Table 36 :

Research Councils

SERC - Science and Engineering Research Council
MRC - Medical Research Council
NSF - National Science Foundation
NRCC - National Research Council of Canada

Funding Types

MG - Maintenance Grants
RF - Research Fellowships
RS - Research Studentships
RA - Research Assistantships
PG - Project Grants
EG - Equipment Grants

TABLE 37

DATA FROM ANALYTICAL PAPERS PUBLISHED BY THE 154 SELECTED AUTHORS

H.E.I.	SA	EG		MG		LCA				
		PR	CC	PR	CC	PS	STS/S	FTS	G	I
University										
1. Bangor	5	1	0	9	0	1	5	3	0	2
2. Bath	19	1	1	9	3	12	7	5	0	6
3. Belfast	19	0	0	5	12	21	23	24	1	4
4. Durham	6	1	0	8	2	5	9	4	2	1
5. Kent	9	0	1	5	1	5	3	4	1	5
6. Leicester	11	0	3	7	1	2	7	13	0	3
7. Salford	29	1	1	13	7	35	28	33	2	5
8. Stirling	5	2	0	1	1	1	0	2	0	1
9. Warwick	4	2	1	5	2	0	9	13	2	3
10. York	16	0	0	4	8	5	8	7	2	0
Total	123	8	7	66	37	87	99	108	10	30
Polytechnic										
11. Hatfield	4	0	0	0	1	3	2	3	0	7
12. Huddersfield	1	0	0	0	0	0	3	0	0	0
13. Kingston	6	3	0	2	2	1	6	6	2	3
14. Central London	0	0	0	0	0	0	0	0	0	0
15. Oxford	0	0	0	0	0	0	0	0	0	0
16. Paisley	5	0	0	0	1	0	2	0	0	0
17. Plymouth	2	0	0	1	1	0	0	5	0	1
18. Sunderland	4	1	0	2	0	2	0	5	0	1
19. Wales	3	0	0	0	3	0	0	11	0	0
20. Wolverhampton	6	0	0	2	1	4	2	5	0	1
Total	31	4	0	7	9	10	15	35	2	13
Sample Total	154	12	7	73	46	97	114	143	12	43

Key to Table 37 :

SA - Selected Authors
EG - Equipment Grants
MG - Manpower Grants
PR - Peer Review
CC - Customer-Contractor

LCA - Location of Co-Authors
PS - Permanent Staff (Parent HEI)
STS/S - Short Term Staff/Students (Parent HEI)
FTS - Full Time Staff (Other HEI)
G - Government Organisations
I - Industry

funded is shown in Table 34. There were seven times as many analytical authors funded for universities as for polytechnics. By cross referencing the data from Tables 32 and 33 a Funding Matrix was constructed (Table 35). The second and largest row of the Funding Matrix is the number of Research Council grants. This has been further sub divided into the different research councils involved (Table 36). The largest category of Research Council grants was research studentships with a total of 35. Out of this the Science Research Council provided 33 grants and the Medical Research Council 2.

Table 37 summarises the data from the analytical papers surveyed and is derived from Table 35 by taking the total manpower grants as the sum of the maintenance grants, research fellowships, research studentships and research assistantships, and equipment grants as the same, and separating according to peer review and customer-contractor processes. From this it can be seen that 'peer review type' funding from the analytical papers in the card index was 1.7 and 1.6 times greater than 'customer-contractor type' funding for equipment grants and manpower grants respectively.

5.7 Funding Information from Questionnaires

The source of information provided in the three previous sections (5.4, 5.5 and 5.6) are selected publications in the scientific literature. This information is constrained by the format of the various publishers/learned societies, and the style of presentation and content of the various authors. An alternative source of information are the questionnaires sent to the selected authors which permits a different approach to some of the questions posed and enables a comparison to be made on some of the information gained by the two methods.

Table 38 summarises the data from the first questionnaire and shows that 'peer review type' funding was 3 and 1.9 times greater than 'customer-contractor type' funding for equipment and manpower grants. This shows that equipment grants had more 'peer review type' funding than manpower grants, and may be compared with Table 37 which summarises data for the analytical papers surveyed. The 82 selected authors, who replied to the Questionnaire (Table 38), reported fourteen times as many equipment grants and twice as many manpower grants as the total of 154 selected authors (Table 37). The result of this is that there are greater differences for the proportion of 'peer review type' to 'customer-contractor type' funding in the questionnaire compared with the analytical papers. The reason for a greater number of equipment grants and manpower grants being reported in the questionnaire is a result of authors in analytical papers not stating all the funding they received in the questionnaire.

The number of analytical authors with external funding for equipment and manpower obtained from the replies of the supplementary questionnaire is shown in Table 39. 49% said they had external funding of both equipment and manpower. 7% said they had external funding of equipment only and 4% of manpower only. Some 40% said they had funding of neither. This shows that a large proportion had no external funding out of those who replied.

For the external location of analytical co-authors both the data from the analytical papers and from the first questionnaire were similar. This is shown in Table 40 and is based on Tables 37 and 38. There were between 70% to 72% external co-authors in higher education institutions 6% to 7% in government organisations and 22% to 23% in industry.

TABLE 38

DATA FROM QUESTIONNAIRE

H.E.I.	SA	EG PR	EG CC	MG PR	MG CC	LCA PS	LCA STS/S	LCA FTS	LCA G	LCA I
University										
1. Bangor	4	10	0	9	1	1	5	3	0	1
2. Bath	8	20	4	11	7	3	6	3	0	6
3. Belfast	8	20	7	13	17	6	19	4	1	0
4. Durham	3	9	3	9	1	2	3	3	1	1
5. Kent	3	4	0	1	0	0	1	0	0	0
6. Leicester	5	10	1	16	1	1	6	9	0	1
7. Salford	12	48	14	30	18	9	23	19	1	1
8. Stirling	4	8	0	2	1	1	0	1	0	1
9. Warwick	2	15	1	15	8	0	7	11	2	3
10. York	11	22	4	11	4	3	8	4	1	0
Total	60	166	34	117	58	26	78	57	6	14
Polytechnic										
11. Hatfield	1	0	10	6	2	0	2	0	0	6
12. Huddersfield	1	9	0	2	1	0	3	0	0	0
13. Kingston	5	7	12	8	8	1	6	4	2	3
14. Central London	0	0	0	0	0	0	0	0	0	0
15. Oxford	0	0	0	0	0	0	0	0	0	0
16. Paisley	3	1	1	1	1	0	2	0	0	0
17. Plymouth	2	6	0	3	2	0	0	5	0	1
18. Sunderland	2	3	0	1	0	1	0	0	0	0
19. Wales	3	10	3	11	0	0	0	11	0	0
20. Wolverhampton	5	1	7	2	6	4	2	1	0	1
Total	22	37	33	34	20	6	15	21	2	11
Sample Total	82	203	67	151	78	32	93	78	8	25

Key to Table 38 :

SA - Selected Authors
EG - Equipment Grants
MG - Manpower Grants
PR - Peer Review
CC - Customer-Contractor

LCA - Location of Co-Authors
PS - Permanent Staff (Parent HEI)
STS/S - Short Term Staff/Students (Parent HEI)
FTS - Full Time Staff (Other HEI)
G - Government Organisations
I - Industry

TABLE 39

NUMBER OF ANALYTICAL AUTHORS WITH EXTERNAL FUNDING OF EQUIPMENT AND MANPOWER

Analytical Scientists with external Funding of:	Number	Percentage of Questionnaire Return
Equipment and Manpower	22	49
Equipment only	3	7
Manpower only	2	4
Neither	18	40

TABLE 40

LOCATION OF EXTERNAL ANALYTICAL CO-AUTHORS

	Other Higher Education Institutions	Government Organisations	Industry
Analytical Papers	72%	6%	22%
Questionnaire	70%	7%	23%

TABLE 41

EMPLOYMENT DESTINATION OF TEMPORARY ANALYTICAL AUTHORS

	SEI	HEI	IF	GE	Total
PDRF	1	4	1	0	6
PDRA	0	3	3	1	7
GRA	1	1	1	0	3
GRS	6	15	16	10	47
Total	8	23	21	11	63

Key to Table 41 :

Status

PDRF - Post Doctoral Research Fellow

PDRA - Post Doctoral Research Assistant

GRA - Graduate Research Assistant

GRS - Graduate Research Student

Institution/Establishment

SEI - Secondary Education Institution

HEI - Higher Education Institution

IF - Industrial Firm

GE - Government Establishment

TABLE 42

PEER REVIEW AND CUSTOMER-CONTRACTOR TYPE EXTERNAL FUNDING

	% 'Peer Review type' measured by amount of funding	% 'Customer-Contractor type' measured by amount of funding
(i) Equipment	79	21
(ii) Manpower	64	36

In reply to the question in the letter accompanying the first questionnaire (Appendix 3) asking analytical authors for comments on the concept of AS as a subject area or community of interest only one person who returned the questionnaire accepted the idea of AS as a subject area. The rest of those who replied to this question each felt their work belonged under the headings of co-ordination chemistry, analytical biochemistry, theoretical chemistry (2 authors), optical design, analytical chemistry, biophysical chemistry, synthetic organic chemistry, pharmacology, analytical electrochemistry, gas-phase ion chemistry, physical-organic chemistry and physical biochemistry. This shows that AS at present is not recognised.

As a measure of 'usefulness' of trained manpower the employment destination of temporary analytical authors was obtained from the first questionnaire and is shown in Table 41. The largest category were graduate research students who mainly found employment in higher education institutions or industry with slightly fewer gaining employment in government establishments and secondary education institutions.

For the twenty seven analytical authors in the supplementary questionnaire who said they had external funding, the percentage of 'peer review type' and 'customer-contractor type' measured by amount is shown in Table 42. 'Peer review type' accounted for approximately three quarters of equipment funding and two thirds of manpower funding.

5.8 Patterns of Research Funding

The principal factors pertaining to the development factors in Chapter 4 affecting the patterns of research funding are employee status, intellectual tradition, structural composition and science policy influences in AS.

The employee status of analytical authors was obtained according to internal and external location. For internal research workers there were five permanent academic staff levels. These were the University grades of Head of Department, Professor, Reader, Senior Lecturer and Lecturer levels. The corresponding Polytechnic grades were Head of Department, Reader, Principal Lecturer, Senior Lecturer and Lecturer. The smallest in number was the Head of Department level. Alongside this level there were six times as many professors. For comparison purposes these two levels are taken together and form the SAS component as in Chapter 2. Within these two levels most of the leading analytical workers are found.

The other three permanent levels were the Reader, Senior Lecturer and Lecturer levels. These three levels form the greater part of the internal permanent levels with four times as many lecturers as senior lecturers and eight times as many as readers. Within these three levels most research group leaders will be found.

Below these five internal permanent levels there were four internal temporary levels. These were the Research Fellow, Post Doctoral Research Assistant, Research Assistant and Research Student levels. Out of these the largest number were research students being some five times greater than the next largest number who were research fellows. There were twice as many research fellows as post doctoral research assistants and three times as many as research assistants. These four levels can be considered to be general research workers. Associated with these were Technicians and Students - the former on an internal permanent basis (only 3 in number in the sample) and the latter on an internal temporary basis (only 2 in number).

For external research workers there were two principal categories, being Higher Education Institution Researchers and Industrial Collaborators. Higher education institution researchers involved the same nine levels as the internal research workers but were in other institutions of higher education in the UK and abroad. Industrial collaborators were those people involved in the analytical research surveyed in the sample principally from industry and government establishments.

To determine these levels a 'top down' approach was used accordingly for each level. The first five levels of permanent internal research workers can be seen as those people who not only received funds but who were also the 'fund raisers' who independently or collectively raised funds for their research. The four levels of temporary internal research workers were those who were 'fund receivers'.

The intellectual tradition of AS is predetermined by its origins in analytical chemistry and optical physics. The researchers working in the AS field have brought with them their expertise and knowledge from their respective areas. Funds are, therefore, principally obtained for AS according to the beliefs of the chemistry and physics communities. The intellectual tradition predetermines the way in which funds are obtained. If AS develops successfully from these funds into a recognised entity it will result in an eugenic formation from its origins in chemistry and physics.

The structural composition of AS arises from its interdisciplinary structure involving both physics and chemistry. This is directly influenced by the use of analytical techniques from optical physics and analytical chemistry which requires AS to be carried out in a laboratory setting. Funds are directed towards the provision of laboratory personnel and equipment. The structural composition, therefore, affects the allocation of funds.

Science policy influences are regulated by policy making and funding organisations as well as by academic institutions and industrial enterprises. The research councils made the largest contribution to the number of grants and with academic institutions they formed a greater number of grants by 'peer review' (55%) than industrial enterprises and other organisations that provided the 'customer-contractor type' funding (45%). The SERC is the main policy making and funding organisation for AS. This is apparent since it provides the largest number of grants to HEI's in the sample. AS generally, therefore, received more funds from 'peer review' than 'customer-contractor' sources.

Controlling the rate at which these factors influence the development of AS in terms of funding is the 'mechanism' of development. The mechanism governs the stage of development and this is inherently determined by the historical antecedents to the present state of AS. The mechanism of development is perceptual evolution and is still in its early state, so that AS is at the emergence stage according to the general sequential mechanism in 4.3. Further development will depend on the instigators of the development attracting the sort of funds that will bring full development. Since AS is a stable area due to there being a low number of single author papers (15%) in the sample in relation to multiple author papers (85%), it should on this basis develop successfully in the future.

TABLE 43

COMPARISON OF ANALYTICAL SCIENCE PUBLICATIONS AND SERC FUNDING WITH SCIENCE AND ENGINEERING PUBLICATIONS AND SERC FUNDING (1970 - 79)

H.E.I.		Science and Engineering		Analytical Science	
		Publications	SERC Grants (£)	Publications	SERC Grants (£)
University					
1.	Bangor	2,575	1,026,000	7	112,024
2.	Bath	2,584	1,048,000	27	38,545
3.	Belfast	6,105	1,857,000	59	545,342
4.	Durham	2,785	1,808,000	29	407,382
5.	Kent	1,590	1,156,000	19	128,268
6.	Leicester	4,577	3,391,000	21	401,477
7.	Salford	4,668	1,675,000	112	153,515
8.	Stirling	1,455	564,000	5	63,940
9.	Warwick	2,461	3,046,000	23	133,976
10.	York	1,956	1,404,000	29	684,595
	Total	30,756	16,975,000	331(1%)	2,669,064(16%)
Polytechnic					
11.	Hatfield	650	265,000	20	8,893
12.	Huddersfield	589	32,000	2	10,437
13.	Kingston	920	130,000	17	24,683
14.	Central London	664	261,000	0	0
15.	Oxford	672	37,000	0	0
16.	Paisley	686	101,000	12	0
17.	Plymouth	1,090	74,000	9	0
18.	Sunderland	948	147,000	8	35,553
19.	Wales	751	67,000	10	5,078
20.	Wolverhampton	274	28,000	10	1,000
	Total	7,244	1,142,000	88(1%)	85,644(7%)

The present pattern of funding shows this present stage of development for AS and can be obtained by comparing SERC grants obtained by the institutions (as mentioned in Table 11) with those obtained by the selected authors (as listed in the SERC literature). Although SERC funding to selected authors is not necessarily to AS it gives an indication of the funding received. This is illustrated in Table 43. It can be seen that in the sample AS generally had 1% of the publications for both universities and polytechnics and 16% and 7 % of the grant money. This suggests that the funding being attracted to AS is yet to filter through into a similar proportion of publications resulting in its establishment.

The number of analytical authors receiving SERC grants, the number of grants and the amount of money they received between 1971 and 1979 for the sample is shown in Table 44. Universities had an average of 3 grants and £37,592 for each analytical author funded. Polytechnics had an average of 2 grants and £14,274 for each analytical author. For the sample total there was an average of 3 grants and £35,775. However, the total number of grants for university AS was 226 compared with only 10 for polytechnics. The amount of the grants to universities was, therefore, very much greater.

The association of the figures for analytical authors, papers and grants is shown in Table 45. This shows that there is a close relationship for these research quantities for analytical work in each institution in the sample.

The analysis of analytical work shows that 'excellent' work was produced according to peer adjudicated analytical papers written. 'Useful' work was produced in terms of the number of temporary analytical co-authors who

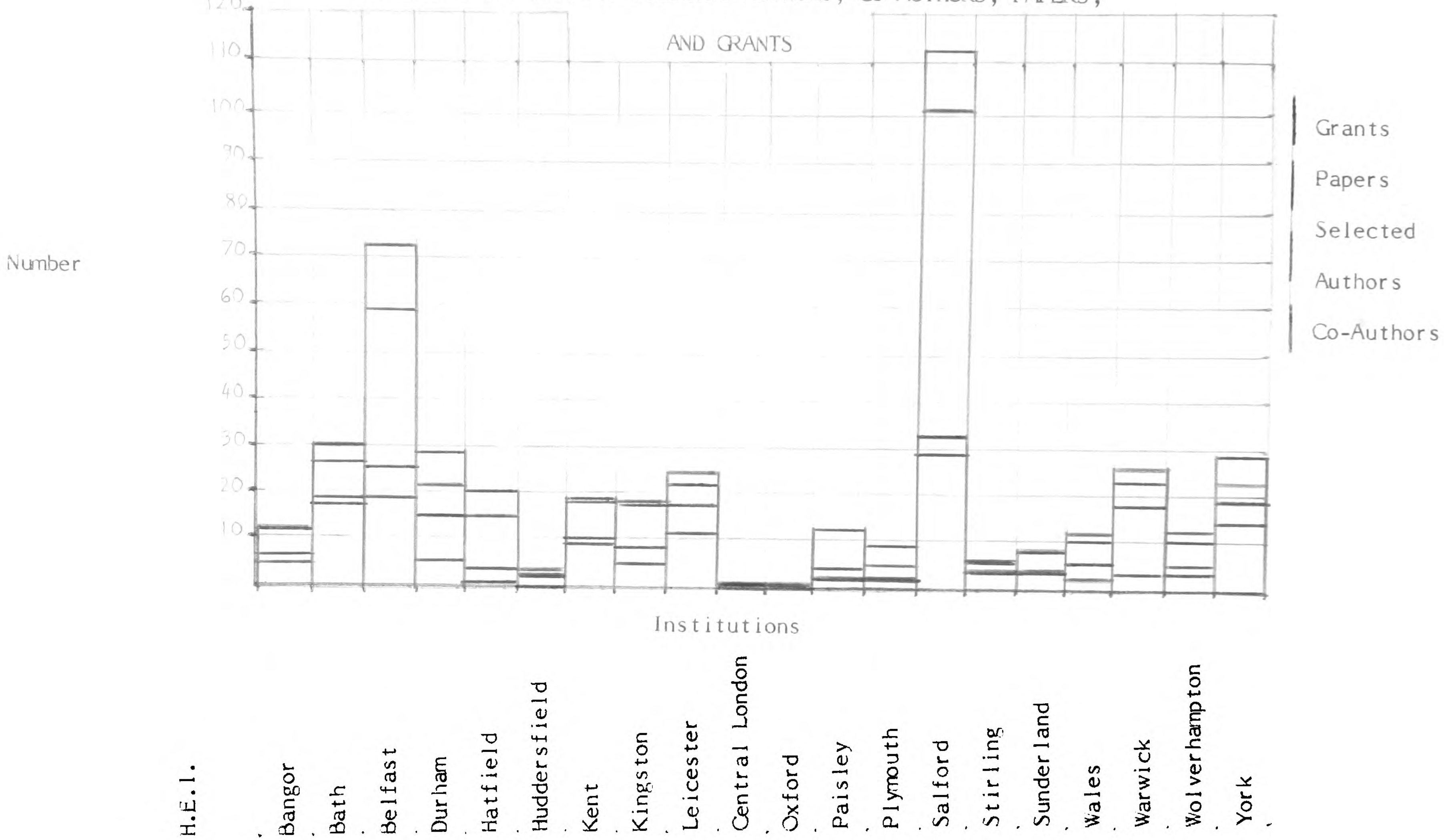
TABLE 44

SERC GRANTS AND MONEY RECEIVED BY ANALYTICAL AUTHORS IN THE SAMPLE BETWEEN 1971 AND 1979

H.E.I.		Number of Analytical Authors	Number of SERC Grants	Amount of Money (£)
University				
1.	Bangor	3	7	112,024
2.	Bath	5	5	38,545
3.	Belfast	12	45	545,342
4.	Durham	5	28	407,382
5.	Kent	7	13	128,268
6.	Leicester	6	43	401,477
7.	Salford	11	17	153,515
8.	Stirling	5	9	63,940
9.	Warwick	4	21	133,976
10.	York	13	38	684,595
	Total	71	226	2,669,064
Polytechnic				
11.	Hatfield	1	3	8,893
12.	Huddersfield	1	2	10,437
13.	Kingston	1	2	24,683
14.	Central London	0	0	0
15.	Oxford	0	0	0
16.	Paisley	0	0	0
17.	Plymouth	0	0	0
18.	Sunderland	1	1	35,553
19.	Wales	1	1	5,078
20.	Wolverhampton	1	1	1,000
	Total	6	10	85,644
	Sample Total	77	236	2,754,708

TABLE 45

NUMBER OF ANALYTICAL SELECTED AUTHORS, CO-AUTHORS, PAPERS, AND GRANTS



qualified and found employment in various industrial and commercial spheres in society. From this it is apparent that the efficacy of 'peer review' and 'customer-contractor type' funding can be found in terms of analytical papers and analytical manpower respectively.

A comparison is possible between 'peer review' and 'customer-contractor' support for the analytical research surveyed in this work using the criteria outlined in 5.3. The proportion of each type has been identified from these separate sources of information as shown in Table 46 which is a summary of information in Tables 37, 38 and 42. In each case it emerges that the percentage of funding by 'peer review' is larger than 'customer-contractor' for equipment (63%, 75% and 79%) than for manpower (61%, 66% and 64%).

In so far as 'peer review' is directed to 'excellence' and 'customer-contractor' is directed towards 'usefulness' it is possible to quantify the output. Clearly these terms have considerable overlap as well as a separate identity in terms of these outputs. Analytical papers which satisfy the 'peer review' refereeing procedure have an element of 'excellence'. Work carried out by the equipment - some of which is reported in the literature - has an element of 'usefulness'. The manpower identified by the co-author analysis receives training for posts in industry, government and education in which 'useful' work is deemed to take place. Again there is overlap between 'excellence' and 'usefulness' for the outputs of analytical papers, work carried out by equipment and the training of manpower.

An important question that needs to be posed is whether there is a

TABLE 46

A COMPARISON OF ANALYTICAL FUNDING DATA

Data Base	Published Papers				First Questionnaire				Second Questionnaire			
	Equipment (No. of Items)		Manpower (No.)		Equipment (No. of Items)		Manpower (No.)		Equipment		Manpower	
	PR	CC	PR	CC	PR	CC	PR	CC	PR	CC	PR	CC
154 Selected Authors from 419 Papers	12	7	73	46								
82 Respondents					203	67	151	78				
45 Respondents									79 %	21 %	64 %	36 %
% Type Funding	63	37	61	39	75	25	66	34	79	21	64	36

community of analytical scientists? Working parties draw attention to the lack of chairs/readerships which would identify a community by leaders who 'wear the badge'. The present work begins from a data base identified by the journals in which analytical research is published for 20 institutions and finds a healthy input in terms of funding and output in terms of publications.

In general the selected authors of these publications do not 'wear the badge' of AS. In this respect they are unwilling or unknowing members of the invisible college of AS and probably subscribe to invisible colleges in other disciplines.

As a peroration, the low figures for the funding of leading analytical authors in 5.3 from the SERC grants is due to grants being obtained from 'customer- contractor type' instead of 'peer review type' sources received by analytical authors generally in the sample. This in turn is due to the esoteric nature of the funding channels through which analytical leaders receive industrial funding. In the future analytical authors generally will probably receive most of their funding from industry like their colleagues in the higher echelon. This difference caused by the leaders, with the consequent inculcation of their fellow analytical authors, will probably stimulate the funding patterns in this area leading to the recognition of AS. Eventually the support from 'peer review' and 'customer-contractor type' funding should be eurhythmic.

CHAPTER 6

Conclusions

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Although there are many definitions of research all emphasise the acquisition of new knowledge. The two principal types of research are pure and applied, one being directed towards obtaining new knowledge and understanding, the other towards a specific aim or purpose.

For the activity of research to be undertaken it requires funds. The patterns of research funding show how research has been supported in the past and from this it is possible to determine future priorities.

The two principal types of funding are provided on the basis of peer review and customer-contractor processes. For 'peer review type' funding higher education institutions and research councils provide the funds. For 'customer-contractor type' funding government, industry and charities form the principal funding agencies.

The peer review system operates by academics determining the grants that are given to their fellow researchers. The research committee is the means by which this is done. By using the peer review system it is possible to determine new disciplinary areas that show promise. This can be done by assessing the quality of research proposals for new areas. 'Excellence' tends to be the fundamental criterion for support in the peer review system. Because of this it is directed towards attracting funds for pure research.

The customer-contractor principle, on the other hand, provides grants to a contractor who undertakes the work according to what the customer wants (since the customer pays for it). This has been stated mainly for the provision of funds for applied research of practical application.

In order to determine the extent to which funding by the peer review system and customer-contractor principle are provided, the research activity of a sample of higher education institutions in the UK was measured. There are three principal types of research measurement. These are input, process and output measures. The most common output measure is research publications.

For the sample of 20 institutions from 1970 - 79 65,110 publications were produced. There were approximately four times as many publications from universities as polytechnics. By taking account of the fact that there were about twice as many academic units in universities as in polytechnics this meant that on average university units produced twice as many publications as polytechnic units.

The rate of growth of publications was found to increase in a 'wave-like' pattern. From this it was deduced that there was a 'publication cycle'. The factor considered to cause this was the impact of new researchers. The growth of publications in the sample was found to agree with de Solla Price's doubling time of between 10 and 15 years, and this was proved by the doubling time approximation.

For the measurement of the input of resources on the research process, the amount of funding is the best measure in terms of the number of grants. As a preliminary exercise the funding of the arts and sciences each side of the binary line was studied.

The publications from this funding showed a close similarity in the relative numbers in universities and polytechnics for Arts and Social Sciences (A & S) and Science and Technology (S & T) and the parallel growth patterns for the two areas. It was also found that the proportion of A & S to S & T publications was marginally higher in the polytechnics than in the universities selected for the present study. This is contrary to the perceptions of a number of educationalists.

The Senior Academic Staff (SAS) have an important influence on the procurement of funds for universities and polytechnics in these two main areas. In universities the average number of SAS was 52 whereas in polytechnics it was 25 for the year 1979 - 80 in the subsample of 10 institutions. The average number of publications was 15 and 22 respectively in university A & S and S & T areas from 1970 - 79, and 6 and 4 publications in the A & S and S & T areas in polytechnics.

The nature of funding in S & T was further investigated by comparing science with engineering. Because of the special emphasis on theory in science and on practice in engineering, the scientist can be seen as a 'theoretician' whereas the engineer can be seen as a 'practician'. Due to this fundamental difference funds are mainly obtained for the intellectual development of disciplines on the one hand and for ideas of practical value on the other.

The number of science publications in the sample was six times larger than the number of engineering publications. There was a greater proportion of engineering publications in polytechnics than universities, being 20% compared with 12%. This shows that polytechnics are more directed towards engineering.

The greater pattern of activity for science publications compared with engineering publications for the sample follows the larger amount of funding for science from the Science and Engineering Research Council (SERC), formerly the Science Research Council (SRC). Because of this greater activity accorded by funding and publications and due to the 'conceptual' nature of science there tends to be more change in science than engineering disciplinary divisions. As a result new areas constantly emerge in science resulting in the development of new disciplines. (However, funding of the Engineering Board now exceeds that of the Science Board which should compensate for this trend).

The general theory of the development of scientific disciplines is characterised by the empirical common formulations of discernable development factors, of a mechanism of development and of instigators of the development.

Factors involved in the development of a scientific discipline can be categorised into social features, cultural phenomena, organisational aspects, and economic and political influences. Out of these the first three factors have had substantial study, whereas economic and political influences require further refinement.

The general mechanism of development involving the factors of development shows evolutionary progression through the stages of origins, emergence, growth and development, establishment, maturity and sometimes decline. The mechanism of development is controlled by instigators of the development who are usually formed into a recognisable group.

The members of the group, who are leaders in their new area, influence the development economically and politically according to their own and to other science policy objectives by attracting funding. By studying the funding of Analytical Science (AS) as a new scientific area it has been possible to create a greater understanding of these economic and political influences. The leaders involved in AS have formed a group that has viewed their area of science in a new way. By doing this they have undertaken a 'Gestalt shift'. The development of AS will depend on whether the analytical 'shift' group can obtain the sort of funds that are required to establish it as a scientific entity. The analytical authors in this group are bound together by technical solidarity in that they are all implicated in the use of analytical instruments.

In order to find out how AS is being developed the research funding patterns were found from the sample of analytical authors in 20 higher education institutions. It was found that AS is a fairly stable area due to there being about six times as many co-author papers as single author papers in the sample. Due to this solid base AS has a good chance of being developed into a recognised scientific entity.

Analytical authors in the sample were located in the three main areas of higher education institutions (90%), government research laboratories (2%)

and industry (8%). As far as the status of analytical authors was concerned, the largest in number were lecturers totalling 144 at the higher education institutions in the sample. The average length of papers produced by analytical authors was 7 pages and the average number of authors per paper was 2.

For the number of pieces of equipment used there was about one piece of equipment per analytical author. The most common piece of equipment was the spectroscope in its various forms. This was found to be commonly used in both analytical chemistry and optical physics - the two main areas of AS.

For the patterns of funding of analytical authors and equipment two principal types of support were studied. These were non-pecuniary and pecuniary. Non-pecuniary was principally in the form of gifts and only accounted for a small proportion. Whereas, pecuniary, in the form of funding was the principal type. Pecuniary support is provided through the mechanisms of funding agencies in the form of grants.

Out of the grants paid for the support of personnel, research studentships were the largest in the sample with 57. This is because they are actively sought after by analytical authors, as in other areas. Out of all the different types of grant, project grants were the largest being 59 in number, with research studentships being the second largest. Research councils provided the largest number providing 47% of all grants. The number of analytical authors receiving these grants was 159 in all. This gives an average of about 8 per institution. There were about seven times as many analytical authors funded for universities as for polytechnics.

The funding matrix constructed from the type and source of grants showed that research council studentships were the largest in number in the sample with a total of 35. Out of these the SERC (then the SRC), provided 33.

The four principal research quantities of selected authors (the same number as senior authors) co-authors, periodical papers and grants that were involved in the research funding patterns were all found to be numerically associated in the sample.

The general pattern of funding in AS showed that not only is the percentage of funding by 'peer review' greater than for 'customer-contractor', it is also larger for equipment than for manpower. Finally, AS work was found to be 'excellent' in terms of analytical papers and 'useful' in terms of the employment of analytical manpower.

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Appendices

Appendix 1 - Analytical Periodicals

Appendix 2 - Scrutiny of Analytical Papers

Appendix 3 - Analytical Science Questionnaire

Appendix 4 - Supplementary Analytical Science Questionnaire

Appendix 1

Analytical Periodicals

A. Analytical Chemistry

1. Analusis
2. Analyst
3. Analytica Chimica Acta
4. Analytical Biochemistry
5. Analytical Chemistry
6. Analytical Letters
7. Association of Official Analytical Chemists Journal
8. Association of Public Analysts Journal
9. Atomic Spectoscopy
10. Biomedical Mass Spectrometry
11. Bunseki Kagaku
12. Critical Reviews in Analytical Chemistry
13. Chemia Analityczna
14. Chemical, Biomedical & Environmental Instrumentation
15. Chemical Society. Analytical Division Proceedings
16. Chromatographia
17. European Spectroscopy News
18. Fresenius' Zeitschrift Fuer Analytische Chemie
19. International Journal of Environmental Analytical Chemistry
20. Journal of Analytical Chemistry of the USSR
21. Journal of Automatic Chemistry
22. Journal of Chromatographic Science
23. Journal of Chromatography
24. Journal of Electroanalytical Chemistry and Interfacial Electrochemistry
25. Journal of Electron Spectroscopy and Related Phenomena
26. Journal of Labelled Compounds and Radiopharmaceuticals
27. Journal of Radioanalytical Chemistry
28. Journal of Raman Spectroscopy
29. Journal of Thermal Analysis
30. Material und Organismen
31. Mikro Chimica Acta
32. Organic Mass Spectrometry
33. Rassegna Chimica
34. Review of Polorography/Polarogurafi
35. Reviews in Analytical Chemistry

36. Separation and Purification Methods
37. Separation Science and Technology
38. Silikaty/Silicates
39. Surface and Interface Analysis
40. Talanta
41. Thermal Analysis Abstracts
42. X-Ray Diffraction Abstracts
43. X-Ray Spectrometry
44. Zavodskaya Laboratoriya
45. Zeolites
46. Zhurnal Analiticheskoi Khimii

B. Optical Physics

47. Acoustical Imaging and Helography
48. Applied Optics
49. Applied Spectroscopy
50. Applied Spectroscopy Reviews
51. Canadian Journal of Spectroscopy
52. Canadian Spectroscopic News
53. Electro Optics
54. Die Farbe
55. Fiber and Integrated Optics
56. Fondazione Giorgio Ronchi
57. I.E.E. Journal of Microwaves, Optics and Acoustics
58. Inform' Optique
59. Infrared Physics
60. International Journal of Infrared and Millimeter Waves
61. International Journal of Mass Spectrometry and Ion Physics
62. Inter-Society Colour Council News
63. Jemna Mechanika A Optika/Fine Mechanics and Optics
64. Journal de Microscopie et de Spectroscopie Electroniques
65. Journal of Applied Spectroscopy
66. Journal of Luminescence
67. Journal of Molecular Spectroscopy
68. Journal of Optics
69. Journal of Optics/Nouvelle Revue D'Optique
70. Journal of Quantitative Spectroscopy and Radiative Transfer
71. Kep-Es Hangtechnika
72. Laser and Unconventional Optics Journal
73. Laser Focus with Fiberoptic Communications
74. Laser Report

75. Laser Und Elektro-Optik
76. Lasers in Surgery and Medicine
77. Luce E Immagini
78. Neues Optikerjournal
79. Optica Acta
80. Optica Applicata
81. Optica Pura Y Aplicada
82. Optical and Quantum Electronics
83. Optical Engineering
84. Optical Society of America Journal
85. Optical Spectra
86. Optics and Laser Technology
87. Optics and Lasers in Engineering
88. Optics and Spectroscopy
89. Optics Communications
90. Optics Letters
91. Optics News
92. Optik
93. Optika I Spektroskopiya
94. Optiko-Mekhanicheskaya Promyshlennost
95. Progress in Nuclear Magnetic Resonance Spectroscopy
96. Society of Photo-Optical Instrumentation Engineers Proceedings
97. Soviet Journal of Optical Technology
98. Spectrochimica Acta. Part A : Molecular Spectroscopy
99. Spectrochimica Acta Part B : Atomic Spectroscopy
100. Spectroscopia Molecular
101. Spectroscopical Society of Japan. Journal/Bunko Kenkyu
102. Spectroscopy Letters
103. Spex Speaken

Appendix 2.

Scrutiny of Analytical Papers

Methodology :

1. Check author(s) name. See which authors are at other institutions (i).

2. Check title.

3. Check reference.

4. Read abstract.

5. Read contents of paper.

6. Note equipment used (ii).

7. Note the funding of :

   a. equipment,
   b. authors (iii).

8. Note any cross references to previous analytical papers by the authors in the paper for the period 1970 to 1979 (iv).

Appendix 3

Analytical Science Questionnaire

THE POLYTECHNIC OF WALES
POLITECHNIG CYMRU

Director J. D. Davies
MSc, PhD, DSc, CEng, FICE, FIStructE

Department of Science

Head of Department W. O. George
BSc, PhD, DSc, CChem, FRSC, FRSA

Pontypridd Mid Glamorgan CF37 1DL
Telephone (0443) 405133

Date

Dear

O/Ref Sc/BCT:jg Y/Ref

I am working on a project concerning 'Research Funding Patterns in the UK with special reference to Analytical Science'. The aims are to determine the amount of funding received by researchers in Analytical Science according to source and type and from this to determine the patterns for the funding of manpower and equipment.

Analytical Science is not a clearly defined area but emerges in a number of ways e.g. (Report of the Analytical Science Panel, September (1979). Report of the Analytical Science Working Group, March (1981). SERC, Swindon).

Any definition of Analytical Science has to be somewhat arbitrary. I have, therefore, selected those papers published in periodicals falling within the areas of Analytical Chemistry and Optical Physics according to the Ulrich classification.

I have abstracted information from your published papers (1970-79) listed in an Appendix and would be most grateful if you would complete the questionnaire attached relating to this equipment and manpower information and return to me in the stamped addressed envelope provided within a month if possible.

I would also be most interested to receive any comments you may have on the concept of Analytical Science as a subject area or community of interest. Alternatively you may like to comment on any other heading under which you feel your work belongs.

I look forward to hearing from you.

Yours faithfully

BRYCHAN C THOMAS, BSc(Hons), MSc.

APPENDIX

ANALYTICAL PAPERS

ANALYTICAL SCIENCE QUESTIONNAIRE

REF :

Please fill in the following two tables relating to the list of papers (Appendix).

1. Equipment. Please complete columns 3, 4 and 5 and column 2, if incomplete, of Table 1. (The list of equipment includes the main items of instrumentation cited in the papers.)

Table 1. Equipment.

Column	Funding Criteria				
	1.	2.	3.	4.	5.
	Type	Make and Model	Location	Source of Funding	Approximate Value at the Time of Purchase (Also year of purchase if known.)
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

2. **Manpower.** Please complete columns 3, 4, 5 and 6 of Table 2. (This relates to total duties rather than those concerned with the published work).

Table 2. Manpower.

Column	1.	2.	3.	4.	5.	6.	
	Co-author	Location indicated by publication.	Status*	Funding Body†	Number of Years supported	Present Location and Position (if known)	
						Position	Institution/ Organisation
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							

* Internal permanent member of staff, internal short-term research appointment, post-doctoral research fellow, post-doctoral research assistant, graduate research assistant, graduate research student, technician and technical support staff, and other.

† Parent Institution, Research Council (eg S.E.R.C., M.R.C.), Government Department (eg D.o.I.) Local Education Authority, Nationalised Industry (eg C.E.G.B.), Private Industry (eg Unilever, B.P.), Charitable Trust or Society etc., Self Supporting, Other Source.

Appendix 4.

Supplementary Analytical Science Questionnaire

THE POLYTECHNIC OF WALES
POLITECHNIG CYMRU

Director J. D. Davies
MSc, PhD, DSc, CEng, FICE, FIStructE

Department of Science

Head of Department W. O. George
BSc, PhD, DSc, CChem, FRSC, FRSA

Pontypridd Mid Glamorgan CF37 1DL
Telephone (0443) 405133

Date

O/Ref Sc/BCT:js Y/Ref

Dear

Research Funding Patterns in the U.K.
with special reference to Analytical Science.

You kindly returned a questionnaire in relation to the above project and I enclose a summary of the information that was gained. As a follow up I would be grateful if you would provide the information on the appended form.

By peer review type funding is meant the provision of external funds based on decisions by active researchers in similar fields, who decide on the merit of the work by the internal criteria of their community, typically a Research Council.

By customer-contractor type funding is meant funds on the Rothschild principle which are largely made by the organisation who needs the information, typically a government department or industrial enterprise.

I would be pleasedif you could kindly return the completed form to me in the stamped addressed envelope, within a month if possible.

I look forward to hearing from you.

Yours faithfully,

BRYCHAN C. THOMAS. B.Sc. (Hons), M.Sc.

APPENDIX

ANALYTICAL PAPERS

QUESTIONNAIRE

From the Publications (1970-1979) appearing in periodicals identified as publishing 'Analy-tical Science' (Appendix) please could you answer the following questions:

1. In relation to external funding could you estimate the following:-

	% "Peer Review type" Measured by amount of funding.	% "Customer-Contractor type" Measured by amount of funding.
(i) Equipment		
(ii) Manpower		

2. Could you provide examples of external measures, or your own judgement, of 'excellence' or 'usefulness' deriving from this work in relation to one or more of the above four categories.

Name:

Institution: