Survey on Scholarship, Research and Development

Performed by the

UNIVERSITY OF STELLENBOSCH (Centre for Interdisciplinary Studies)

on behalf of the

Department of Arts, Culture, Science and Technology

as part of the

National Research and Technology Audit

Table of Contents

List of Tables and Figures

Figures

List of Abbreviations

AMI	Access Marketing International
ARC	Agricultural Research Council
Border	Border Technikon
CapeTech	Cape Technikon
CEPD	Centre for Education Policy Development, Evaluation and Management
CSD	Council for Science Development
CSIR	Council for Scientific and Industrial Research
DACST	Department of Arts, Culture, Science and Technology
ECapeTech	Eastern Cape Technikon
FRD	Foundation for Research Development
FSTech	Free State Technikon
HES	Higher Education Sector
HSRC	Human Sciences Research Council
LHA	Louis Hale & Associates
ManTech	Mangosuthu Technikon
MED	Medical University of South Africa

MLSultan	M L Sultan Technical College
MRC	Medical Research Council
NAC	National Accelerator Centre
NGO	Non Governmental Organisations
NRTA	National Research and Technology Audit
NWTech	North West Technikon
OECD	Organisation for Economic Co-operation & Development
Pentech	Peninsula Technikon
PeTech	Port Elizabeth Technikon
PTech	Pretoria Technikon
PUCHE	Potchefstroom University for Christian Higher Education
R&D	Research and Development
RAU	Rand Afrikaans University
Rhodes	Rhodes University
S&T	Science and Technology
SABS	South African Bureau of Standards
SAPSE	South African Post-Secondary Education
SSRD	Survey on Scholarship, Research and Development
STET	Scientific and Technical Education and Training
STS	Scientific and Technical Services
TechNat	Natal Technikon
TSA	Technikon South Africa
Twits	Witwatersrand Technikon
UCT	University of Cape Town
UDW	University of Durban-Westville
UFH	University of Fort Hare
UFS	University of the Free State
UN	University of Natal
UNIN	University of the North
UNISA	University of South Africa
Unitra	University of Transkei
Univen	University of Venda
UNW	University of the North West
UP	University of Pretoria

UPE	University of Port Elizabeth
US	University of Stellenbosch
UWC	University of the Western Cape
VaalTech	Vaal Triangle Technikon
Vista	Vista University
Wits	University of the Witwatersrand
Zulu	University of Zululand

Acknowledgements

The authors wish to extend their sincere appreciation to the organisations and individuals listed below. This research survey would not have been possible without their assistance and support.

?? The University of Stellenbosch for financial support.

?? Profs. Johan Groenewald, HC Marais, Joe Muller, Calie Pistorius and Arie Rip who made essential contributions during the conceptualisation phase of the project.

?? Dr Ursula van Beek for her administrative co-ordination of the project.

?? Prof. H.C. Marais and Mrs Magdal Pienaar who assisted with the interviews.

?? Mr Jan Evertse and Mr Jacob du Plessis for database support.

?? Mss Charline and Sanet Mouton and Mr Hein du Plessis who did the initial data-capture.

?? Mr Gareth Caffin and Mike Baker who did the final editing of the database.

?? Mrs Fran Ritchie and Ilse Evertse who provided key administrative and secretarial support throughout the project.

?? Our contact persons at each of the institutions who assisted with the management and administration of the surveys and provided information on a continuous basis.

?? And finally, every respondent at a technikon, university, government department, science council, ngo and other research organisations who set aside time to complete our questionnaires.

J. Mouton
H. Hackmann
September 1997

Executive Summary

Type of R&D

?? The HES spends the largest proportion (50%) of its direct costs on basic research. However, it is noteworthy that the larger part of this is devoted to strategic, rather than fundamental research. This means that pure curiosity-driven, or so-called blue-sky research, currently makes up less than one quarter of all research within the HES and less than 5% of all R&D in the public sector.

?? The fact that the HES devotes such a large proportion of its resources to basic research, makes it the biggest overall player in this category in the public sector. However, because of the large proportion of resources devoted to strategic research within the government sector (22%), the overall distribution of expenditure in the domain of basic research is now much more evenly balanced (55: 44).

?? All performers in the public sector devote more than one third of their expenditure to applied research. The percentages range from 37% to 41%. As expected, the government sector (especially the science councils) produces the biggest chunk of applied research (61%) which is in line with their missions as problem-oriented research institutions.

?? There has been an overall increase in expenditure devoted to developmental work. This is particularly true of the HES where there has been an increase of 4% between 1993 and 1995/6. A comparable trend is evident in the government sector. Although these are not large percentages, they signify a shift to more development-oriented and technology-driven research.

Source of R&D funding

?? Government is the largest source of funding in the public sector. If one combines its direct and indirect contribution (agency funding), the amount sums to more than 60% of all R&D expended.

?? Government also funds R&D indirectly through contracts awarded to science councils and universities. Previous R&D surveys (1991 and 1993) show that government's contribution to the public sector is very high (88% in 1991 and 90% in 1993) with the remainder coming from the private sector. A rough estimate would be that government's contribution to R&D expenditure in the public sector is in the region of between 75% and 85%.

R&D Expenditure

?? The business and industrial sector dominates domestic investment in R&D (66%), followed by the Science Council sector (18%), Higher Education Institutions (13%) and Government (3%)

?? The total estimated R&D expenditure of R4.9 billion in 1995/96 constitutes 1.15% of Gross Domestic Product (R430 billion). This finding is significant because it means that estimates of R&D expenditure that have been used over the past number of years have grossly misrepresented the true state of affairs.

?? However, although the results show an increase in R&D expenditure over the past five years (as expressed in % of GDP), one should be cautious to interpret this as proof of a real increase. It is much more likely that the figures cited for the Business Sector in previous R&D surveys had always under-estimated true expenditure.

?? The fact that R&D expenditure is more than 1.0% of total GDP is a positive finding. Although it does not compare favourably with the proportionate expenditure of highly industrialised countries such as Germany and the USA, it signifies a bigger national investment and commitment in R&D than previously thought. The real challenge, of course, is to ensure that this expenditure is applied to meet the true needs of the South African society.

?? More than half of public sector expenditure is directed at three sectors - agriculture, mining and quarrying, and manufacturing. This is due to the dominance of three large science councils (CSIR, ARC and MINTEK) in this sector. Although this highly skewed picture has identifiable historical roots (the traditional importance afforded to the agricultural sector and the mining industry in the SA economy, for example), the result is proportionately low spending on areas that are high priorities in GEAR, such as health, community services, housing and energy.

?? Although expenditure within the HES is slightly more evenly spread, with a greater emphasis on education and social services, there are also a number of areas that receive very little benefit from R&D, such as communication and information services, energy, the hospitality sector and tourism.

?? The overarching image that one is left with, is that current R&D priorities express the socio-economic goals of the past and that a major reshaping is required to bring expenditure more in line with current and future national priorities!

Human Resources and R&D

?? The proportionate distribution of human resources across sectors of performance has remained constant since 1991. Of the other upper-middle-income countries listed, the South African profile is most similar to that of Argentina. It reveals an even closer similarity to Australia, classified by the World Bank as an upper-income economy. The proportion of human resources across sectors (from the HES to the general service (government) and productive (business) sectors) for these three countries is as follows :

?? South Africa (1995/96) : 48.4: 23.4: 27.8

?? Argentina (1988) : 50.5: 28.8: 20.7

?? Australia (1990) : 49.3: 22.7: 27.9

?? Compared to the above, the profile for the Czech Republic displays a reverse trend, with the highest proportion of human resources located in the productive sector, and the lowest in the HES. This profile is also reflected in the data for Germany and the United States. The proportionate distribution of human resources across sectors for these three countries is as follows :

?? Czech Republic (1994) : 12.9: 37.2: 49.7

?? Germany (1991) : 25.8: 15.6: 58.5

?? United States (1993) : 13.3: 6.2: 79.4

?? What is noteworthy in this comparison, is that the high proportion of HR in the productive or business sector, especially in Germany, does not occur at the expense of the HES (where the German system of autonomous research institutes is renowned), but rather because of a very small amount of HR (15.6%) in the government sector. This is even more striking in the case of the USA where only 6.2% of HR is located in the government sector.

?? A comparison between the HES with the government sector (predominantly "science councils") with respect to human resource profiles shows huge differences. Whereas the social sciences and humanities make up more than half (54%) of all HR in the HES, this picture is exactly reversed in the government sector where the natural sciences constitute more than half (51%). The small proportion of engineering sciences and technology HR in the HES (7%) is "corrected" in the government sector (31%).

Patterns of R&D collaboration

?? As far as the issue of multiple authorship is concerned, the high rankings of fields such as the chemical sciences and agricultural sciences are not unexpected. However, the fairly high ranking of "social sciences" is. One should note that co-authorship and co-editorship of books are more prevalent within the social sciences. This is arguably a weaker form of collaboration than co-authoring a research article.

?? The social sciences scored high on proportion of joint funding raised. This is a somewhat surprising result and means that we might have to revise some traditional conceptions about the nature of research practices in this field. Its profile, and this is surely due to increasing commercialisation of social sciences research, is closer to some natural science fields, than it is to the humanities and arts.

?? As far as interdisciplinary collaboration is concerned, three fields stand out as not being involved in any significant interdisciplinary work: Arts, Humanities and the Economic Sciences. Methodological styles and disciplinary traditions clearly would account for the uni-disciplinary focus in the Arts and Humanities, but not necessarily for the result with regard to the Economic Sciences. This requires further analysis.

?? The most noteworthy result as far as inter-institutional collaboration is concerned, is that we found very low degrees of inter-sectoral co-operation (only 21%). The macro picture suggests that university scholars prefer to work with university colleagues within their own institutions or in other universities. Again, one has to add that further, more detailed, analysis might reveal interesting patterns at lower levels.

R&D Output

?? Summing the total number of scientific publications, conference papers and unrefereed reports per scientist, allows a "rough" comparison of per capita R&D output across the sectors surveyed. This comparisons reveals that highest per capita output was recorded for the Higher Education Sector (5.00), followed by the Science Councils (4.36), Museums (4.17), NGOs (4.0), Industry-based organisation (3.1) and Government Departments (2.9). These statistics, however, mask big differences between institutions within the various sectors.

?? Another measure of "R&D productivity" was calculated by looking at the cost of producing one unit of scientific and technological output. As far as the former is concerned (average cost per scientific output), the most cost-effective sectors are the HES (R16 800 per unit) and museums (R35 800). The least cost-effective sectors are Government (R140 000) and Industry-based organisations (R103 000). As far as the average cost per technology is concerned, the most cost-effective sectors are the HES (R384 000) and the Science Councils (R1.4 million). Again, these figures should be read with caution, as they do not address qualitative differences between different kinds of publications or technologies.

?? The per capita output differs quite significantly across sectors and mostly in the expected direction. Highest per capita production of scientific publications occurs in the HES and Government and Museum Sectors and, rather surprisingly, also industry-based organisations. The small number of NGOs included in the survey make any strong conclusions about these results rather precarious.

?? Per capita output of unrefereed publications is highest in the science councils where contract research is dominant, as well as in NGOs. Surprisingly, the comparable statistic for the HES is quite low (0.279) but this figure might mask big disciplinary and institutional variations.

?? Output of conference papers is high across the board, whereas per capita output of technologies is highest in the science councils.

?? The overall picture that emerges from these findings is in line with patterns concerning expenditure and type of research discussed above. The emphasis on basic research in the HES is manifested in high per capita output of scientific publications and conference papers. Similarly, the emphasis on applied research and developmental work within the government sector results in higher per capita output of unrefereed reports and technologies.

General conclusions

The SSRD has generated a wealth of information about Scholarship, Research and Development within the South African S&T system. The picture that emerges is of a system that comprises a diversity of research cultures and practices. It demonstrates strong capacity in a number of sectors and fields, clear divisions of labour with regard to type of research and research output across scientific fields and institutions, clear patterns of research collaboration, and established strengths in certain niche areas. It is also a picture of "imbalances" in capacity and output, huge variations in human capital across fields and sectors, significant differences in type of research and cost of output, and weak inter-institutional and inter-sectoral collaboration.

The study has revealed a number of surprising results. It serves to correct current wisdom on total R&D expenditure and several other trends over the past five years. It shows clear shifts in type of research in line with international trends, such as the growing importance of Mode 2 forms of knowledge production. It suggests a growing rapprochement amongst scientific fields engaged in commercial, contract-type research. It also suggests a growing rift between discipline-based fields and increased inter-disciplinarity in other fields.

There are a number of danger signs that require attention: a decline in expenditure on basic research, weak inter-sectoral collaboration and non-alignment of expenditure with socio-economic priorities as far as application is concerned. The above comments, led to the following recommendations:

Recommendations

?? The capacity for R&D within the natural sciences within the HES to be strengthened.

?? Government needs to increase its support for applied policy-related and developmental social scientific work outside of the HES.

?? Key players within the HES should be encouraged and re-trained to manage the shift towards Mode 2 research practices.

?? The National Research Foundation (which is to be established) should address as a matter of urgency the promotion of inter disciplinarity and trans-disciplinarity.

?? Government should spend more on basic research, particularly within the HES.

?? Government should develop mechanisms to ensure that science councils, and particularly the HSRC, enter into collaborative or joint ventures.

?? DACST should organise a national workshop to address the question of research collaboration across sectors.

?? DACTS should launch a specific programme to develop mechanisms to promote quality research management.

?? Government should give serious consideration to the launching of a national initiative aimed at undertaking interdisciplinary, policy and development-driven research.

****

Chapter One

1. Introduction

1.1 Background

In 1996, the Department of Arts, Culture, Science and Technology (DACST) commissioned a National Research and Technology Audit (NRTA) as part of the continuing process of redefining and informing a new science and technology (S&T) policy for South Africa. The main rationale for initiating such an audit was defined as assessing "the strengths and weaknesses of South Africa's science and technology system" and reaching "a better understanding of the forces shaping the long-term future of our science and technology system" (Audit Brochure).

The NRTA was divided into a number of mutually supporting components, one of which was aimed specifically at undertaking a research and technology audit during the second part of 1996 in order to establish benchmark information covering a wide range of factors. Five primary studies were contracted, comprising surveys on the S&T infrastructure of South Africa, the technology base of the South African business sector, the human resource base in research and technology, research and training equipment and research and scholarship. This report covers the Survey on Scholarship, Research and Development (SSRD).

1.2 Terms of reference

The brief for the SSRD was summarised as follows:

> "To obtain, organise and analyse data related to on-going research projects in South Africa, including information on their resourcing".

A more detailed specification of the objectives of the SSRD indicated that the following aspects were to be covered by the survey:

- ?? A description of the nation's research projects in terms of their monetary value, key objectives, key researchers, full-time equivalent (FTE) effort, sources of funding and key users
- ?? A description of such research projects in terms of socio-economic sector, technological output, scientific discipline and nature of science
- ?? A classification of such research projects by main performance sector (higher education sector, science councils, government departments, significant businesses by industry sector and relevant museums and non-government organisations).

1.3 Outline of the report

This report is structured as follows:

Chapter Two is devoted to a discussion of the key conceptual issues as they pertain to the SSRD. The chapter also introduces a framework that was used as a heuristic tool to guide data collection and data analysis in the study. Chapter Three contains a detailed discussion of research design and methodological issues. It focuses on the peculiar problems of defining the target population in the higher education sector (HES) as well as the realisation of the sample achieved. Issues of measurement and data collection in the field are also referred to.

The bulk of the report consists of three chapters, which contain the main findings as well as the recommendations arising from the study. Chapter Four organises the results according to performance sectors: the higher education sector (comprising universities and technikons); government departments and parastatal organisations (science councils); non-government organisations (NGOs); and business and industry. This discussion is aimed at understanding the dynamics of research and development (R&D) within a particular sector, emphasising differences and similarities between institutions within a sector. In Chapter Five, the main results of the study are integrated. The emphasis shifts to patterns and trends that cut across sectors. In addition, some international data are referred to where appropriate. Finally, Chapter Six contains the key recommendations that flow from the study.

The appendices contain copies of the classification framework and the two questionnaires used in the survey.

****

Chapter Two

A Conceptual Framework

2.1 Introduction

This chapter addresses a whole range of issues related to matters of definition and classification specific to the Scholarship, Research and Development Survey. It should be emphasised at the outset of the report that, although there is some overlap between the objectives of the SSRD and traditional R&D surveys, there are also significant differences. Traditional R&D surveys, including those conducted in South Africa, have used international protocols established by the OECD and codified most clearly in the Frascati Manual. In a number of discussions among the consultants responsible for conducting the SSRD, it was emphasised that our work – for obvious reasons – should follow as closely as possible the international standards embedded in documents such as the Frascati Manual. At the same time, the peculiar objectives of the NRTA made it necessary and desirable to deviate in certain crucial areas from the approach followed in previous R&D surveys.

The most significant differences between the NRTA and previous R&D surveys are the following:

?? The broader meaning attributed to "research and development" as manifested in the inclusion of the term "scholarship". As we will argue later in this chapter, the "expansion" of the SSRD to include other forms of scholarship is not merely a matter of terminology. It extends beyond the inclusion of an additional word in the title of the study.

?? The specific emphasis on measures of output. This was evident from the numerous references made at meetings of the consultants to the Scholarship and Research "Outputs" Survey. This deviation from the original terms of reference was not unexpected, given the need to position the entire NRTA, and thus also the SSRD, within a larger policy debate about issues such as current strengths and weaknesses, priorities and future agendas. Within such a discourse, there is understandably more interest in output measures, utility, relevance and value than on input measures (such as expenditure and human resources) alone.

?? The level of detail to be attained in the SSRD. As spelt out in the terms of reference, the SSRD was expected to produce information on projects and programmes across all scientific disciplines – something never attempted in South Africa on this scale before. We will show later that, although it is practically impossible to achieve complete coverage of each current project undertaken by a South African scientist or scholar, the approach followed in the SSRD has produced an extremely fine-grained picture of the South African research and technology landscape.

Thus, although there are significant differences between the SSRD and other R&D surveys, many standardised definitions and classifications were used in order to ensure comparability with international studies of this kind. Before discussing these in some detail, we present a heuristic framework that guided the work of the project team.

2.2 A framework for the SSRD

Research and development typically form part of the larger science and technology system of a country. In the Frascati Manual, the relationship between S&T activities and R&D is defined as follows:

Scientific and technological activities comprise systematic activities, which are closely concerned with the generation, advancement, dissemination and application of scientific and technical knowledge in all fields of science and *technology. These include such activities as R&D, scientific and technical education and training (STET) and the scientific and technical services (STS).*[1]

There are thus at least three main types of science and technology activities:

?? Research and development (R&D)

?? Scientific and technical education and training (STET)

?? Scientific and technical services (STS)

It is usually relatively easy to distinguish between the first two categories (although we will comment on this relationship within the higher education sector). It is more difficult to distinguish between R&D activities and some of the activities that are included under the heading of STS. According to the Frascati Manual, the latter includes the following:

?? *Activities involved in the translation and editing of S&T literature;*

?? *Surveying activities (hydrological, geological and socio-economic, etc.);*

?? *Prospecting;*

?? *Data collection activities in the human sciences;*

?? *Testing, standardisation and quality control;*

?? *Client counselling activities (agricultural, psychological, educational and industrial advisory services);*

?? *Patent and licence activities by public bodies;*

?? *Policy-related activities* [2].

The division between these domains was important for the SSRD because it provided the basis for the inclusion or exclusion of certain institutions and government departments. For example, the Central Statistical Services (Statistics South Africa) and the South African Bureau of Standards were excluded from the

---

[1] Frascati Manual. 1992. *Proposed Standard Practice for Surveys of Research and Experimental Development*. Final draft of the fifth edition. Organisation for Economic Cooperation and Development (OECD), Paris. p.18.

[2] Idem, p. 18.

SSRD as being involved primarily with routine data collection and standardisation and quality control respectively.

It is sufficient for our discussion to note that R&D activities are embedded within the larger S&T system and should be distinguished from the other related activities listed above.

Figure 2.1 represents the major elements and dynamics of the research and development process.

The diagram distinguishes between five components:

I. Research and development activities
II. Forms of institutionalisation
III. Input measures
IV. Output measures
V. Utility measures

Key definitions of each of these terms, as well as their implications for the SSRD, are discussed in the following section. In each case, the subdivisions of each stage are further articulated.

FIGURE 2.1

THE R&D PROCESS

III

INPUT MEASURES

?? HUMAN
?? RESOURCES
?? TIME SPENT ON
?? R&D
?? EXPENDITURE
?? EQUIPMENT
?? INFRASTRUCTURE

I

RESEARCH AND DEVELOPMENT ACTIVITIES

?? TYPE OF RESEARCH
?? MAIN SCIENTIFIC FIELD
?? SCIENTIFIC DISCIPLINE AREA OF SPECIALISATION

III

FORMS OF INSTITUTIONALISATION

?? UNIVERSITIES/TECHNIKONS
?? SCIENCE COUNCILS
?? GOVERNMENT
?? BUSINESS AND INDUSTRY
?? CIVIL SOCIETY

2.3 Scholarship, research and development [I]

2.3.1 Definitions of core concepts

The term "scholarship" was defined in the SSRD as comprising "all activities directly associated with the generation of new knowledge". For the purposes of the survey, and especially pertaining to the HES, activities such as teaching, preparing lectures and marking tutorials are excluded. The term "scholarship" was included in the SSRD primarily because of some of the connotations attached to the terms "research and development". There is a perception, especially among the arts and humanities communities, that traditional R&D surveys tend to favour work done in disciplines (natural sciences, engineering, empirical social sciences) where research work is seen as a predominantly experimental or quantitative endeavour. This leads to the exclusion, or at least neglect, of those forms of research or scholarship that use more qualitative and interpretative methodologies.

This perceived bias is also carried over to the notions of "development" and "technology". Developmental work is believed to be confined to "experimental development" and not to include, for example, the activities of scholars in educational and social services departments that are engaged in activities such as curriculum development, programme development and design. Similarly, in many circles, "technology" is believed to refer only to the packaged skills and applications that result from the work done in natural science and engineering laboratories. Again, the notion of a distinct set of "human science technologies" (cf. Prinsloo[3] and Marais[4]) is underplayed. For all these reasons, it was decided to refer to this component of the NRTA as the "Scholarship, Research and Development" survey. In practical terms, we do not believe that the "logic" and "structure" of scholarship activities are significantly different from those of "research" – especially as defined in the SSRD. In fact, the definition of "research" presented below has been adapted from Frascati specifically to make it more generally applicable across disciplines.

---

[3] Prinsloo, R.J. (ed.) 1993. *Human sciences technology: Ways of solving problems in the human domain.* Pretoria: HSRC.

[4] Marais, H.C. 1996. *Human sciences technology.* In: Garbers, J.G. (ed.) *Effective research in the human sciences.* J.L. van Schaik Publishers. pp. 80–108.

On the recommendation of one of the task groups of the audit, the following definition (adapted from Frascati) was accepted for the purpose of the SSRD:

> *Research comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and/or directed towards specific practical aims or objectives.*

Development work/activities in the context of S&T that builds on previous research is defined as follows:

> *Systematic work drawing on existing knowledge gained from research and/or practical experience that is directed towards production of new or improved materials, products, devices, services, systems, programmes or to improving those already produced or installed.*

(This definition combines features of the Frascati and Irvine & Martin definitions.) Development thus defined is carried out predominantly in industry (where it typically accounts for between 80% and 90% of company R&D budgets) and in mission-oriented government agencies. (In the latter case, the state is also the customer for the final envisaged product, such as advanced military hardware.)

2.3.2 Classification of scholarship, research and development [SRD]

Two different kinds of classification of SRD activities are normally applied in terms of Frascati definitions – firstly, in terms of *type of activity* (functional classification) and secondly, in terms of *content or subject areas* (principal sector classification).

2.3.2.1 ....Functional classification of SRD

For the purpose of subdividing research into further categories (or Frascati *types of activity*), a classification proposed by Irvine & Martin was recommended. This entails that research be further divided into *basic* and *applied research*. *Basic research* is then further subdivided into *fundamental* and *strategic research.*

Irvine & Martin give the following definitions:

Basic research

> *Original investigation with the primary aim of developing more complete knowledge or understanding of the subject(s) under study.*

Fundamental research

> *Basic research carried out without working for long-term economic or social benefits other than the advancement of knowledge, and no positive efforts being made to apply the results to practical problems or to transfer the results to sectors responsible for their application.*

Fundamental research, together with teaching, is usually taken to be the main function of the academic, university-based research system.

Strategic research

> *Basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognised current or future practical problems.*

Strategic research is most often carried out in universities and government laboratories, as well as in most larger science-based companies (in which it typically accounts for no more than between 5% and 10% of the R&D budget).

Applied research

> *Original investigation undertaken in order to acquire new knowledge, and directed primarily towards specific practical aims or objectives such as determining possible uses for findings of basic research or solving already recognised problems.*

Applied research is mainly carried out by industry and the laboratories of mission-oriented government agencies, although also undertaken (under contract or as part of targeted government research programmes) within the academic research system.

(Experimental) development

Development work in the context of S&T that builds on previous research is defined as follows:

> *Systematic work drawing on existing knowledge gained from research and/or practical experience that is directed towards production of new or improved materials, products, devices, services, systems, programmes or to improving those already produced or installed.*

(This definition combines features of the Frascati and Irvine & Martin definitions.) Development thus defined is carried out predominantly in industry (where it typically accounts for between 80% and 90% of company R&D budgets) and in mission-oriented government agencies. (In the latter case, the state is also the customer for the final envisaged product, such as advanced military hardware). Where applicable, it might be useful to distinguish further between different kinds of research-based development work. In such cases, which are most likely to be in the manufacturing sector, the following two-fold classification is recommended:

?? Exploratory development

?? Incremental development

Exploratory development

Systematic work which involves all efforts of proof of concept and proof of design and the development of pre-production prototypes.

Incremental development

Systematic work that is directed at the improvement or modification of existing materials, products, devices, processes, programmes, services, systems or methods, typically after they have been manufactured or introduced to the market.

2.3.2.2 Principal sector classification of SRD

As part of the work of the NRTA, a task group was established to address issues of classification. In its report to the audit management team, the task group recommended that all consultants follow the following three-tiered framework. (The complete, updated classification framework is attached as Appendix A.3.)

1. *Broad scientific fields* (for example, biological sciences, earth and marine science, engineering, health and medical sciences, mathematical sciences, physical sciences, social science, economic and management sciences, humanities)

2. *Main scientific disciplines* (for example, anthropology, botany, business management, civil engineering, computer science, forest science, geography, geology, microbiology, philosophy, psychology, sociology, statistics, veterinary science, zoology)

3. *Areas of specialisation* (for examples, animal management, chemical pathology, functional analysis, industrial psychology, manufacturing processes, political philosophy, radio-biology, seed science, toxicology, wildlife biology)

2.4 Forms of institutionalisation [II]

Although generically similar, research and development activities do not "look" the same in different sectors of the national STS system. SRD take on different forms depending on the institutional context and philosophy in which they are performed.[5] We have already alluded to some of these institutional differences in the explanatory notes on types of research (for instance, the fact that more applied research is done in government and business than in academia).

The influence of the institutional context on the nature of SRD is fundamental. It affects the goals and objectives of research and, therefore, what are assessed to be important outputs. It affects the "culture of research" determining the research agenda and research priorities. It also affects the "social context" of research leading to varying emphasis on relevance and utility and thus to differences in reward systems. This is not confined to national science and technology systems. As a result of the increasing globalisation of science and technology, national forms of R&D are increasingly being affected by international developments.[6]

Frascati[7] distinguishes the following five sectors (mainly on practical grounds) for R&D purposes:

---

[5] Mouton J. 1996. *The nature and structure of the practice of science.* In Garbers, J.G.(ed) *Effective research in the human sciences*. J.L. van Schaik Publishers. pp.14–36.

[6] Nel P. 1996. *The globalization of science, technology and research*. In Garbers, J.G. (ed) *Effective research in the human sciences*. J.L. van Schaik Publishers. pp. 37–50.

[7] Frascati Manual. 1992. *Proposed Standard Practice for Surveys of Research and Experimental Development*. Final draft of the fifth edition. Organisation for Economic Cooperation and Development (OECD), Paris. Chapter 3.3.

?? Business enterprise
?? Government
?? Private non-profit
?? Higher education
?? Abroad

A similar classification was followed in the NRTA with the following divisions:

?? Business sector and industry-based organisations
?? Government departments and associated institutions (museums)
?? Science councils (parastatal organisations)
?? Civil society (selected NGOs)
?? Higher education

The SSRD undertook primary data collection in the last four sectors. The business sector data were collected by AMI.

Differences between these institutional contexts for R&D have made it necessary to follow two different approaches in data-collection. Within the HES, research and development activities are mainly still managed by individual scientists (working on their own or in loosely grouped teams/programmes). There are, of course, a number of research centres and institutes at universities or technikons, but again, these are usually built around prominent scholars.[8] The individual scholar/scientist remains the reporting unit or, in terms of the Frascati definition, "the entity from which the information is collected". In the government and parastatal sectors, research is increasingly organised and managed within larger interdisciplinary units, departments and divisions. These are not merely differences in organisational culture but also relate to matters of scale. Precisely because of the predominance of applied research (especially contract-driven Mode 2 research) and technology development in

[8] Mouton J. 1995. Human sciences research at South African universities. In *Directory of Human Sciences Research Organisation and Professional Associations in South Africa*. Pretoria: HSRC. pp. 11–38.

the government, parastatal and business sectors, it is inevitable that teams of researchers conduct research in this sector. This does not mean to say that similar trends are not also found in certain areas of university and technikon research.

Against this background, two different questionnaires were used for the collection of primary data (Appendices A.1 and A.2). Within the HES, questionnaires were sent to individual scientists and scholars at each university and technikon. Within the government and parastatal sectors, questionnaires were sent to heads of divisions or programme leaders to complete on behalf of the unit.

As regards time frame, within the HES, the study covered the 1995 academic year. Specifically, respondents were asked to provide information on their research that either commenced or was current during 1995. In order to ensure that as little overlap between projects as possible was reported, respondents in the HES were specifically asked only to provide information on projects of which they were the principal investigator or project-leader.

Within the government and parastatal sectors, respondents were asked to report on the research activities of the programme or research unit for the 1995/96 financial year.

2.5 Input measures [III]

Five standard categories of input measures are distinguished:

?? Human resources (research and development staff)
?? Time spent on research (only for the HES)
?? Expenditure
?? Equipment (not covered in this report)
?? Infrastructure (not covered in this report)

Human resources

Within the HES, questionnaires were sent to all academic and research staff. The discussion of the realisation of the sample in the following chapter provides a summary profile of the human resources in this sector. In the other sectors, respondents were requested to provide information on all the professional staff members (research and research support) that were directly involved in the research of the particular unit or programme.

In cases where team research was being undertaken, information was also gathered from respondents in the HES on other project members.

Time devoted to research

Questions on the time spent on research were only included in the HES questionnaires. Because academic staff spend time on formal instruction, research and community-related activities, respondents were asked to estimate how much time they devoted to research and research-based activities (research management, conferences, workshops and research-based consultancies) during 1995. This information is interesting in its own right, but is also used in the formula to calculate total labour costs (as component of R&D expenditure) within the HES.

Expenditure on SRD

R&D expenditure refers to "all expenditures within a statistical unit or sector of the economy irrespective of source of funding".[9] It includes both current expenditure and

[9] Frascati Manual. 1992. *Proposed Standard Practice for Surveys of Research and Experimental Development*. Final draft of the fifth edition. Organisation for Economic Cooperation and Development (OECD), Paris. p 97.

capital expenditure. Current expenditure, in turn, includes both labour costs (which usually account for more than 60% of all R&D expenditure), as well as operational costs (supplies and services, for example, subsistence and travel and expendable materials). Capital expenditure refers to expenditure on land, buildings, instruments and equipment when these are directly used for R&D purposes. Expenditure on equipment is covered in a different survey, the figures from which should be added to total R&D expenditure figures reported on here to obtain a comprehensive picture.

Within the HES, total expenditure was calculated as follows. Expenditure per individual respondent consists of labour costs and operational costs. The latter was directly requested in the questionnaire. The former was calculated using the formula:

Time spent on research (%) x Average labour costs for staff category = Labour costs

Average labour cost figures were obtained for five categories.[10] Respondents had to report on their current position (for example, professor, senior scientist). Expenditure on capital items and overheads is reported in SAPSE tables. The latest statistics were used (in most cases for 1994, otherwise for 1995). This information was added at institutional level. Within the government and parastatal sectors, respondents were asked to report separately on labour costs, operational costs and overheads.

Items on sources of funding were included for all sectors. Distinctions were made between internal sources of funding (university and technikon funding in the case of the HES and baseline funding in the case of the science councils) and external sources of funding (domestic or foreign). In order to minimise potential double counting of sources of funding (especially at the HES), two measures were implemented. In addition to the qualification that only the project leader should

---

[10] Van Vuuren A. 1997 *Report on the Subvention of Salaries of Academic Staff in Science, Engineering and Technology Faculties at Higher Education Institutions*. Pretoria: Foundation for Research Development.

provide the research information, respondents were asked specifically to indicate if outside funding had been procured individually or jointly with other researchers. In the latter case, all projects jointly funded to the value of more than R50 000 were individually checked to ensure that joint funding had not been counted twice.

2.6 Output measures [IV]

The measurement of R&D output is not without difficulties. The following categories of outputs were included in the SSRD:

?? Scientific publications (in other words, refereed publications)
?? Unrefereed reports (including contract reports)
?? Scientific presentations
?? Technologies
?? Patents
?? Licences
?? Graduate students (HES only)

Scientific publications have traditionally been viewed as one of the best measures of scientific output because they represent a judgement of quality by one's peer group. Five categories of publications were distinguished: journal articles in overseas journals, journal articles in local journals, books or monographs, chapters in books and published conference proceedings.

The increasing shift from basic to applied research (from Mode 1 to Mode 2 knowledge production) has been accompanied by an increasing emphasis on unrefereed reports, for example, in-house technical reports and contract reports for clients. This is particularly true for the parastatal and business sectors. Although outputs of this kind are not peer reviewed and sometimes have limited dissemination, they still represent a significant category of R&D output.

Scientific presentations fall into a similar class. Again a distinction was made between presentations at conferences locally or abroad.

For the purpose of our survey, four sub-categories of technologies were distinguished:

?? Product technologies (for example, product specification)
?? Process technologies (for example, analytic methods)
?? Support technologies (for example, welding technologies)
?? Information technologies (for example, information systems)

A further distinction was made between whether a new technology was developed, a prototype designed and/or an existing technology improved upon.

Information was requested about the number of patents and licences registered in South Africa during 1995. In addition, a short description of the patent/licence was requested.

In addition to these categories, the questionnaire included an open-ended category that allowed respondents to list other kinds of R&D outputs, such as artefacts (especially in the technikon sector) and cultivars (particularly in agricultural research).

Finally, it was decided to add to the HES questionnaire a question on the number of masters and doctoral students supervised during 1995 (including both those that completed their degree that year and those that continued studying in subsequent years). Frascati specifically mentions that postgraduate research work (and at least

50% of the work for a masters degree or doctorate usually comprises research activities) should be included in calculating expenditure.[11]

2.7 Utility measures [V]

Various stakeholders have an interest in the work of the science and technology sector of a country, ranging from small sub-communities of scientists working in the same fields to the general public.

Firstly, output was classified by socio-economic sector in terms of its general usefulness to society. This option applies logically only to research classified as "applied" or development work. Sixteen categories were identified:

?? Agriculture, hunting, forestry and fishing
?? Mining and quarrying
?? Manufacturing
?? Electricity, gas and water supply
?? Construction
?? Wholesale and retail trade/personal and household goods
?? Transport and storage
?? Financial and business institutions
?? Community and social
?? Private households
?? Defence
?? Educational services
?? Hospitality sector
?? Health sector
?? Communication and telecommunications
?? Environment/conservation (post-coded)
?? Sport and recreation (post-coded)

---

[11] Frascati Manual. 1992. *Proposed Standard Practice for Surveys of Research and Experimental Development*. Final draft of the fifth edition. Organisation for Economic Cooperation and Development (OECD), Paris. p. 98.

Secondly, the usefulness of output was also measured through four open-ended questions. Respondents had to indicate:

?? which users would benefit directly from their R&D

?? how the research outputs were of relevance to them

?? which other persons would benefit indirectly from their R&D activities

?? how the research outputs would be of relevance to them

2.8 Concluding comments

Any study that attempts to measure something as complex and multifaceted as scientific research and development must invariably face a host of conceptual and classificatory challenges. This chapter has been devoted to a discussion of the major conceptual issues faced and the decisions made in the SSRD. Conceptual issues that arose from the data collection and data analysis stages are discussed in the following chapter. Recommendations arising from the lessons learnt through this exercise are made in the final chapter.

****

Chapter Three

3. Research design and methodology

3.1 Introduction

This chapter provides an overview of the survey's research design and methodology for each of the five sectors covered:

- ?? Higher education sector: Section 3.2
- ?? Science councils (parastatal organisations): Section 3.3
- ?? Government departments and associated institutions (museums): Section 3.4
- ?? Civil society (selected NGOs): Section 3.5
- ?? Business sector and industry-based organisations: Section 3.6

In addition, the realisation of the survey sample in the higher education sector is discussed in Section 3.7.

3.2 The higher education sector

Data collection from each of the 21 universities and 15 technikons in the country proceeded by means of mailed questionnaires and unstructured interviews, as well as the gathering of relevant documentary information. Details pertaining to the various phases of this process are reported on below.

3.2.1 Interviews and documentary information

Personal interviews were conducted with key informants, consisting primarily of vice-chancellors and deans or directors of research at each of the institutions included in the HES. The project team completed this phase of the survey during August and September 1996. A comprehensive interview schedule is provided below.

Table 3.1: Interviews conducted with key informants in the HES

Institution	Interviewee(s)	Interviewer
Border Technikon	Mr G Mulder (Associate Director: Computer Studies)	H Hackmann
Cape Technikon	Prof TC Shippey (Rector) Prof EA Uken (Director: Research Development)	H Hackmann
Eastern Cape Technikon	Dr SPK Boni (Chair: Research Committee)	H Hackmann
Free State Technikon	Prof CA van Rensburg (Vice-Rector) Prof B Frey (Dean of Research)	J Mouton
Technikon Mangosuthu	Mr G Kruger (Acting Vice-Principal: Academic) Dr L Oberholster (Chair: Research Committee)	H Hackmann

Medical University of Southern Africa	Mr CW Berndt (Chair: Research Ethics Committee)	HC Marais M Pienaar
ML Sultan Technikon	Mrs K Naidoo (Acting Head: Staff Development)	H Hackmann
Technikon North-West	Dr Manamela (Vice-Rector: Academic)	HC Marais M Pienaar
Technikon Northern Transvaal	Dr P Kok (Chair: Research Committee) Dr H Koen (Acting Head: Research)	HC Marais M Pienaar
Peninsula Technikon	Dr J Tromp (Vice-Rector) Dr H Fransman (Chair: Research Committee)	J Mouton H Hackmann
Port Elizabeth Technikon	Dr P van Breda (Director: Unit for Research Development) Mrs C Marsh	J Mouton H Hackmann
Potchefstroom University for Christian Higher Education	Prof C Reinecke (Vice-Chancellor) Prof S Coetzee (Deputy Vice-Chancellor) Prof A Viljoen (Vice-Rector: Academic) Prof H Moraal (Chair: Research Committee Natural Sciences) Prof D Wissing (Chair: Research Committee Human Sciences) Mr P van der Walt (Head: Research Administration)	HC Marais M Pienaar
Technikon Pretoria	Prof DJ van Rensburg (Rector) Prof HH Durrheim (Vice-Rector)	HC Marais M Pienaar
Rand Afrikaans University	Prof PMS von Staden (Acting Rector & Registrar: Academic)	HC Marais M Pienaar
Rhodes University	Prof D Woods (Vice-Chancellor) Prof H Parolis (Dean of Research) Mr J Lancaster (Head: Research Administration)	J Mouton
Technikon Natal	Dr L du Preez (Vice-Principal: Academic) Members of the Research Committee	H Hackmann
Technikon South Africa	Prof Buitendach (Rector) Dr L Botha (Director: Research)	HC Marais M Pienaar
Technikon Witwatersrand	Mr H van Eede (Acting Vice-Chancellor & Principal) Mr J Fouche (Research Administration)	HC Marais M Pienaar
University of Cape Town	Prof J Martin (Deputy Vice-Chancellor) Dr D Miller (Director: Research Support Services)	J Mouton H Hackmann
University of Durban-Westville	Prof M Balintulo (Rector/Principal) Prof R Baruthram (Acting Vice-Principal: Academic) Mr N Moodley (Head: Research Administration)	J Mouton A Rip
University of Fort Hare	Prof J Brand (Dean of Research)	J Mouton
University of the Orange Free State	Prof C Small (Vice-Rector: Research) Mr W Malherbe (Registrar)	J Mouton
University of Natal	Prof B Gourley (Vice-Chancellor) Prof E Preston-Whyte (Vice-Chancellor: Research and Development)	J Mouton
University of the North	Prof N Ndebele (Vice-Chancellor) Prof Wessels (Head of Research)	J Mouton
University of South Africa	Prof M Dockel (Vice-Tector: Research)	HC Marais M Pienaar
University of the Transkei	Prof AH Dye (Dean of Research)	H Hackmann

University of Venda	Prof GM Nkondo (Rector) Prof J Nchabeleng (Chair: Research Committee)	J Mouton
University of the North-West	Prof Mutabe (Vice-Chancellor: Student Affairs) Prof NB Manson (Chair: Research Committee) Mr Humpfrey (Dean: Education) Dr J Lewis (History)	HC Marais M Pienaar
University of Pretoria	Prof J van Zyl (Rector) Prof T Erasmus (Director: Research Dr Z Ofir (Director: Research)	HC Marais M Pienaar J Mouton
University of Port Elizabeth	Prof W Oelofsen (Chair: Research Committee) Mr R Ncwadi (Research Admin)	J Mouton
University of Stellenbosch	Prof W Claassen (Vice-Rector: Academic) Prof J Groenewald (Director: Research Development)	J Mouton
University of the Western Cape	Dr R Christie (Dean of Research)	J Mouton
University of the Witwatersrand	Prof F Sellschop (Vice-Rector)	J Mouton
Vaal Triangle Technikon	Dr J Pretorius (Director: Research)	HC Marais M Pienaar
Vista University	Prof K Nyamopfene (Deputy Vice-Chancellor) Prof van der Linde (Dean: Faculty of Science)	HC Marais M Pienaar
University of Zululand	Prof C Dlamini (Rector) Prof A Thembela (Vice-Rector)	J Mouton A Rip

The purpose of these interviews was manifold. They were intended, firstly, to provide background information for the NRTA and to clarify the objectives of the SSRD within this context. Secondly, the interviews served to secure the support of research executives for the survey, particularly for the complex logistical arrangements it involved. In this regard, the research design and strategy were fully explained to the interviewees. Interviewers negotiated their assistance in the distribution and collection of questionnaires, the compilation and updating of a mailing list and the sending out of reminders to non-respondents. A third objective was to gather substantive information about the research cultures, profiles and budgets of the various institutions in order to supplement and contextualise data gathered from individual academics and/or researchers by means of questionnaires. Apart from information supplied during the interview, interviewees were requested to provide us with relevant documents, including annual reports containing details of research outputs and expenditure, research policy statements, organograms of research administration structures, and any other relevant research-related information. In the majority of cases, the request for such information had to be followed up with both written and telephonic reminders.

3.2.2 Questionnaires

3.2.2.1 The sample: development of a comprehensive mailing list

In the original tender submitted to the audit management, we proposed covering South Africa's most "active" or "productive" researchers/ scientists, whom we estimated to number between 5 000 and 6 000. However, at the request of the audit management, we agreed to include in the survey the entire HES target population.

During July and August 1996, a comprehensive mailing list covering this population was compiled. This was done by collecting the latest versions of calendars, yearbooks or prospecta from all universities and technikons. Where available, up-to-date internal telephone or contact directories were obtained. In some cases, these were provided in electronic format.

Using these sources, the names and addresses of all academic staff with a qualification of four or more years were included in the mailing list. This covered the entire spectrum of faculties and disciplines at each of the universities and technikons. Given that we had no means of assessing whether individuals were either teaching or research academics, the final list comprised a total of 15 570 records.

The purpose of developing this mailing list was to enable us to personalise the questionnaires sent out. It further served as a mechanism for assessing response rates and, ultimately, for providing us with a record of non-respondents.

Tables 3.2 and 3.3 provide a detailed breakdown of the number of questionnaires mailed, returned and captured for the HES. This information was gathered during both the first and second rounds of sending out questionnaires, and the figures contained in these tables will be referred to in later discussions of these two waves of data collection.

3.2.2.2 Questionnaire construction and pilot testing

The construction of the questionnaire to be used in the HES began in July and was completed by the end of August 1996. An initial draft was pre-piloted with four senior academic staff from the University of Stellenbosch (two from the natural and two from the human sciences). The pre-piloted questionnaire was then presented to and discussed by participants at a survey planning workshop on 9 August 1996. Apart from ourselves, the following people were present at this meeting:

?? Prof J Groenewald: Research Development, University of Stellenbosch
?? Prof HC Marais: Consultant to the project
?? Prof J Muller: Department of Education, University of Cape Town
?? Ms M Pienaar: Consultant to the project
?? Prof C Pistorius: Institute for Technological Innovation, University of Pretoria
?? Dr U van Beek: Project administrator (July to September 1996)
?? Dr P van Eldik: Research Director, Pretoria Technikon.

After being altered on the basis of workshop feedback and discussions, the questionnaire was piloted with 16 academic staff (eight each from the natural and social sciences) from the five tertiary institutions in the Western Cape – six from the University of Stellenbosch, two from the University of Cape Town, three from the University of the Western Cape, one from Cape Technikon and four from Peninsula Technikon.

Before the questionnaire was finalised, lengthy discussions were held with Prof A Rip (University of Twente, Netherlands), a visiting professor and leading scholar in the field of science and technology studies. In addition, feedback on the questionnaire was obtained from Dr I Amuah and Dr A West of the audit management team.

A copy of the questionnaire used in the HES is attached as Appendix A.1.

3.2.2.3 Data collection: first wave

During the first three weeks of September 1996, 16 047 questionnaires were delivered to the research offices or central registries of the 36 universities and technikons for distribution to their academic and research staff. A breakdown of the numbers of questionnaires sent to each institution is provided in Tables 3.2 and 3.3.

Telephonic spot checks, to ensure that questionnaires had been successfully distributed, were conducted during the last week of September.

After 10 October 1996 – the original deadline for the return of questionnaires – we entered into a series of follow-up communications with relevant contact persons – mostly Deans or Directors of Research – at all the institutions. They were informed of the response rate for their particular institution and requested to send out electronic circulars to members of staff that had not returned the questionnaire, reminding them to do so and informing them that the deadline had been extended until mid-November. In most cases, the contact people were extremely cooperative and took it upon themselves to chase non-respondents on our behalf.

The return of questionnaires to the Centre for Interdisciplinary Studies was managed in two ways. Of the 36 institutions covered, 17 collected questionnaires internally (via their research offices) and couriered batches to us on a regular basis. Questionnaires distributed to the remaining 19 institutions were returned in self-addressed and stamped envelopes.

By the beginning of January 1997, a total of 2 325 responses had been received. Further follow-up communication was undertaken with the institutions from which there had been a particularly low response rate. As a result of these efforts, a further 365 questionnaires were returned, resulting in a total of 2 690 (2 231 of which were from universities and 459 from technikons) by the end of February. Tables 3.2 and 3.3 provide a breakdown of responses received per institution.

Table 3.2: Sample, Distribution and Returns Information (Universities)

University	SSRD Mail1	SSRD1 Total Returned	SSRD1 Captured	SSRD1 Incom-plete	SSRD1 Refusals	SSRD Mail2	SSRD2 Total Returned	SSRD2 Captured	SSRD2 Incom-plete	SSRD2 Refusal
Medunsa	321	56	53	3	0	0	0	0	0	
Potchefstroom	493	107	102	3	02	121	48	48	0	
Rand Afrikaans	317	86	85	1	0	90	78	75	1	
Rhodes	264	60	59	1	0	72	15	15	0	
Cape Town	1110	189	182	7	0	390	68	62	4	
Durban-Westville	382	40	40	0	0	106	9	9	0	
Fort Hare	230	15	15	0	0	0	0	0	0	
Orange Free State	631	95	87	2	6	201	48	44	3	
Natal	1432	108	106	2	0	168	30	27	2	
North	473	33	32	1	0	46	16	16	0	
South Africa	1653	578	505	63	10	148	28	26	0	
Transkei	306	25	25	0	0	0	0	0	0	
Venda	187	24	20	4	0	0	0	0	0	
North-west	218	9	9	0	0	0	0	0	0	
Pretoria	1245	268	250	7	11	232	123	122	1	
Port Elizabeth	250	36	36	0	0	69	15	14	1	
Stellenbosch	717	158	144	7	7	271	108	104	1	
Western Cape	655	97	93	2	2	106	18	18	0	
Vista	504	45	41	3	1	0	0	0	0	
Witwatersrand	1696	157	149	7	1	248	28	26	1	
Zululand	309	45	44	1	0	64	15	14	1	
TOTAL	13393	2231	2077	114	40	2332	647	620	15	

Table 3.3: Sample, Distribution and Returns Information (Technikons)

Technikon	Mailed	Total Returned	Incomplete	Refusals	DATABASE Total
Border	35	5	2	0	3
Eastern Cape	106	0	0	0	0
Cape	163	30	2	0	28
Free State	83	46	5	0	41
Mangosuthu	104	31	5	0	26
ML Sultan	180	14	2	0	12
North-West	25	0	0	0	0
Northern Transvaal	132	112	27	0	85
Peninsula	164	9	0	0	9
Port Elizabeth	255	42	4	0	38
Pretoria	159	62	4	0	58
Natal	170	28	9	0	19
South Africa	254	49	7	0	42
Witwatersrand	248	19	1	0	18
Vaal Triangle	99	12	5	0	7
TOTAL	2177	459	73	0	386

3.2.2.4 Development of a database of "productive scientists"

Before sending out a second wave of questionnaires, a profile of university-based respondents was constructed. This indicated whether or not they had been listed as recent grantholders by one of the three national funding agencies in the country, namely the Foundation for Research Development (FRD), the Centre for Science Development (CSD), and the Medical Research Council (MRC). The databases provided by these agencies contained the names and institutional affiliations of grantholders from 1991 to 1995, and comprised a total of 6 400 records, of which approximately 1 000 were listed as either technikon, independent or overseas-based researchers. According to our calculations, only 20% of the university-based respondents were grantholders. Given that the databases supplied by the FRD, CSD and MRC contained records covering a period of five years, it was necessary to compare the information with our original mailing list in order to check for accuracy, to discard duplicates, and to update records in cases where individuals had retired, were deceased or had left an institution. The information was double-checked by requesting the research offices of most of the universities to work through our updated lists and make any necessary corrections. This exercise revealed that a large part of the information contained in the merged database was redundant and hence resulted in a new database containing only 3 516 records of grantholders at the 21 “productive” researchers/scientists in the country. This estimate was much closer to universities in the country (see Table 3.8). According to this updated information, 29% (rather than the originally calculated 20%) of our first wave of university-based respondents proved to be grantholders.

The decision was then made to target the remaining 71% of university-based grantholders in a second wave of questionnaires. Interestingly enough, this decision is in line with our original estimate of there being approximately 5 000 to 6 000

the 3 516 listed grantholders than the figure of 15 570 (13 393 from universities and 2 177 from technikons) individuals eventually included in the target population.

It should be noted that the notion of a “productive” scientist was not used uncritically. In the first place, it is acknowledged that ideas of scientific activity and productivity are conceptually distinguishable and that the former does not necessarily imply the latter. Furthermore it is recognised that there are numerous criteria that may be applied to define scientific productivity. We would nevertheless argue that an individual’s track record in terms of obtaining resources from a national funding agency is a widely used and valid criterion. Given our access to existing databases from South Africa’s national funding agencies, this also proved to be a readily applicable and hence pragmatic criterion.

The reason for targeting only the universities during the second wave was that the response rate of technikons during the first wave (22%) provided us with an adequate sample of the research population at these institutions. This decision was supported by discussions with a number of senior technikon research management personnel, many of whom made considerable efforts to ensure that their research staff had completed the questionnaire.

3.2.2.5 Data collection: second wave

In the light of severe financial constraints, the second round of sending out questionnaires was eventually limited to 15 of the 21 universities in the country. This selection was made on the basis of the size of the institution as well as the response rate yielded during the first wave. As a result, by the end of April 1997, an additional 2 332 questionnaires were printed and delivered to the relevant institutions for distribution. A breakdown of the numbers sent out per institution is provided in Table 3.3.

In an attempt to encourage those targeted in the second round to participate in the survey, vice-rectors or vice-chancellors of most of the universities agreed to our request to send out a letter of motivation to accompany the questionnaire. Furthermore, the original questionnaire was considerably shortened to reduce the amount of time it would take to complete it.

For the second wave, the return of questionnaires to the Centre for Interdisciplinary Studies was supervised through the research offices of the institutions involved. Batches of questionnaires were either personally collected by members of the project team or mailed to us on a regular basis. Despite a deadline of 12 May (and 19 May for two of the universities), questionnaires were received until mid-June. By the end of June a final count yielded a return of 647 questionnaires (see Table 3.3).

3.2.3 Data capturing, editing and validation

The capturing of data in Microsoft Access format started in November 1996. First wave returns were captured by the end of February 1997. Second wave returns were captured during June. In the process, five data capturers spent a total of 670 hours completing the task.

As from March 1997, two additional part-time members of staff were contracted to edit and clean the data already captured. In addition to the 490 hours that they expended on this particular task, a further 50 hours were put in by ourselves. Despite these efforts, the extent of the workload, as well as severe time constraints, forced us to restrict editing and cleaning activities to the categories of information immediately required for analytical purposes.

Data validation involved checking for both internal and external consistency. With regard to external consistency, captured data were checked against both primary and secondary sources. The primary sources were the actual questionnaires, while the latter included information obtained from relevant documentary sources, as well as SAPSE statistics. Internal consistency was ensured by checking for obvious errors such as the incompatibility of codes pertaining to an individual's disciplinary affiliation and his or her area of specialisation. In addition, spell-checks were run and, as far as possible, obvious information gaps were filled.

3.3 Science councils (parastatal organisations)

Data collection within this sector was by means of personal interviews with key informants, the gathering of documentary information and data from electronic databases, as well as mailed questionnaires.

3.3.1 Interviews and documentary information

During September 1996, personal interviews were conducted with senior staff at seven of the science councils, as well as one of the national facilities managed by the FRD. Follow-up interviews were conducted at two of these organisations during May 1997. A comprehensive interview schedule is provided below.

Table 3.4: Interviews conducted with key informants at each of the science councils

Institution	Interviewee(s)	Interviewer
Agricultural Research Council (ARC)	Dr JH Terblanche (President)	HC Marais M Pienaar
Council for Geoscience	Dr C Frick (Head of Research) Mr J du Plessis (Administration)	HC Marais M Pienaar J Mouton
Council for Scientific and Industrial Research (CSIR)	Dr A Paterson (Vice-President) Dr R Kfir (Director: Technology Management)	J Mouton

Human Sciences Research Council (HSRC)	Dr R Stumpf (President) Dr A Oberholster Dr J Beukes	HC Marais M Pienaar
Medical Research Council (MRC)	Dr JA Louw	J Mouton
Mintek	Dr AM Edwards (President) Dr MA Ford (Director: Planning)	HC Marais J Mouton
National Accelerator Centre (NAC), FRD	Prof J Sharpey-Schafer (Director)	J Mouton
South African Bureau of Standards (SABS)	Dr JP du Plessis (President)	HC Marais M Pienaar

The purpose of interviews in the parastatal sector (as for the HES, discussed in Section 3.1) was essentially to gather substantive information about research structures and activities within these organisations. The main objective was to negotiate access to electronic databases containing details of research staff, outputs and expenditure according to main research fields or programmes. In the absence of such databases, and in addition to them, relevant documentary sources of information – including annual reports and directors' reports – were collected.

3.3.2 Electronic databases

Existing electronic databases – internal project information systems – were obtained from both the Medical Research Council (MRC) and the Human Sciences Research Council (HSRC). The Council for Scientific and Industrial Research (CSIR) compiled an electronic database on its activities for the specific information needs of the survey. This was based on the survey questionnaire (see Section 3.2.3 below) and was completed for each of the 58 programmes run by the CSIR.

Because the electronic databases mentioned differed in structure and reporting format, the task of integrating categories of information into one database proved to be extremely complicated. This necessitated scrupulous checking in order to ensure both the accuracy and consistency of the merged product.

3.3.3 Questionnaires

The questionnaire used in the HES was designed to obtain information from individual researchers, but the one used for the parastatal sector was modified to collect data at the level of programmes or main research fields. It was thus designed to be completed by programme (or division) managers on behalf of a team of researchers. Apart from this modification, the questionnaire remained essentially the same, with the same information categories as used in the HES questionnaire (see Appendix A.2).

Questionnaires were sent out for the purpose of gathering information from organisations in the parastatal sector for which documentary sources were deemed inadequate. In addition, certain tables (particularly those referring to research outputs and expenditure) were sent out in cases where there were crucial information gaps in existing electronic databases or data supplied by the organisation.
Questionnaires were thus sent to heads of the 17 institutes of the Agricultural Research Council (ARC) across the country. These included:

?? Agrimetrics Institute
?? Animal Improvement Institute
?? Animal Nutrition and Animal Products Institute
?? Grain Crops Institute
?? Institute for Agricultural Engineering
?? Institute for Soil, Climate and Water
?? Institute for Tropical and Sub-Tropical Crops
?? Nietvoorbij Institute for Viticulture and Oenology
?? Onderstepoort Institute for Exotic Diseases
?? Onderstepoort Veterinary Institute
?? Plant Genetics Research Institute
?? Plant Protection Research Institute
?? Range and Forage Institute
?? Roodeplaat Vegetable and Ornamental Plant Institute
?? Small Grain Institute
?? Stellenbosch Institute for Fruit Technology
?? Tobacco and Cotton Research Institute

In addition to the above, questionnaires were mailed to the three national facilities of the FRD, namely, the National Accelerator Centre, the Hartebeesthoek Radio

Astronomy Observatory and the South African Astronomical Observatory. After a series of telephonic reminders, all responded by mid-June 1997.

In the case of the HSRC, tables pertaining to research outputs and expenditure were faxed to the organisation in May 1997 with the request that they be completed for each programme. The Council for Geoscience was asked to complete the table on research outputs per research programme at the beginning of June.

3.3.4 Data capturing, editing and validation

Apart from the integration of electronic databases, data gathered by means of questionnaires and documentary sources were captured and edited in Microsoft Access format during May and June 1997.
Data validation involved similar processes to those employed for the HES data (see Section 3.1.3 above).

3.4 Government departments and associated institutions (museums)

According to information supplied by LHA Management Consultants, who were working on the Science and Technology Infrastructure Survey of the NRTA, we were supposed to include in our survey of the government sector 12 national government departments (with various directorates and sub-directorates), ten provincial departments and ten museums.

As in the case of other sectors, data gathering in this case proceeded by means of personal interviews with key informants, mailed questionnaires and the collection of documentary sources of information.

3.4.1 Interviews and documentary information

Before receiving the list of government departments to be included in our survey, we conducted personal interviews with senior staff at 13 departmental directorates and/or sub-directorates and one museum during September and October 1996. A comprehensive interview schedule is provided below.

Table 3.5: Interviews conducted with key informants at government departments and museums

Department / Institution	Interviewee	Interviewer
Department of Arts, Culture, Science and Technology: Africa Institute	Mr B Fischer	M Pienaar
Department of Arts, Culture, Science and Technology: Transvaal Museum	Dr IL Rautenbach	J Mouton M Pienaar
Department of Education	Dr C Madiba and staff	J Mouton M Pienaar
Department of Environmental Affairs and Tourism: Environmental Management	DR JB Pretorius	M Pienaar
Department of Environmental Affairs and Tourism: National Parks Board	Dr P Novellie	J Mouton M Pienaar
Department of Environmental Affairs and Tourism: SATOUR	Mr J Seymore	M Pienaar
Department of Environmental Affairs and Tourism: Weather Bureau	Mr E Poolman	J Mouton M Pienaar
Department of Finance: Central Economic Advisory Service	Mr EG van Eck	M Pienaar
Department of Health	Dr M Jeenah	J Mouton M Pienaar
Department of Labour	Dr G Mhone	J Mouton M Pienaar
Department of Mineral and Energy Affairs	Mr J Basson	J Mouton M Pienaar
Department of Welfare	Ms A du Toit	J Mouton M Pienaar
National Intelligence Agency	Staff	J Mouton
South African Police Service	Dr ID de Vries	M Pienaar

Apart from obtaining an insight into the research structures and activities of these departments, interviews provided an opportunity to ask for existing documentary information (including annual reports) about research staff, outputs and expenditure. If we deemed it necessary, we asked interviewees to prepare tables of data according to the information categories of the questionnaire. After numerous written and telephonic reminders, the Transvaal Museum and the following four departments complied with our request and submitted relevant documentation:

?? Department of Mineral and Energy Affairs

?? Department of Arts, Culture, Science and Technology: Africa Institute

?? Department of Environmental Affairs and Tourism: Weather Bureau and National Parks Board

?? South African Police Services

3.4.2 Questionnaires

The questionnaire used for the parastatal sector was also used in the case of government departments and museums (see Appendix A.2).

By February 1997, researchers from the HSRC working on the Human Resources Survey were able to supply us with an updated list of government departments (excluding museums) to include in our survey. The information they provided was based on interviews they had conducted in this sector at the end of 1996. On the basis of this information, and in consultation with the HSRC team, we decided to include in our survey (and they in theirs) directorates or sub-directorates with a research staff complement of five or more.

3.4.2.1 Data collection: first wave

In the light of the decision to include only directorates or sub-directorates with a research staff complement of five or more, a total of 37 government sector questionnaires were sent out in March 1997. Of these, 16 went to directorates or sub-directorates of national departments and nine to provincial departments (all falling under the Department of Agriculture). We had not visited any of these during September the previous year. In addition, questionnaires were sent to three directorates that had been visited but from which documentary information had not yet been received, as well as nine museums.

At the beginning of May, a questionnaire was sent to the Department of Defence according to instructions provided by them. This resulted from a meeting between members of the department and the audit management team and consultants in February 1997 in order to determine the data gathering procedures to be followed for this department.

By mid-May 1997 (despite a deadline of 7 April), only eight directorates or sub-directorates of government departments had submitted responses; three of these had indicated that the questionnaire was not relevant to them. In addition, six of the targeted museums had returned their completed questionnaires.

3.4.2.2 Data collection: second wave

Given the poor rate of response from government departments, intensive efforts were made throughout the rest of May, in June and during the first week of July to secure information from non-respondents. This entailed a series of telephonic reminders (most were contacted at least half a dozen times) and, in the six cases where originals had been misplaced or discarded, the re-faxing of questionnaires.

In addition to these efforts, directorates or sub-directorates of government departments that had submitted documentary information only were contacted and requested to quantify research outputs and expenditure according to the relevant categories specified in the questionnaire.

By mid-June, it was clear from the numerous telephonic discussions that had been held with contact persons in the government sector (excluding museums) that neither the LHA nor the HSRC contact list was entirely reliable. At a working session held between ourselves and the HSRC team, and attended by Mr J Neethling of the Department of Arts, Culture, Science and Technology, this problem was confirmed. Discrepancies between information gathered by ourselves and the HSRC team clearly demonstrated the extent to which the government sector is still in flux and, hence, the enormous difficulty of trying to assess its current research profile. In some cases, directorates that had provided the HSRC with information about research staff responded to our questionnaire by claiming that they had no research function at all. In the light of problems of this kind, it was decided to include only those government departments with a known and clearly defined research capacity (see Table 3.6 below).

By the end of the first week of July 1997, adequate information for the purpose of the survey had been gathered from all ten of the museums and 14 of the 18 directorates or sub-directorates of government departments. Given the severe time constraints, further follow-up efforts were halted at that point.

Table 3.6 provides an overview of government departments and museums eventually included in the survey, as well as an indication of those from which no response was received.

Table 3.6: Government departments and associated museums included in the survey

Department	Directorate / Sub-Directorate / Institution	Response Received
Department of Agriculture	Department of Agriculture, Provincial Administration: Western Cape	Yes
Department of Agriculture	Mpumulanga Department of Agriculture	Yes
Department of Agriculture	KwaZulu-Natal Department of Agriculture	Yes
Department of Agriculture	Department of Agriculture, Conservation and Environment: Gauteng	Yes
Department of Agriculture	Department of Agriculture North West Province	Yes
Department of Agriculture	Eastern Cape Provincial Government	No
Department of Agriculture	Free State Provincial Government	No
Department of Agriculture	Northern Cape Provincial Government	No
Department of Agriculture	Northern Province Provincial Government	No
Department of Arts, Culture, Science and Technology	Africa Institute	Yes
Department of Arts, Culture, Science and Technology	JLB Smith Institute of Ichthyology	Yes
Department of Arts, Culture, Science and Technology	Natal Museum	Yes
Department of Arts, Culture, Science and Technology	National Cultural History Museum	Yes
Department of Arts, Culture, Science and Technology	National Museum	Yes
Department of Arts, Culture, Science and Technology	South African Cultural History Museum	Yes
Department of Arts, Culture, Science and Technology	South African Museum	Yes
Department of Arts, Culture, Science and Technology	South African National Museum of Military History	Yes
Department of Arts, Culture, Science and Technology	Transvaal Museum	Yes
Department of Environmental Affairs and Tourism	National Botanical Institute	Yes
Department of Environmental Affairs and Tourism	National Parks Board	Yes
Department of Environmental Affairs and Tourism	Sea Fisheries Research Institute	Yes
Department of Environmental Affairs and Tourism	Weather Bureau	Yes

Department of Justice	South African Law Commission	Yes
Department of Labour	National Productivity Institute	Yes
Department of Trade and Industry	Industrial Development Corporation	Yes
Eastern Cape Provincial Government	Albany Museum	Yes
Natal Provincial Government	Natal Parks Board	Yes
South African Police Service	National Standards and Management Services	Yes

3.4.3 Data capturing, editing and validation

Data capturing and editing in MS Access format was done during June and the first week of July 1997. Data validation followed similar procedures to those used for the HES.

3.5 Civil society (selected NGOs)

LHA Management Consultants provided a list of 14 research NGOs to be included in the survey. Data were collected from these organisations by means of mailed questionnaires.

3.5.1 Questionnaires

During March 1997, the LHA list of NGOs was updated (contact details of several of the organisations proved to be incorrect) and questionnaires – the same as those used for science councils and government departments – were faxed to the following 14 organisations:

- ?? Centre for Education Policy Development, Evaluation and Management (CEPD)
- ?? Centre for Policy Studies (CPS)
- ?? Centre for Rural Legal Studies (CRLS)
- ?? Community Agency for Social Enquiry (CASE)
- ?? Environment and Development Agency (EDA)
- ?? Human Rights Committee
- ?? Institute for Democracy in South Africa (IDASA)
- ?? Labour Research Service (LRS)
- ?? Land and Agriculture Policy Centre (LAPC)

?? Minerals and Energy Policy Centre

?? National Labour and Economic Development Institute (NALEDI)

?? Ort Science and Technology Education Project (Ort-STEP Inst)

?? South African Institute of Race Relations (SAIRR)

?? Western Cape Environmental Monitoring Group (GEM)

By mid-May, not a single response had been received! Efforts to secure information from this sector were sustained until the first week of July. Apart from telephonic reminders and/or requests, questionnaires were re-faxed and, in cases where contact persons claimed not to have sufficient time to complete these, we asked that they forward annual reports and other relevant documentation to us.

By the end of the first week of July 1997, information had been received from the following six NGOs on our list:

?? CEPD

?? CPS

?? CASE

?? EDA

?? GEM

?? SAIRR

As further follow-up efforts had to be halted at that point, the 1995 HSRC *Directory of Human Sciences Research Organisations and Professional Associations in South Africa* was used to provide basic information about the remainder of the organisations in this sector. Only two NGOs – the Minerals and Energy Policy Centre and the Ort Science and Technology Education Project – were not covered by this directory, and information about them has thus not been included in the survey.

3.5.2 Data capturing, editing and validation

Data capturing, editing in MS Access and data validation were done during June and the first week of July 1997 using similar procedures to those outlined for the HES in Section 3.1.3 above.

3.6 Business sector and industry-based organisations

According to the division of labour of the NRTA, as determined by the audit management team, consultants from Access Marketing International (AMI) gathered data on the business sector. They provided information on research outputs and expenditure within this sector to the survey project team at the beginning of July 1997. The report by the AMI to the audit management team discusses their research design and methodology.

Contact details of the seven industry-based organisations to be included in the survey, were provided by LHA Management Consultants. The following organisations were listed:

- ?? Epidemiology Research Unit
- ?? Institute for Commercial Forestry Research
- ?? LIRI Technologies
- ?? Oceanographic Research Institute
- ?? South African Institute for Medical Research
- ?? South African Sugar Association Experiment Station
- ?? Sugar Milling Research Institute.

Data were gathered from these organisations by means of personal interviews, questionnaires and the collection of documentary sources of information. The workload was shared between ourselves and researchers from the HSRC working on the Human Resources Survey of the NRTA. Two of the organisations – the Epidemiology Research Unit (Mining Industry) and the South African Institute for Medical Research (SAIMR) – were covered by the HSRC. In the case of the former, a telephonic interview based on the survey questionnaire was conducted and, in the case of the latter, an annual report, as well as electronic data on research staff, was obtained. We gathered information for the purposes of the SSRD and the Human Resources Survey (except in the case of LIRI Technologies) from the remaining five organisations listed in this sector.

3.6.1 Interviews and documentary information

Personal interviews with senior staff at the four organisations listed in Table 3.7 below were conducted in April 1997:

Table 3.7: Interviews conducted with key informants in Industry Based Organisations

Institution	Interviewee	Interviewer
Institute for Commercial Forestry Research	Prof PJT Roberts (Director)	H Hackmann
Oceanographic Research Institute	Prof AJ de Freitas (Director)	H Hackmann
South African Sugar Association Experiment Station	Dr PH Hewitt (Chairman) Mr R Bond	H Hackmann
Sugar Milling Research Institute	Dr BS Purchase (Director)	H Hackmann

Again, the purpose of these interviews was to obtain substantive information about the research structures and activities of the organisations and to collect relevant documentation about research staff, outputs and expenditure according to main research field or programme. Where we deemed it necessary, the interview was also used as an opportunity to negotiate the completion of a questionnaire or, at least, those parts of the questionnaire not adequately covered by documentary sources.

3.6.2 Questionnaires

The questionnaire used for industry-based R&D organisations was the same as that used for science councils, government departments and NGOs (see Appendix A.2). Questionnaires were left with the organisations during the listed in Table 3.7, except in the case of the Oceanographic Research Institute, which was able to provide sufficient documentary information. In addition, a questionnaire was mailed to the director of LIRI Technologies. After a series of telephonic reminders, all responses were received by the end of June 1997.

3.6.3 Data capturing, editing and validation

Data capturing and editing in MS Access format was done during June 1997. As in the case of the parastatal sector, data validation involved similar processes to those employed for the HES.

3.7 Sample realisation and weighting: the HES

A detailed description of the realisation of the sample for the universities and technikons is given in Tables 3.8 and 3.9. In the case of the universities, a breakdown for each wave of data-collection is given.

The final realised sample for the university sector came to 23.7% and for the technikon sector to 17.7%. We also calculated our sample as a proportion of the edited database of grantholders. This percentage came to 46.4% (universities only), which is an indication that we managed to survey almost half of the "productive" scientists in the universities.

In order to allow us to estimate with reasonable accuracy the population values in the HES, a number of weighting factors were calculated and applied in the appropriate tables. These were the following:

?? A SAPSE weight correcting for the differences between universities of the proportion of expenditure on formal instruction and research

?? An expenditure weight correcting for differences between universities on the proportion of grantholders in our database

?? A sample weight for differences between universities on the actual realised sample.

Different models, using different weighting values, were fitted to arrive at final results that are consistent with SAPSE and other available data (including data provided by universities).

Table 3.8: Sample realisation (universities)

University	HSRC Audit survey	SAPSE 1994	SSRD Mailed	SSRD Returned	Grantholders in database (FRD, CSD, MRC)	Previous as % of total grantholders
Medunsa	391	250	321	56	16	37.2
Potchefstroom	460	448	493	155	98	57.3
Rand Afrikaans	309	350	317	164	126	90.0
Rhodes	324	355	264	75	55	49.1
Cape Town	963	1084	1110	257	178	35.2
Durban-Westville	468	425	382	49	32	24.8
Fort Hare	291	220	230	15	9	20.5
Orange Free State	745	556	631	143	91	36.7
Natal	853	734	1432	138	89	38.7
North	0	0	473	49	29	49.2
South Africa	1407	1163	1653	606	192	61.1
Transkei	395	0	306	25	15	39.5
Venda	0	0	187	24	4	21.1
North-West	219	0	218	9	5	13.2
Pretoria	1304	1064	1245	391	246	69.1
Port Elizabeth	243	233	250	51	35	38.9
Stellenbosch	862	942	717	266	192	53.5
Western Cape	643	546	655	115	71	44.7
Vista	707	467	504	45	10	18.5
Witwatersrand	1114	1138	1696	185	106	32.4
Zululand	320	224	309	60	31	38.8
TOTAL	12018	10199#	13393	2878	1630	46.4

If SSRD Mail figures are used to fill in the gaps (4 universities), the total comes to 11 383. The latter was used in calculating the percentage (24.3

Table 3.9: Sample realisation (technikons)

Technikon	HSRC Database	SSRD Mailed	SSRD Returned	Incomplete	Database as % of mailed	Databas Total
Border	114	35	5	2	8.6	
Cape	181	163	30	2	17.2	
Eastern Cape	0	106	0	0	0	
Free State	221	83	46	5	49.4	
Mangosuthu	100	104	31	5	25.0	
ML Sultan	276	180	14	2	6.7	
Northern Transvaal	175	132	112	27	64.4	
North-West	52	25	0	0	0	
Peninsula	223	164	9	0	5.5	
Port Elizabeth	255	255	42	4	14.9	
Pretoria	750	159	62	4	36.5	
Natal	328	170	28	9	11.2	
South Africa	280	254	49	7	16.5	
Witwatersrand	362	248	19	1	7.3	
Vaal Triangle	262	99	12	5	7.1	
TOTAL	3579	2177	459	73	17.7	

Chapter 4

Sector profiles

4.1 Higher education sector

4.1.1 Database

The results for the 21 universities reported on are based on a sample of almost 24%, whereas the sample for the 15 technikons constitutes 18% of the target population. One has to add, however, that the exact size of the "target population" is a matter of some debate. These realisation figures are based on information gathered from yearbooks and university data provided to the SSRD (see Table 3.8). If the realised response is calculated as a proportion of the number of grantholders (universities only), the sample constitutes 46% of the target population. We believe, therefore, that the higher education section of the database contains information on between 40% and 50% of the active or "productive" scientists/scholars in South Africa.

4.1.2 Projects/programme profile

The 3 079 individuals included in the database listed a total of 4 039 projects, which represents an average of 1.31 per person. However, this statistic hides the fact that almost 10% of the respondents (420) did not list any research projects/programmes. This means that 2 659 individual respondents documented 4 039 projects. Of these, slightly more than half (54%, or 1 444) listed one project/programme only, another 36% (965) described two projects and the remaining 10% (250) three projects or more.

In Table 4.1, we present information on the number of respondents per university or technikon, the number of projects listed, the average number of projects per respondent, total (running) costs for the respondents from that particular institution, and average expenditure per project. The technikons are listed first, followed by the universities.

Some of the points highlighted by the table are:

?? The substantial differences between the technikons and universities in terms of the average number of projects per individual (0.65 and 1.25 respectively), the average time spent on research (31% and 41% respectively) and average expenditure per project (R12 700 and R24000 respectively). In terms of these "indicators", university respondents "outperform" their technikon counterparts, reaffirming the big differences in research traditions and research cultures between these types of higher education institutions.

Table 4.1: Project profile by HES organisation (unweighted): 1995/96

Organisation	Indivi-duals	Projects	Average Projects	Time Spent %	Total Expenditure	Average Expenditure
Border Technikon	3	2	0.67	33.3	R 1 800	R 900
Cape Technikon	28	24	0.86	32.5	R 430 000	R 1 792
Free State Technikon	41	34	0.83	30.7	R 1 351 650	R 39 765
Mangosuthu Technikon	26	15	0.58	24.6	R 48 500	R 3 233
ML Sultan Technikon	12	10	0.83	35.0	R 493 830	R 49 383
Northern Transvaal Technikon	83	51	0.61	36.5	R 336 276	R 6 594
Peninsula Technikon	9	8	0.89	43.3	R 205 530	R25 691
Port Elizabeth Technikon	38	27	0.71	27.4	R 989 714	R 36 656
Pretoria Technikon	58	49	0.84	26.0	R 1 120 900	R 22 876
Technikon Natal	19	13	0.68	27.9	R 88 600	R 6 815
Technikon South Africa	41	24	0.59	41.2	R 98 850	R 4 119
Technikon Witwatersrand	18	8	0.44	26.7	R 35 525	R 4 440
Vaal Triangle Technikon	7	4	0.57	40.0	R 6 000	R 1 500
Sub-total	383	269	0.65	30.36	R 5 207 175	R 12 768.86
Medical University of SA	53	65	1.23	38.9	R 1 726 827	R 26 569
Potchefstroom University	150	196	1.31	39.5	R 11 548 779	R 58 922
Rand Afrikaans University	160	215	1.34	46.8	R 8 523 550	R 39 644
Rhodes University	73	103	1.41	46.9	R 4 373 798	R 42 464
University of Cape Town	244	388	1.59	46.7	R 32 024 684	R 82 538
University of Durban-Westville	49	69	1.41	41.8	R 1 257 156	R 18 220
University of Fort Hare	15	17	1.13	37.3	R 96 770	R 5 692
University of Natal	132	232	1.76	41.4	R 10 415 064	R44 893
University of Port Elizabeth	50	71	1.42	41.4	R 1 332 515	R 18 768
University of Pretoria	370	550	1.49	39.0	R 23 154 144	R 42 098
University of South Africa	527	669	1.27	41.7	R 8 845 427	R13 222
University of Stellenbosch	248	380	1.53	44.8	R 21 706 094	R 57 121
University of the Free State	130	178	1.37	47.7	R 6 478 112	R 36 394

University of the North	48	50	1.04	52.3	R 6 027 286	R120 546
University of the North West	9	10	1.11	42.2	R 46 500	R 4 650
University of the Western Cape	110	150	1.36	42.3	R 4 551 140	R30 340
University of the Witwatersrand	176	256	1.45	43.5	R 14 150 850	R55 277
University of Transkei	25	28	1.12	44.4	R 913 865	R 32 638
University of Venda	20	21	1.00	41.5	R 937 383	R 44 637
University of Zululand	59	66	1.12	40.3	R 1 099 071	R16 653
Vista University	41	42	1.00	37.8	R 787 618	R 18 753
TOTAL	2689	3756	1.25	40.83	R 159 996 633	R 241 834

?? There are equally big differences within each group. Among technikons, there is a big difference between the top players (Cape, Pretoria, Port Elizabeth, Peninsula, and Free State) and the rest. Among universities, the historically advantaged institutions fare best overall. The top five universities in each of the three categories are:

Number of projects (mean)	***Time spent (average)***	***Project expenditure (average_***
Natal	**North**	**North**
Cape Town	**Free State**	**Cape Town**
Stellenbosch	**Rhodes**	**Potchefstroom**
Pretoria	**Rand Afrikaans**	**Stellenbosch**
Witwatersrand	**Cape Town**	**Witwatersrand**

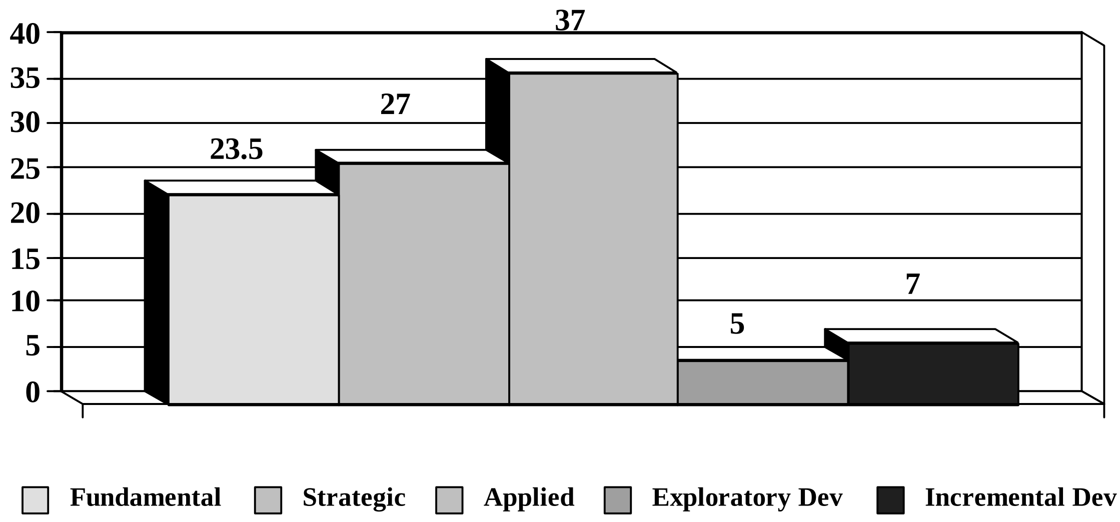
(Note: The results for the University of the North should be treated with caution, given the small sample of 48. In this case, three individuals of these individuals listed programmes exceeding R1 000 000 each.)

4.1.3 Type of research and development

A summary of the type of R&D across all institutions is provided in Fig. 4.1. The overall ratio between the standard categories of basic, applied and development work is 50:37:13. Although it is worth noting that researchers in the HES classify half of their work as basic research – and this has been a consistent trend over the past decade – it is equally interesting that more than half of this "basic" research

(27%) is aimed at some form of future application (and may thus be defined as "strategic" research). Stated differently, only 23% of all research done in the HES is classified by researchers as fundamental or curiosity-driven research. We would suggest that this is one of a number of indicators that signify a clear trend towards more "application-driven research" (to use Gibbons's term) at South African universities and technikons. The drop in fundamental research at our institutions of higher learning is cause for concern.

Figure: 4.1: Type of R&D (HES): 1995/96



The balance of Basic, Applied and Development Work is different in different science cultures.

Table 4.2: Type of R&D by science culture (HES): 1995/96

Science culture	Basic	Applied	Development	n
Arts	64	24	12	87
Economic and business sciences	43	39	18	369
Engineering sciences	29	44	27	473
Humanities	67	25	8	1256
Medical and health sciences	34	50	16	696
Natural sciences	53	37	10	1746
Social sciences	47	38	15	1502
	48%	37%	15%	6129

(Note: The total of 6 129 is the result of the fact that respondents could categorise their projects in more than one of the three categories.)

Not surprisingly, science cultures such as the arts (64%) and humanities (67%) devote more of their time to basic research than, for example, the engineering sciences (29%) and medical and health sciences (34%). Conversely, researchers in the engineering sciences spend more time on applied research and development work.

4.1.4 Expenditure on R&D

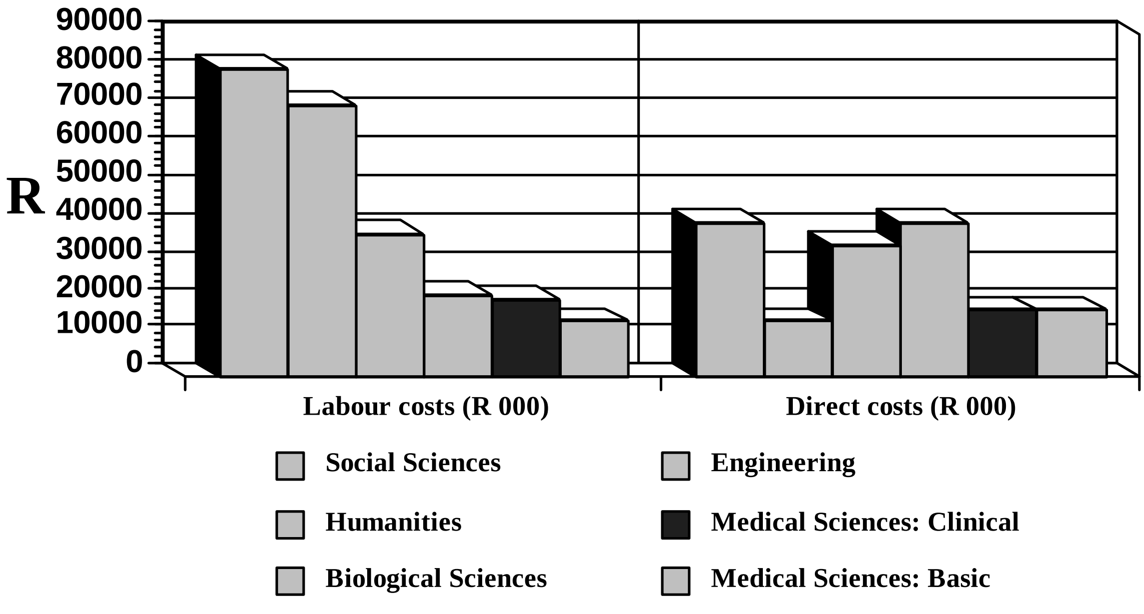
Total expenditure on R&D in the HES is estimated to have been approximately R660 million in 1995. This total is made up of estimated labour costs of R357 million, direct projects costs of R285 million and expenditure on replacing and upgrading equipment amounting to R21 million.

A comparison with the 1991 R&D survey (R690 million) suggests that these are very conservative estimates. In fact, spot checks of the weighted expenditure figure for certain universities confirmed that our estimates were lower than the institutional research budgets. However, one has to add that these budgets differ greatly in terms of the items that are included or excluded. Suffice it to say that we believe that the estimate of R660 million is conservative.

The breakdown by institution again reveals huge differences among institutions. The top five universities (Cape Town, Pretoria, Stellenbosch, Witwatersrand and Natal) contribute more than 60% to total direct expenditure.

As far as expenditure by Main Scientific Field is concerned, it is important to distinguish between labour costs and operational costs (The first is skewed because of the large number of scholars in the humanities and social sciences).

Figure: 4.2: Labour and direct cost by main science field (HES): 1995/96



4.1.5 Sources of funding

One of the most striking results of the SSRD relates to sources of R&D funding. The overall picture shows that university and technikon researchers get most of their funding for R&D (64%) from sources external to the university, a further 22% through second stream funding (funding agencies) and a small proportion (14%) from their own institution. However, it should be added that the category of "external funding" includes a variety of sources ranging from government contracts to funding from business, industry and overseas foundations/donations. A finer analysis shows that approximately 65% of the sources of "external funding" are South African, including business, public enterprises (like Sasol, Eskom, Telkom), government departments, and local foundations and trusts. Most of the 35% from abroad is contributed by foundations such as Glaxo Wellcome, Ford, USAID, DANIDA, Kelloggs, Mellon, Von Humboldt.

4.1.6 R&D output

One of the primary objectives of the SSRD was to construct a picture of outputs in terms of kind, volume and their relationship to other input measures, such as human resources and expenditure.

The discussion below compares outputs (unweighted) across organisations and also focuses on measures of "productivity", such as per capita output (number of publications, conference papers, technologies per scientist) and cost–output ratio. The absolute volume (for example, the total number of scientific publications) is not meaningful on its own. Its significance will become evident only after follow-up studies in the future.

The table below summarises per capita output for four categories across the universities. The categories are "scientific publications" (local and overseas journal articles, monographs, chapters in books and published conference proceedings); "conference papers" (local and overseas), "reports" (contract and technical reports) and "technologies" (product, process, information and support technologies).

Table 4.3: Per capita output by organisation (universities): 1995/96

University	n	Total published	Per capita	Conference papers	Per capita	Reports	Per capita	Techno-logies	Per capita
Rand Afrikaans	159	605	3.81	439	2.76	154	0.97	77	0.48
Natal	132	460	3.48	382	2.89	99	0.75	17	0.13
Cape Town	242	839	3.47	559	2.31	211	0.87	28	0.12
Witwatersrand	176	540	3.07	458	2.60	125	0.71	26	0.15
Pretoria	366	1094	2.99	935	2.55	331	0.90	129	0.35
Rhodes	72	214	2.97	144	2.00	39	0.54	4	0.06
Stellenbosch	246	725	2.95	640	2.60	154	0.63	51	0.21
Orange Free State	129	351	2.72	396	3.00	65	0.49	27	0.20
Port Elizabeth	49	125	2.55	105	2.14	82	1.67	18	0.37
Medunsa	53	128	2.42	114	2.15	30	0.57	7	0.13
Western Cape	109	246	2.26	222	2.04	87	0.80	2	0.02
Potchefstroom	150	327	2.18	270	1.80	70	0.47	8	0.05
Durban-Westville	49	105	2.14	111	2.27	20	0.41	4	0.08
North	48	102	2.04	69	1.44	37	0.77	14	0.29
South Africa	528	932	1.77	626	1.19	207	0.39	24	0.05
Zululand	59	86	1.46	65	1.10	35	0.59	12	0.20
Vista	40	48	1.20	48	1.20	12	0.30	6	0.15
TOTAL	**2607**	**6927**	**2.56**	**5583**	**2.12**	**1758**	**0.70**	**454**	**0.18**

[Note: Small sample sizes could obviously skew results. We have therefore excluded the universities of Venda, the North-West, Fort Hare and Transkei because they each had sample sizes of less than 40.)

Any discussion of output (especially publication output) will invariably be compared with the annual SAPSE output data. We must therefore emphasise that such a comparison is inappropriate for two reasons. Firstly, the category of "scientific publications" used in the SSRD is broader than the SAPSE definition as it also includes published conference proceedings and chapters in books that are often rejected for subsidy purposes. Secondly, the figures presented in Table 4.3 are obviously unaudited information. For these reasons, we believe that a comparison of "per capita output" is more revealing and valid.

The mean per capita output of scientific publications was 2.56. Stated differently, every scientist produced an average of two and a half scientific publications in 1995. The average for eight of the universities exceeded the overall average; these were Rand Afrikaans, Natal, Cape Town, the Witwatersrand, Pretoria, Rhodes, Stellenbosch and the Orange Free State. The remaining ten universities (many of which are historically disadvantaged institutions) fell below the average. The per capita profiles for conference papers and reports did not differ substantively from this. It is, of course, to be expected that university scholars will produce more scientific publications (2.56) than conference papers (2.12) and contract or technical reports (0.7) per year. [Note: these statistics are all slightly above the average for the HES as a whole because the focus is on the universities. Cf. Chapter Five].

The average number of technologies across all universities was 0.18 for 1995. The universities that performed significantly better than average were: the Rand Afrikaans (0.48), Pretoria (0.35), Port Elizabeth (0.37), the North (0.29), Stellenbosch (0.21) and the Orange Free State (0.20). However, it is important that we understand what our respondents meant when they marked "technology" in the questionnaire. The tables below provide some qualitative and illustrative information on research projects for which the respondent indicated that a new technology was being developed or an existing technology improved. Projects over a certain minimum expenditure were included. (Table 4.4 lists human sciences projects costing more than R10 000; the remaining tables list projects costing in excess of R100 000.)

Table 4.4 Human sciences: technologies (HES)

Science culture	Project: description of goals
Economic and business sciences	Developing methodologies for the demarcation and analysis of retail trade areas
Economic and business sciences	Devising specifications and developing software for real estate investment analysis
Economic and business sciences	Measuring the quality of service in the medical aid industry and the sewing industry
Economic and business sciences	Providing registers containing addresses and key classification information of institutions for the more important sectors of the economy
Humanities	Developing and improving a computer program for computer-assisted instruction in Greek (SPHINX 2000); research by means of the program
Social sciences	Developing effective criteria for cross-cultural counselling
Social sciences	Developing courseware (software and book-based exercises) for reading (normal improvement and remedial intervention): junior primary levels (8 modules) in English; part of 20 module program in English; 22 modules in Afrikaans
Social sciences	Developing a diagnostic assessment battery for English reading to address the difficulties of both first and second language speakers of English in the early stages of learning to read
Social sciences	Assessing the needs of and possible risks to each person sentenced to serve a term in prison and compiling a development plan in terms of social work; psychology; education and training; and religious dimensions
Social sciences	Comparing the effectiveness of two treatments in the group treatment of social phobia
Social sciences	Developing a training program for different businesses which can be adapted to the needs of any organisation
Social sciences	Utilising contemporary cross-cultural, psychological principles and recent innovations in modern testing theory for constructing and adapting tests for socially diverse societies

Human science technologies typically involve the construction of psychological test batteries for the purposes of diagnostic assessment, the development of databases and computer software for various applications, programme development and evaluation, the development of new courseware and curricula, and certain methodological development projects (for example, for devising new measurement techniques).

Table 4.5 Engineering sciences: technologies (HES)

Science culture	Project: description of goals
Engineering sciences	Applying chemical and biochemical engineering principles to reducing the impact of human activities on the aquatic environment while improving the lot of mankind
Engineering sciences	Developing cost-effective methods for the preparation of geopolymers from South Africa waste materials. The effect of the conditions of geopolymerisation and pozzolonic cement-ferming on the immobilisation and hence leaching behaviour of encapsulated contaminants
Engineering sciences	Developing solutions to industrial problems in the manufacturing, process and mining, and mineral industries concerning the electronic processing of energy and the electronic control of plant and processes
Engineering sciences	Developing structural, functional and maintenance designs for mine haul roads
Engineering sciences	Developing principles for the design of stainless steel structural members
Engineering sciences	Developing, designing, processing and manufacturing new materials/ applicable materials to suit requirements
Engineering sciences	Conducting education and training in the field of telecommunication engineering. Identifying a niche area for research and development in the field of personal communications. Developing an improved wireless communication system suitable for domestic applications
Engineering sciences	Developing high power, high performance, power electronic converters for power quality, traction and electrification (including renewable energy)
Engineering sciences	Investigating heavy manual labour in construction and small scale agriculture. Designing and evaluating solutions to physical strain problems. Evaluating the potential for reducing injuries
Engineering sciences	Investigating power and high frequency transformers and inductors, busbars and transmission lines, conducted electromagnetic interference, induction heating and heating plasmas
Engineering sciences	Developing more efficient systems in terms of energy consumption. Increasing performance in heating and cooling capacity. Reducing costs
Engineering sciences	Power systems engineering and analysis. Power systems control and operations. Power system protection
Engineering sciences	Simulating building, HVAC system and control. Verifying simulations. Developing low energy technologies
Engineering sciences	Teaching liberation models. Diagnostic teaching of ores. Jet reactors for teaching noble metals. Self-soft attrition of ores. Acid leaching of base metals
Engineering sciences	Defining and developing an optimum education model and infrastructure to facilitate a constructivist approach to the in-service education and training of teachers, employing distance education
Engineering sciences	Using ion-exchange resins. Adsorption, elution of activated carbon (i.e. gold and organics). Using composite and carbon membranes in the chemical industry

Technological development in the engineering field typically involves systems design and development, the development and improvement of existing technologies (for example, power electric converters, communication systems) and the development and refinement of existing methodologies (simulation models).

Table 4.6 Medical and health sciences: technologies (HES)

Science culture	Project: Description of Goals
Medical and health sciences	Investigating whether "new" cases are recrudescent or truly "new", and whether “mini epidemics” are caused by different strains or the same strain
Medical and health sciences	Defining YuRH hormone receptor interaction for new drug development
Medical and health sciences	Developing a long-lasting heart valve which endothelialises but does not calcify
Medical and health sciences	Developing novel immunodulatory pharmacological agents with anti-misubial and/or anti-inflammatory properties, as well as anti-cancer activity

Medical and health sciences	Developing precise, three dimensional measurement techniques for use in medicine and dentistry
Medical and health sciences	Developing scaffolds that stimulate the body to re-grow a new artery of the heart valve after the removal of the diseased one
Medical and health sciences	Eosinophil and neutrophil isolation techniques and the effect of specific newer generation antihistamines on eosinophil and neutrophil stimulation
Medical and health sciences	Insurance-sponsored claims assessments on an interdisciplinary basis. This links medical and ergonomic personnel in a service orientation, the proceeds of which are ploughed into technology acquisition which fuels the research activities of the group
Medical and health sciences	Developing respiratory equipment
Medical and health sciences	Researching burns
Medical and health sciences	Establishing a national normative database on musculo-skeletal output parameters (normal and pathological) with particular reference to the endemic labour force

Examples of medical and health technologies include the development of new drugs, new methodological procedures (for example, measurement techniques), biotechnological developments (respiratory equipment, heart valves) and informational technologies.

Table 4.7 Natural sciences: technologies (HES)

Science culture	Project: description of goals
Natural sciences	Constructing a database from which high value oil producers are screened for biotechnological applications
Natural sciences	Determining ultra trace elements using platented filter furnace –the filter furnace in a graphite insert which fits inside the graphic room of an electrothermal atomic absorption spectrometer
Natural sciences	Developing strategies to ensure the survival of endangered fish species. Developing procedures to detect habitat changes. Indexes of biotic integrity.
Natural sciences	Developing a laboratory suited to the production of photovoltaic materials and cells. Fabricating and characterising solar cell devices
Natural sciences	Developing scientific and practical protocols for the commercial farming of aquatic organisms (fresh water and marine)
Natural sciences	Establishing and evaluating small-scale commercial integrated aquaculture–agriculture farming systems. Developing and evaluating intensive ornamental fish production unit
Natural sciences	Harnessing cell regulation to improve cell inactivation for tumour control
Natural sciences	Improving state-of-the-art systems using logic program analysis and transformation techniques
Natural sciences	Making a mechanistic description of the behaviour of the soil–plant–atmosphere continuum accessible on farms
Natural sciences	Pruning, training, improving fruit size and enhancing fruit quality
Natural sciences	Replacing defective bone by artificial microporous apatite
Natural sciences	Studying the composition of cereal grains after harvest and during processing so as to provide predictive and remedial actions by processors in optimizing processes and product quality
Natural sciences	Studying biology and ecology of commercial fish species, assessing stock and developing management strategies
Natural sciences	Acquiring expertise in the production of natural history programs. Developing new techniques and technology for the production of natural history programmes
Natural sciences	Determining the applicability of daily and monthly time-step models for simulating runoff from Southern African catchments, given the limitations of available information
Natural sciences	Determining the immunogenicity of recombinant magoviruses expressing various SIV CTL epitopes or HIV-1nef in mice and macaques with the aim of developing a vaccine for HIV-1
Natural sciences	Developing a rapid screening test for drug resistance and characterising this resistance in M.Tuberculosis. Establishing strain patterns in drug resistance
Natural sciences	Developing guidelines for assessing the water supply alternatives for relatively small-scale rural

	development projects and incorporating the guidelines into a decision support system

The natural science technologies listed in Table 4.7 include the development of new information systems (for example, decision support systems, new algorithms), methodological protocols and systems (for example, guidelines for assessing water supplies), programme development and evaluation (for example, assessing farming systems) and the development of new vaccines and drugs.

This more qualitative overview of types of technology development and improvement shows that respondents understood the categories well and that similar kinds of technologies were listed across scientific fields and science cultures. Detailed reading of the various project titles suggests that approximately 75% of the total number of "technologies" listed could correctly be classified as such.

4.1.7 Output: postgraduate students

An obvious category of output is the number of postgraduate students (masters and doctoral) that were supervised during 1995. Table 4.8 summarises these results, distinguishing between students hat completed their studies in 1995 and those that continued studying in subsequent years.

Table 4.8 Postgraduate students by main scientific field (HES): 1995/96

Science culture	N	Masters ongoing	Per cap	Masters complete	Per cap	Doctoral ongoing	Per cap	Doctoral complete	Per cap
Arts	51	107	2.1	21	0.4	21	0.4	5	0.1
Economic/ business sciences	238	619	2.6	374	1.6	82	0.3	15	0.06
Engineering sciences	212	459	2.2	139	0.7	178	0.4	26	0.12
Humanities	611	1192	1.95	380	0.6	563	0.9	113	0.18
Medical and health sciences	356	1051	2.95	265	0.7	188	0.5	50	0.14
Natural sciences	809	2300	2.8	388	0.5	698	0.9	120	0.15
Social sciences	782	1959	2.5	679	0.9	734	0.9	174	0.22
TOTAL	**3059**	**7687**	**2.5**	**2246**	**0.7**	**2464**	**0.8**	**503**	**0.16**

4.1.8 A case study: linkages and networks of collaboration

The issue of research collaboration and the degree of inter-disciplinary and inter-sectoral co-operation are addressed in Chapter 5. However, in our analysis of technology and development-related work, we were also interested in establishing how much co-operation is taking place in these areas. We focused on the engineering sciences in our investigation of the nature of linkages between different sectors as far as research funding and networks of co-operation are concerned.

Of the 266 engineers included in the database, we selected those that had indicated that they collaborated with other researchers and that they had either developed a new technology or improved on an existing technology during 1995. This gave us a final list of 29 (see Table 4.9). It is noteworthy that this subgroup raised nearly 30% of all funds listed in the field of the engineering sciences field and also that the average cost of their projects was almost R400 000. This group clearly includes some of the more active and entrepreneurial engineering scientists in the country.

Table 4.9 Sources of funding (engineering scientists) (HES): 1995/96

Department	Agency	Own Institution	Business	Overseas	Other	Direct Expenditure R
Chromium Steels Research Group			Columbus - Samancor - CMI (Chrome Development Institute)			300 000.00
Biomedical Engineering				ODA / EV		300 000.00
Chemical Engineering	FRD	OWN	Gencor, Impala, Sasol			292 000.00
Chemical Engineering	FRD	OWN	Mintek, Sasol, AAC	Australian Research Council		252 000.00
Chemical Engineering	FRD	OWN	AAC, Impala Platinum, Gencor			147 700.00
Chemical Engineering	FRD	OWN				62 000.00
Civil Engineering	FRD	OWN				205 000.00
Civil Engineering					Water Research Commission	360 000.00
Civil Engineering	FRD	OWN	Cement Industry / LTA Construction		Construction companies	1 230 000.00
Electrical and Electronic Engineering	FRD	OWN	Aluminium Industry			115 000.00

Electrical and Electronic Engineering	FRD	OWN	Eskom, Spoornet, Somchem	EPRI (indirect)		460 000.00
Electrical and Electronic Engineering			Hewlett Packard			160 000.00
Electrical and Electronic Engineering	FRD	OWN				145 000.00
Electrical and Electronic Engineering	FRD					137 000.00
Environmental Design and Management			Dept of Mineral and Energy			60 000.00
Industrial Electronics	FRD					200 000.00
Industrial Electronics	FRD					1 000 000.00
Materials Engineering	FRD		Eskom			300 000.00
Materials Science and Metallurgical Engineering			Eskom, Iskor, SASTECH, Columbus (Joint Venture)			350 000.00
Mechanical Engineering	FRD	OWN	Ralmech			96 000.00
Mechanical Engineering	FRD	OWN				55 000.00
Mechanical Engineering	FRD		MBSA / VWSA / National Springs		PE Technikon	81 000.00
Mechanical Engineering	FRD		TEMMI / ESKOM			405 000.00
Mining Engineering			AAC/ISCOR			114 000.00
Mining Engineering					CSIR Miningtek	90 000.00
Power Engineering	FRD		Eskom / Ernest Oppenheimer Trust			100 000.00
Energy Research Institute	FRD	OWN	Industry / Dept of Mineral and Energy affairs h			515 000.00
Faculty of Engineering	FRD	OWN	Murray & Roberts / 1st National Bank			401 000.00
Pollution Research Group	FRD		Eskom and Sasol	IAWQ		2 080 000.00
Research Institute for Industrial Pharmacy	FRD	OWN	Research and development funds			1 030 000.00
Chemical Engineering	FRD		VML / Gencor			55 000.00
School of Chemical Engineering	FRD		Sentrachem / Sasol			295 000.00
Process and Materials Engineering	FRD		Delta (emd), Barbroor Mines		Mintek	161 000.00
	2,690,400	2,258,70(	5,414,600	410,000	780,000	11 553 700
	23%	20%	47%	3%	7%	

A summary of the collaborative networks of this subgroup reveals that of the 33 projects listed by the 29 scientists, 29 (88%) involved collaboration with colleagues and students at their own institution, ten with colleagues at other South African institutions, five with scientists at overseas institutions, four with colleagues at science councils (CSIR and MINTEK) and two with scientists at other organisations (for example, ESKOM and ISCOR).

We drew the following conclusions:

?? The more "entrepreneurial" scientists in a field are able to procure significantly more funds per project than their colleagues. In the case of engineering the "high flyers" expend an average of three and a half times more on their projects than the rest of the scientists in the field.

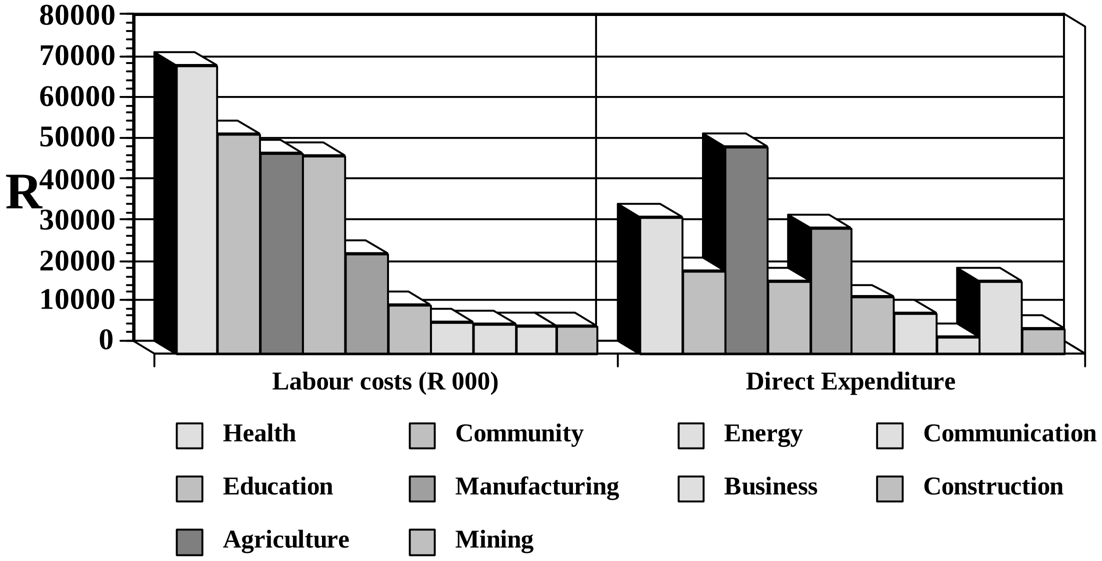
?? They seem to be able to utilise all three streams of funding equally well, receiving good support from their own institutions (20%, which is higher than the average of 14%), equally substantial support from the national funding agencies (23%) and significant funding from business and industry.

?? Compared to the national average, they engage in more extensive inter-sectoral collaboration

4.1.9 R&D expenditure by sector of application

Respondents that indicated that they were involved in either applied or developmental research were asked also to indicate the sector of the economy to which their research was most applicable. Figure 4.3 summarises these results for the top ten fields in terms of both labour costs and direct costs.

Figure: 4.3: Expenditure by sector of application (HES): 1995/96



Although the ranking differs with respect to labour and direct expenditure, the top five fields of application in both cases are health, education, agriculture, community and social services, and manufacturing. Expenditure in these five fields constitutes almost 75% of all expenditure on labour and direct costs.

4.1.10 Summary

The following are the main findings of the SSRD as they relate to the higher education sector:

?? Total expenditure on R&D in 1995 (R660 million) reflects a decline in real terms compared to 1991 results.

?? Basic research is the category that accounts for the largest percentage of expenditure (50%), followed by applied research (37%) and development work (13%). However, finer analysis shows that within the category of basic research 27% of the funding is on strategic research and 23% on fundamental research.

?? R&D output in the HES is heavily concentrated in between five and seven universities and between three and five technikons, all of which are historically advantaged. Many different indicators all point to the same skewness in the system, for example, the number of projects listed, the average time spent on research, per capita expenditure, per capita output, total volume of output and R&D funds raised.

?? Although the measures of output differ slightly from those used in other surveys, the results are consistent with previous findings. Not surprisingly, most of the intellectual energy is directed at scientific publications, followed by conferences papers and unrefereed reports.

?? A more qualitative analysis of the type of "technological development" undertaken suggests that respondents across all science cultures use comparable definitions of "technology". The notion of "human sciences technology" seems to have become accepted, especially among social and business scientists.

?? An in-depth analysis of the engineering research community shows big differences between average scientists and "high-flyer, entrepreneurial" scholars. The top scientists in this field are more successful than their colleagues at raising project funds and seem to have closer links with business and industry and stronger collaborative networks.

?? Nearly three-quarters of all R&D expenditure in the higher education sector occurs in the following five sectors: agriculture, health, education, community and social services and manufacturing. This represents another form of skewness in the system. Equally important fields, such as energy, tourism, conservation and communications, are clearly not supported by a strong research base.

4.2 Science councils

4.2.1 Database

All the science councils, with the exception of the SABS, are included in the database. The data used in this analysis are derived either from in-house project databases (HSRC, MRC) or questionnaires (CSIR, FRD national facilities, ARC) or a combination of questionnaires and other official organisational reports (MINTEK and the Council for Geoscience). In this way, a complete coverage of all research programmes at the science councils was achieved.

4.2.2 Profile of programmes

We used the research programme, thrust or focus area as the unit of analysis for the science council sector. The rationale for this was that science councils typically organise their research activities around larger and more long-term programmes rather than around the more short-term interests of individual scientists. Information about 161 such programmes was captured. A summary is provided in Table 4. 10.

Table 4.10 Research programme and expenditure by group/division (science councils): 1995/96

Organisation	Division/group	Prog-ramme	Expenditure R
ARC	Animal Sciences Institutes	5	82 169 902
ARC	Plant Sciences Institutes	12	158 375 378
ARC	Specialist Institutes	4	31 529 410
CSIR	Division of Building Technology	5	19 313 000
CSIR	Division of Communication and Information Networking Technology	8	46 369 000
CSIR	Division of Food Science and Technology	5	16 119 000
CSIR	Division of Manufacturing and Aeronautical Systems	9	102 914 000
CSIR	Division of Materials Science and Technology	12	67 148 000
CSIR	Division of Mining Technology	3	48 883 000
CSIR	Division of Roads and Transport Technology	4	25 473 000
CSIR	Division of Textile Technologies	4	12 583 000
CSIR	Division of Water, Environment and Forestry Technology	8	80 586 000
FRD	Hartebeesthoek Radio Astronomy Observatory	1	1 675 000
FRD	National Accelerator Centre	4	38 000 000
FRD	South African Astronomical Observatory	1	7 882 000
Geoscience	Economic Geology Division	1	1 676 114
Geoscience	Environmental, Engineering and Marine Geoscience	1	5 954 449
Geoscience	Geophysics Division	1	4 440 194
Geoscience	Mineralogy, Petrology and Geochemistry	1	4 285 241
Geoscience	Regional Geology Division	1	12 047 469
HSRC	Education	10	12 095 102
HSRC	Human Resources	7	7 479 139
HSRC	Science Development	1	299 608
HSRC	Social Dynamics	11	9 496 676
HSRC	Support Services	1	1 331 804
Mintek	Base Metals Programme	1	16 390 055
Mintek	Ferro-alloys and Stainless Steel Programme	1	21 101 265
Mintek	Gold and Uranium Programme	1	11 657 438
Mintek	Industrial Minerals Programme	1	8 914 865
Mintek	Platinum Group Metals Programme	1	8 213 238
Mintek	Refractory, Light and Rare Programme	1	1 516 744
MRC	Community Health Research Group	14	15 792 362
MRC	Health Technology Research Group	3	1 410 423
MRC	Laboratory and Clinical Research Group	15	4 724 962
MRC	Laboratory and Clinical Research Programme	3	4 662 900
TOTAL		**161**	**892 509 738**

A superficial analysis of some of the features of these programmes reveals significant differences between the science councils. In Table 4.11, the number of scientists and expenditure per programme are compared across the science councils. The different profiles that emerge from this are clearly the result of differences in the way science is managed in the various science cultures, as well as differences in institutional policies. The fact that the programmes of the HSRC have relatively few researchers and relatively low expenditure is an indication of a particular tradition in social science research. The programmes of the MRC must be viewed in the light of the science council's explicit policy to co-sponsor many research units at universities and other institutions. Many of the 35 programmes are in fact university-based units. As far as the national facilities are concerned, it should be borne in mind that four of the six programmes are operated by the National Accelerator Centre which spends more on research than the HSRC and the Council for Geoscience. The relatively high expenditure per programme at Mintek is not unexpected, given the council's emphasis on market-driven thrusts rather than research-driven programmes. On the other hand, the ARC breakdown is somewhat misleading because the figures represent the results for the ARC's 21 institutes. Each of the institutes operates numerous programmes, which were not individually recorded.

Table 4.11 Programme detail, by science council: 1995/96

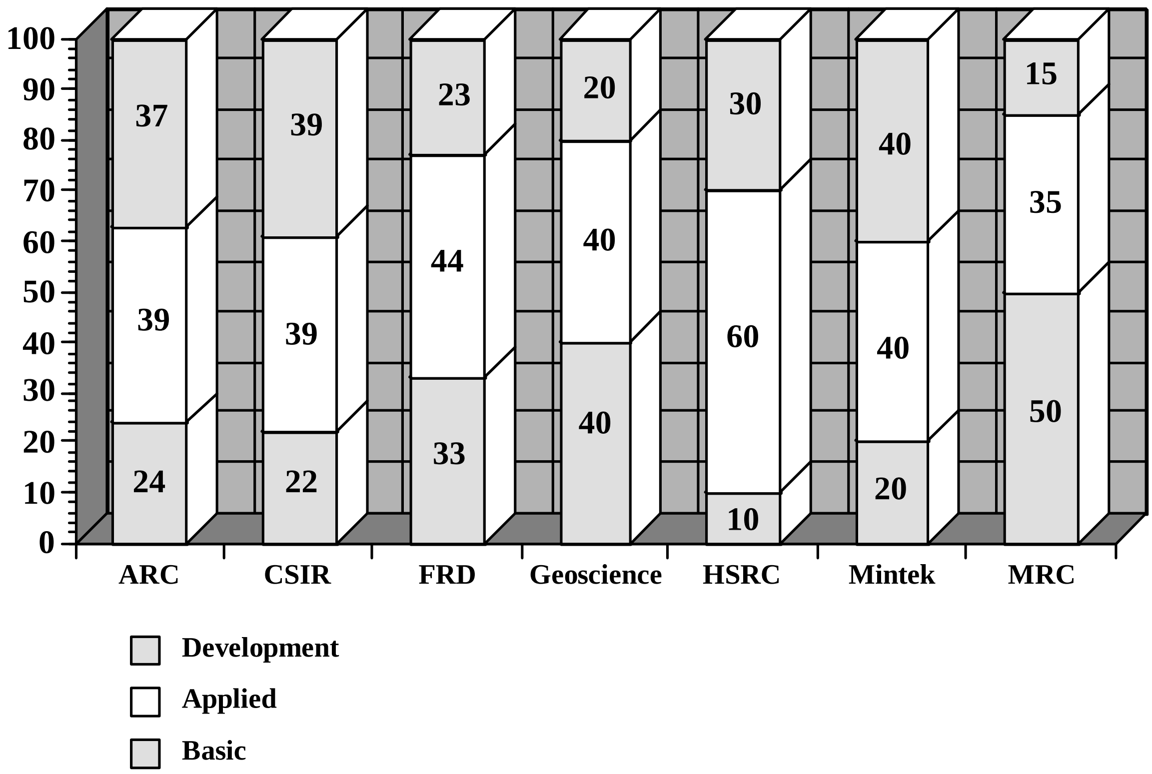
Organisation	Programmes	Scientists researchers	Scientists per programme	Total expenditure R	Expenditure per programme R
ARC	21	701	33	272 074 690	12 955 904
CSIR	58	1099	19	419 388 000	7 230 828
FRD	6	87	14	47 557 000	7 926 167
Geoscience	5	106	21	28 403 467	5 680 600
HSRC	30	178	6	30 702 329	1 023 411
Mintek	6	307	51	67 793 605	11 298 934
MRC	35	309	9	26 590 647	759 733

4.2.3 Type of R&D

The science councils were originally established to undertake problem-driven and applied research. They were always regarded as augmenting and complementing the basic research being undertaken at universities and technikons. There was an emphasis on developing new technological applications, sometimes for very specific sectors, such as mining, agriculture and defence. According to the evidence presented in the previous section, the research programmes of scientists at universities and technikons have, over the past decade, become more applied and development-oriented. The main reason has been the cutbacks in traditional sources of R&D funding and the resultant need to procure funds from business and industry. Together with these changes in the HES, similar cutbacks in government funding to the science councils have resulted in the increasing commercialisation of research in that sector too.

Against this background, it is not surprising that most of the research programmes of the science councils are classified as either applied or development research. Even in cases when a programme was classified as directed towards basic research, it was almost always further specified as belonging to the category of "strategic research". The only significant exception is the substantive amount of basic research being done within MRC programmes. We would contend that the primary reason for this is that they are based within university departments and centres.

Figure 4.4: Type of R&D by Science Council: 1995/96



(Note: The profiles for Mintek, the HSRC and the Council for Geoscience are derived from project descriptions and output information. No primary data were collected for these categories.)

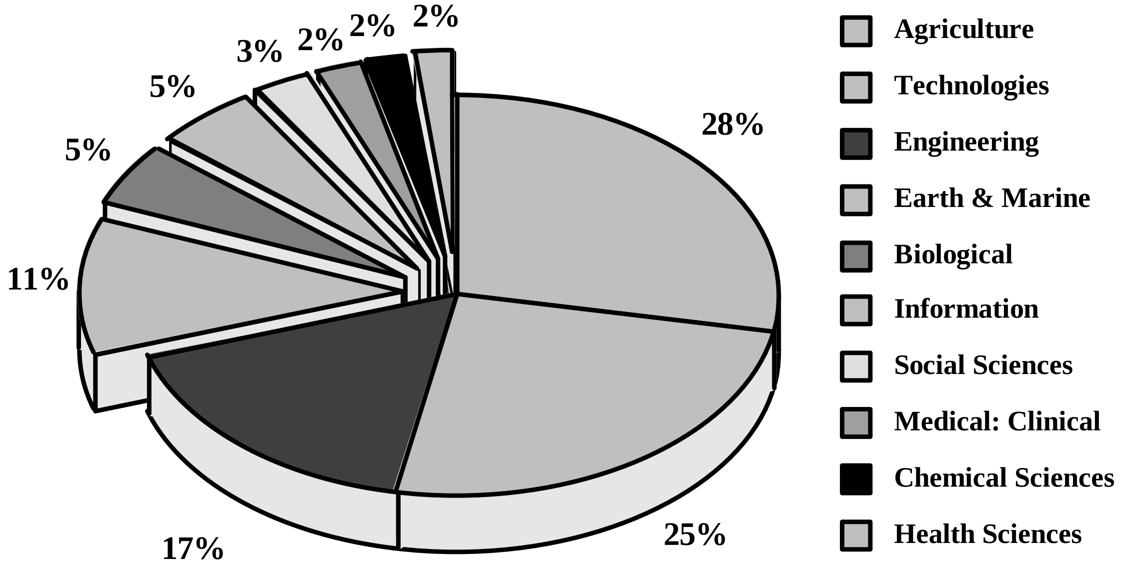
4.2.4 Expenditure on R&D

The total R&D expenditure by the science councils in 1995 amounted to approximately R890 million. The biggest portion (54%) was devoted to salary costs, followed by operational costs (28%), overheads (17%) and the replacement of capital (1%). (We suspect that the estimate for capital expenditure is too low, one reason being that the information was provided by programme managers, who might not be fully informed of such expenditure.) The more detailed breakdown by organisation is presented in Table 4.12 below, while Fig. 4.5 presents a breakdown of total expenditure by main science field for the top ten fields.

Table 4.12: Expenditure and HR, by science council: 1995/96

Organisation	Programme/institute	Scientists per programme	Scientists/ researchers	Total expenditure (R000) R
ARC	21	33	701	272 075
CSIR	58	19	1099	419 388
FRD	6	14	87	47 557
Geoscience	5	21	106	28 403
HSRC	30	6	178	30 702
MINTEK	6	51	307	67 794
MRC	35	9	309	26 590

Figure 4.5: Expenditure by main scientific field (science councils): 1995/96



It is clear from Fig. 4.5 that three areas of scientific research and development – namely, agriculture, technologies and engineering – dominate the research portfolio within the science councils. More than two-thirds of all R&D expenditure is devoted to these areas.

4.2.5 R&D output

Similar categories to those applied in the HES were used to measure output in the survey of the science councils. A summary of the most salient results is presented in Table 4.13.

Table 4.13: Research output, by science council: 1995/96

Organisation	Scientists	Publications	Per capita	Reports	Per capita	Confer-ences	Per capita
ARC	701	513	0.73	1243	1.77	710	1.01
CSIR	1099	388	0.35	6248	5.69	513	0.47
FRD	87	212	2.44	17	0.20	138	1.59
Geoscience	106	92	0.87	162	1.53	55	0.52
HSRC	169	51	0.30	135	0.80	61	0.36
Mintek	307*	57	0.19	562	1.83	26	0.08
MRC	280	360	1.29	22	0.08	412	1.47
TOTAL	2749	1673	0.77	8389	1.49	1915	0.69

* The figure of 307 was extracted from the 1995/96 annual report. It might, however, over-estimate the true number of researchers/scientists at Mintek, which would in turn affect the values of per capita output.

The most salient issues are the following:

?? With the exception of the MRC and the FRD, the output of scientific publications is fewer than one per researcher. Conversely, the output of contract and unrefereed reports is high for most of the science councils, the exceptions being the FRD, HSRC and MRC. The per capita output of conference papers is highest for the MRC and FRD.

?? In terms of overall "productivity" (calculated by totalling the scores for all three measures of productivity), one would rank the science councils as follows:
   ?? CSIR (6.51)
   ?? FRD (4.23)
   ?? ARC (3.51)
   ?? Council for Geoscience (2.92)
   ?? MRC (2.84)
   ?? MINTEK (2.10)
   ?? HSRC (1.46)

?? If one bears in mind that the average per capita output in the HES is 5.00 per researcher, this would suggest that "productivity" in the science council sector (average = 4.36) ranges from good at the CSIR and FRD to very poor at Mintek and the HSRC. One should, furthermore, bear keep in mind that university or technikon researchers each supervise an average of 3.2 masters and 0.96 doctoral students per year.

- ?? There are distinct differences between the MRC and FRD's national facilities on the one hand and the other science councils on the other. It is clear from these figures, as well as other information, that the MRC programmes (many of which are based at universities and the programmes of the three national facilities) are similar in a number of ways to typical university research programmes (for example, more basic research, higher output of scientific publications, lower output of unrefereed reports and technologies), whereas the other science councils manifest most of the features of Mode 2 knowledge production, namely, application-driven research, emphasis on contract and commissioned research and less emphasis on typical "academic" ventures such as scientific publications and conference papers.

Table 4.14 summarises the available information on technologies and patents by science council. (No information was available for Mintek and the Council for Geoscience.)

Table 4.14: Technologies and patents, by science council: 1995/96

Organisation	Scientists	Technologies	Per capita	Patents
ARC	701	135	0.19	31
CSIR	1099	320	0.29	52
FRD	87	1	0.01	0
Geoscience	106	5	0.05	0
HSRC	169	162	0.96	0
Mintek	307	n/a		4
MRC	280	n/a		0
	2749	623	0.19	87

A more detailed analysis of the ARC and the HSRC output in this category shows the following:

- ?? ARC: Approximately half of the technologies are information technologies (databases, directories, GIS applications), a quarter are new cultivars, and the remainder include new vaccines and specifications.

- ?? HSRC: More than 80% of the "technologies" produced are item banks (131) for edumetric purposes. The remainder are databases, directories, training manuals and psychological tests.

Table 4.15 summarises technological output by division of the CSIR.

Typical product technologies are:

?? Microwave heating technology

?? Vacuum filling machines

?? Low cost firebricks

?? Ground vibration test system

?? Missile approach warning system

?? Composite wheel technology

?? Instant hot-water heater

?? Low-splitting *Eucalyptus grandis* clones

?? Cement-bonded composite panels

?? New mosquito repellent

?? Novel fish and food products

?? HA-coated dental implants

Table 4.15 Technological output of the CSIR, by division: 1995/96

Division	Product technology	Process technology	Support technology	Information technology	Patents
Aerotek	27	28	0	4	5
Boutek	4	2	0	0	0
Environmentek	27	31	4	16	12
Foodtek	9	20	1	0	2
Mattek	12	25	4	0	14
Mikomtek	13	5	1	4	14
Miningtek	4	4	0	1	3
Textek	6	7	4	3	2
Transportek	16	15	9	14	0

Typical process technologies are:

?? Plastic injection mould design

?? Flutter analysis

?? Wind-tunnel test

?? Infrared missile protection technology

?? Industry competitiveness analysis methodology

?? On-line optimal measurement technology

?? Water stabilisation technologies

?? Fine chemical manufacturing process for a veterinary drug

?? Novel seed breeding analytical technique

?? Heat treatment technology

?? Automatic compass calibration algorithms

?? Regional geomagnetic-field modelling techniques

Examples of information technologies listed are:

?? Neural networks

?? Operational performance management systems

?? Decision support systems

?? Database project to facilitate community information flow

?? Process learning tools for a distance learning environment

?? Kiosk system for communities

?? Ingest archival and catalogue system and project management

Patents registered include:

?? Microwave heating

?? Composite wheel design

?? Instant hot-water system

?? Side stream patent

?? Appetite suppressant

?? Antioxidant No 457528

?? Morpholine. Novel sorbates and their use as corrosion inhibitors

?? Optical communications system

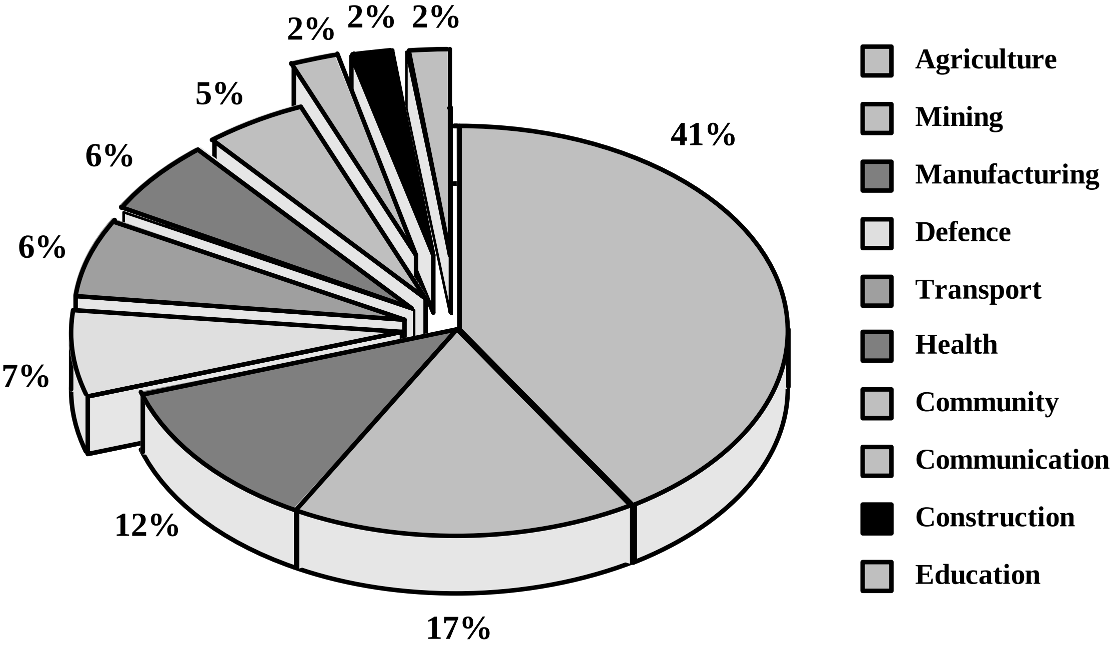
?? Data transmission systems

?? Filtering direct sequence spread spectrum

4.2.6 R&D expenditure, by sector of application

The dominance of the ARC, CSIR and, to a lesser extent, Mintek, in the science council sector is clearly demonstrated in Fig. 4.6. Approximately 70% of all R&D being undertaken at science councils is aimed at applications and technologies within the agricultural, mining and manufacturing sector. Similarly, expenditure on health, education and community services together constitute a mere 13% of R&D expenditure. Other GEAR priorities, such as housing and energy, receive equally little attention. This distribution of R&D expenditure clearly reflects (i) the priorities of a developing country (with an emphasis on agriculture and mining) and (ii) the historically determined socio-economic priorities.

Figure: 4.6: R&D expenditure by sector of application: 1995/96



4.2.7 Summary

In conclusion, the following main issues emerged from our analysis of the science council sector:

?? With a total R&D expenditure of approximately R890 million, the science council sector constitutes the second largest sector (after the business sector) as far as R&D investment and production are concerned.

?? There are significant differences in the profiles of the various science councils that reflect differences in research management styles, size of the organisation, stakeholder needs and long-term R&D objectives. On the one hand, we find that the R&D profiles of the programmes of the MRC and the three FRD national facilities (the National Accelerator Centre, South African Astronomical Observatory and Hartebeesthoek Radio Astronomy Observatory) are in many respects akin to the typical research profiles of university programmes (Mode 1 knowledge production). On the other hand, we find that science councils such as the CSIR, Mintek, ARC and the Council for Geoscience (and, to a lesser extent, the HSRC) have gone through a clear paradigm shift in their thinking: R&D production at these institutions is driven by stakeholder needs and the commercial and technological demands of business and industry, rather than internal research priorities. This distinction is not a hard and fast one because many of the programmes operated by the MRC, as well as the NAC, have been re-orientated to address the needs of communities and other stakeholders. However, it does show that the programmes undertaken by science councils span the whole spectrum from traditional Mode 1 to more application-driven Mode 2 types of R&D.

?? The notion of "research productivity" is not an unproblematic one. A comparison of the science councils using a set of indicators of output reveals fairly large differences. Further analysis of each programme is likely also to show that programmes differ substantially in terms of output. The relatively poor performance of the HSRC could be attributed to the major organisational changes that have occurred in the organisation over the past three years. Its commitment to an affirmative action policy and the appointment of young black scholars will undoubtedly also have to be taken into account in a more comprehensive assessment. A more detailed assessment of the "productivity" of a science council will have to take contextual features (for example, history, technology output, human resources profile, client base, stakeholder needs) into account.

?? The analysis of R&D investment by sector of application clearly shows that the research objectives of the science councils still, to a large extent, reflect the national socio-economic goals of the past decades. There is an urgent need for the science councils to re-align their R&D objectives to ensure that they meet the socio-economic priorities (for example, health, housing, security, energy, telecommunications) as exemplified in the GEAR framework.

4.3 Government departments and museums

4.3.1 Database

Data were collected from all government departments and museums selected for inclusion in the audit by means of interviews and questionnaires. Eventually, information on a total of 24 departments and museums were captured. Our assessment is that the coverage of the museums is good, but that the information on government departments probably represents only between 75% and 80% of all R&D investment. Information from some significant players in the government sector (for example, the departments of Health and Trade and Industry) was unavailable.

4.3.2 Project/programme profile

The database contains information on 31 programmes with a total R&D expenditure of R136 million. A detailed listing of programmes by department and organisation is presented in Table 4.16. With the exception of a few museum programmes which are directed at community and educational services, as well as the work of the South African Law Commission, the South African Police Service and the Africa Institute, most of the programmes focus on areas in agriculture, food production, conservation and other applied natural science fields.

Table 4.16: Programmes/focus areas, by organisation (government): 1995/96

Organisation	Programme/focus area
Africa Institute	African studies
Albany Museum	Entomology, earth and freshwater sciences
Department of Agriculture, North-West Province	Optimal use of agricultural technology in a sustainable manner in the North-West Province
Department of Agriculture, Western Cape	Agricultural economics
Department of Agriculture, Western Cape	Animal production
Department of Agriculture, Western Cape	Sustainable natural resource utilisation
Department of Agriculture, Western Cape	Crop development
Department of Agriculture, Western Cape	Crop protection
Department of Agriculture, Western Cape	Crop science
Department of Agriculture, Conservation and Environment, Gauteng	Ecology
Industrial Development Corporation of South Africa	Economic development.
JLB Smith Institute of Ichthyology	Ichthyology
Department of Agriculture, KwaZulu-Natal	Animal production (grassland science and animal science)

Department of Agriculture, KwaZulu-Natal,	Resource utilisation
Department of Agriculture, KwaZulu-Natal	Crop production
Department of Agriculture, Mpumalanga	Agriculture
Natal Museum	Molluscan research (malacology), invertebrate research (entomology, myriapodology and oligochaetology), archaeology research, historical anthropology research
Natal Parks Board	Conservation and sustainable use of biodiversity.
National Botanical Institute	Plant systematics, ecology and conservation biology
National Cultural History Museum	Cultural resource management
National Museum	Humanities, Biodiversity
National Parks Board	Conservation research
National Productivity Institute	Economic, educational and training research
Sea Fisheries Research Institute	Sea fisheries research
South African Cultural History Museum	Cultural history, Egyptology, women's studies, archaeology
South African Law Commission	All branches of the law of South Africa
South African Museum	Earth sciences, life sciences, human sciences
South African National Museum of Military History	South African military history from 1652 to the present
South African Police Service	Environmental scan and media analysis
Transvaal Museum	Programmes in birds, mammology, herpetology, paleaontology, paleo-environmental studies, archeo-zoology, collioeptera, lepidoptera, entomology, invertebrates
Weather Bureau	Meteorological research

4.3.3 R&D expenditure and sources of funding

As one would expect, the largest proportion of funding for government departments and museums comes from the government, either directly through baseline funding or indirectly though agency funding. Of the total budget of R135 million, 94% is comes from government (Table 4.17).

Table 4.17: Sources of funding by department/institution (government): 1995/96

Department / institution	(Own institution) R	Agency funding# R	Other external* R	Total funding R
Africa Institute	600 000	0	0	600 000
Albany Museum	14 400	159 600	119 258	293 258
Department of Agriculture, North-West Province	3 546 184	0	0	3 546 184
Department of Agriculture, Western Cape	13 669 755	0	210 200	13 879 955
Department of Agriculture, Conservation and Environment, Gauteng	1 332 000	0	6 000	1 338 000
IDC	10 000 000	0	0	10 000 000
JLB Smith Institute of Ichthyology	1 868 765	129 458	84 813	2 083 036
Department of Agriculture, KwaZulu-Natal	14 121 331	0	0	14 121 331
Department of Agriculture, Mpumalanga	10 620 000	0	0	10 620 000
Natal Museum	1 076 000	92 000	55 000	1 223 000
Natal Parks Board	1 743 000	0	0	1 743 000

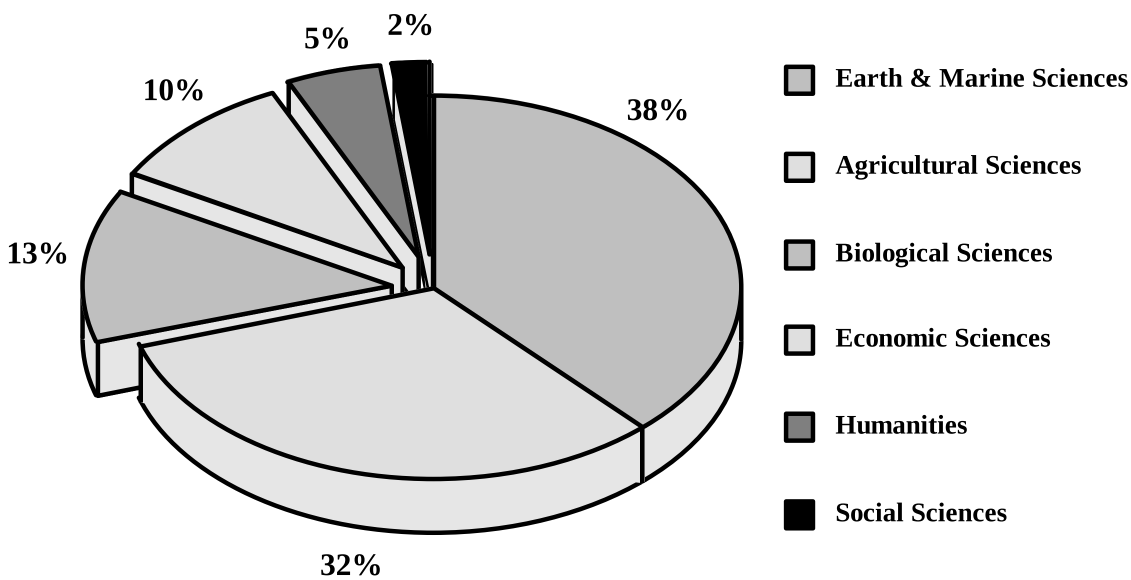
National Botanical Institute	11 100 000	0	100 000	11 200 000
National Cultural History Museum	1 489 562	18 000	37 000	1 544 562
National Museum	1 524 152	27 600	238 477	1 790 229
National Parks Board	5 900 000	0	0	5 900 000
National Productivity Institute	2 991 000	0	0	2 991 000
Sea Fisheries Research Institute	25 763 000	0	7 317 608	33 080 608
South African Cultural History Museum	106 520	4 000	15 000	125 520
South African Law Commission	5 236 000	0	0	5 236 000
South African Museum	1 688 417	328 805	50 000	2 067 222
South African National Museum of Military History	788 700	0	0	788 700
South African Police Service	2 084 236	0	0	2 084 236
Transvaal Museum	1 649 197	234 527	30 000	1 913 724
Weather Bureau	6 692 000	1 000 000	0	7 692 000
TOTAL	**125 604 219**	**1 993 990**	**8 263 356**	**135 862 550**

Includes funding from the FRD, the Cooperative Scientific Division of the HSRC and the Water Research Commission

* Includes funding from the business/private sector, as well as funding from abroad.

The strong focus on applied natural sciences is clearly illustrated by the profile of R&D expenditure by main scientific field (Fig. 4.7). More than 70% of all expenditure is allocated to agricultural and earth and marine research.

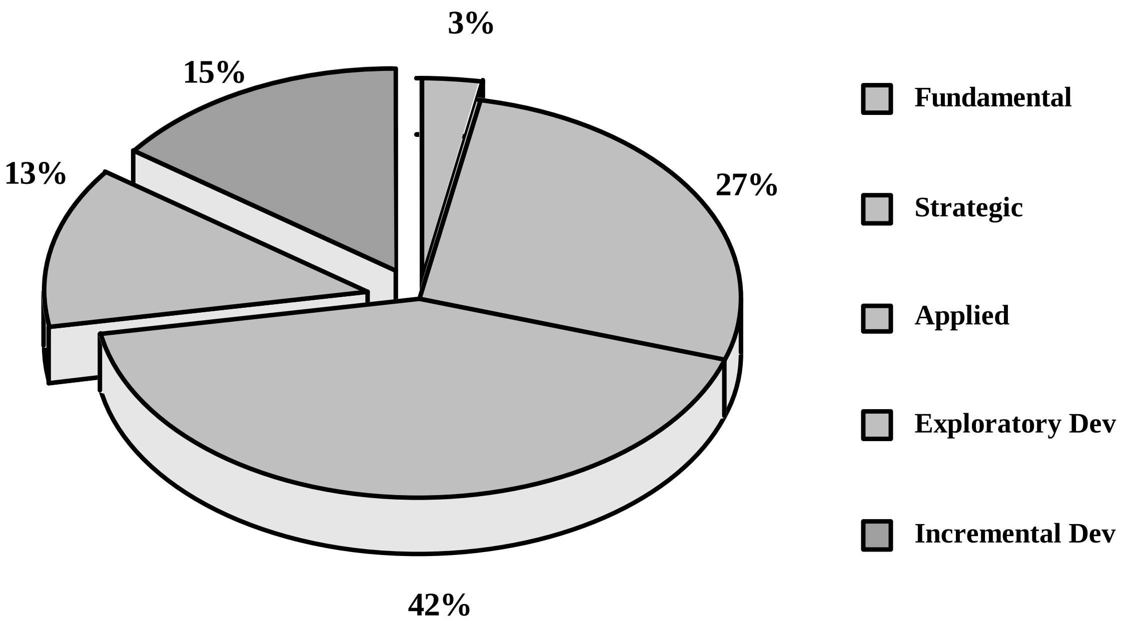
Figure: 4.7: Expenditure by main scientific field (government): 1995/96



4.3.4 Type of R&D

As one would expect, most R&D in government departments is be of an applied or developmental nature. This is in fact the case (Fig. 4.8). A significant proportion (27%) of "strategic research" is, however, being undertaken. Further analysis reveals that this is mostly being done at museums (especially the JLB Smith of Ichthyology and the Transvaal Museum) and a few government departments (the South African Police Service and the South African Law Commission).

Figure 4.8: Type of R&D (government): 1995/96



4.3.5 R&D output

A total of 452 scientists were included in our survey of the government sector. These scientists produced 640 scientific publications, 480 unrefereed reports, 438 conference presentations and 30 technologies and patents during 1995. Table 4.18 presents a summary of these outputs by main scientific field.

Table 4.18: Output by main scientific field (government): 1995/96

Main scientific field	Scientists	Scientific publications	Unrefereed publications	Conference papers	Techno-logies
Biological sciences	130 (29 %)	276 (43 %)	133 (28 %)	201 (46 %)	0 (0 %)
Earth & marine sciences	126 (28 %)	186 (29 %)	91 (19 %)	80 (18 %)	10 (35 %)
Agricultural sciences	121 (27 %)	132 (20 %)	196 (41 %)	108 (25 %)	17 (59 %)
Humanities	43 (9 %)	23 (4 %)	49 (10 %)	18 (4 %)	1 (3 %)
Social sciences	6 (1 %)	15 (3 %)	3 (0 %)	18 (4 %)	0 (0 %)
Economic sciences	26 (6 %)	8 (1 %)	8 (2 %)	13 (3 %)	1 (3 %)
TOTAL	**452**	**640**	**480**	**438**	**29**
Per capita		**1.42**	**1.06**	**0.97**	**0.06**

The output mirrors R&D expenditure, with most output produced in the biological, earth and marine, and agricultural sciences. The per capita output for each category reinforces the fact that a significant proportion of basic (strategic) research is being undertaken in the government sector (especially in the museums). The fact that there is not a big difference in production between scientific publications and unrefereed reports would suggest that there is less of a commercial and contract research culture in the departments and museums surveyed.

The total per capita output (excluding technologies) amounts to 3.45 units per scientist. This does not compare well with the HES (5.00) or the science council (4.36) averages.

4.3.6 Expenditure, by sector of application

Figure: 4.9: Expenditure by sector of application: 1995/96

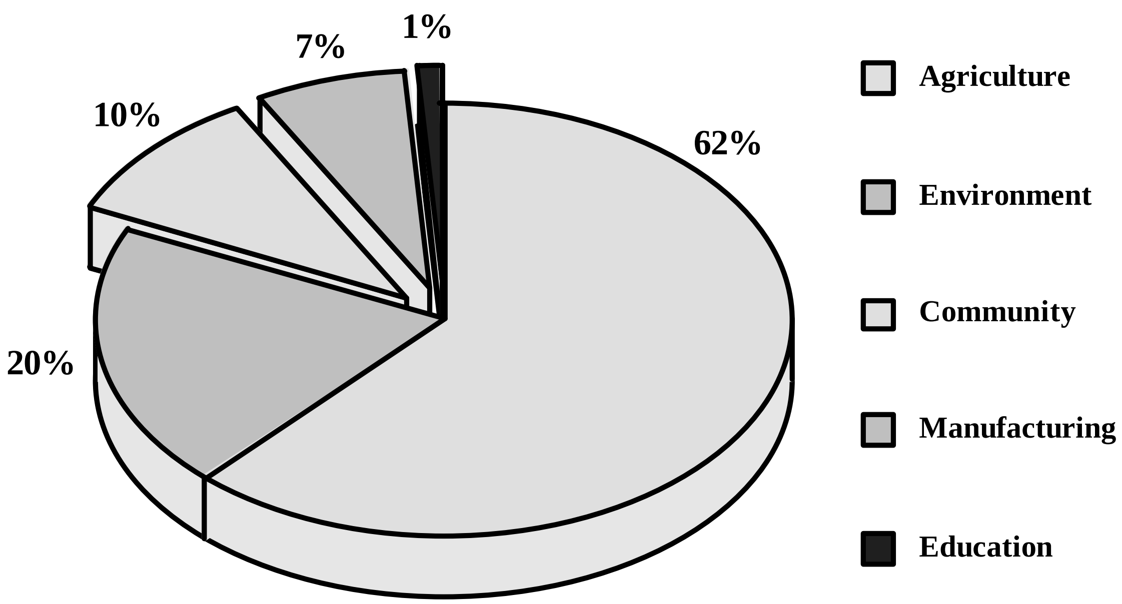


Figure 4.9 clearly shows how R&D in the government sector is focused on agricultural and environmental applications (82%) with fairly insignificant investment in education and community applications (11%).

4.3.7 Summary

?? The government departments included in this component of the survey are primarily involved in applied agricultural, environmental and conservation research. Small pockets of socio-economic research were encountered, but these constitute less than 15% of investment in R&D in this section. Although this profile is undoubtedly due to the over-representation of departments of agriculture in the survey, it still gives an indication of government priorities as far as in-house departmental research is concerned.

?? The R&D being undertaken at the eight museums surveyed manifests a different profile. There is a significant emphasis on strategic research (27%), and the research portfolio covers a number of applied natural science disciplines (entomology, earth and marine science, botany, ecology and conservation research). Both through our data collection and through impressions gained during personal interviews, it became clear that the research culture within the museums and related institutions (JLB Smith Institute of Ichthyology, National Botanical Institute) is more "academic" in nature than the typical application-driven and policy-oriented research evident in government departments.

?? Research productivity across institutions within the government sector is "poor" (3.45) when compared to the science council sector. Further subgroup analysis reveals, however, a big difference between the average output within government departments (2.89) and museums (4.17). The latter statistic puts the museum R&D production on a par with the university and science council sectors.

4.4 Business and industry

4.4.1 Database

AMI surveyed a total of 319 large companies (including 12 public corporations) within the business sector. Their estimate is that these companies cover approximately 35% of total sales output in technology-driven sectors of the South African economy. The SSRD was asked to survey a number of "industry-based organisations” that were not covered by the business survey. Seven organisations were eventually identified as part of this coverage. A complete list of the AMI companies and their main product lines is included in the report on the survey of the business sector. The seven industry-based organisations and their main R&D programmes are listed in Table 4.19.

Table 4.19: Programmes/focus areas of organisations, by main scientific field (industry): 1995/96

Main scientific field	**Organisation**	**Programme/focus area**
Agricultural sciences	South African Sugar Association Experiment Station	Harvesting, transport and irrigation, information transfer, improved productivity, pest and disease monitoring and control, variety improvement using conventional breeding and biotechnology-based techniques
Agricultural sciences	Institute for Commercial Forestry Research	Forestry research
Agricultural sciences	Sugar Milling Research Institute	Sugar milling and refining process improvement
Earth & marine sciences	Oceanographic Research Institute	Marine science and conservation
Health sciences	Epidemiology Research Unit	Occupational health
Medical sciences: basic	South African Institute for Medical Research	Medical research
Technologies and applied sciences	LIRI Technologies	Industrial effluent treatment, Science and technology Education, Preservation of animal hides and skins, Optimisation of the carbon dioxide deliming of hides and skins during leather manufacture

4.4.2 R&D expenditure

A total of R1.4 billion was expended on R&D by the 319 companies surveyed by AMI. If this amount is generalised to the total target population, the estimated total R&D expenditure amounts to R3.2 billion. The total R&D expended by the seven industry-based organisations adds up to R51 million, which should be added to these estimates.

Figure 4.10 presents a breakdown of R&D expenditure by industry sector for the 319 companies surveyed by AMI. A similar breakdown by main sector of application for the industry-based organisations is presented in Fig. 4.11.

Figure: 4.10: Expenditure by Sector (business): 1995/96

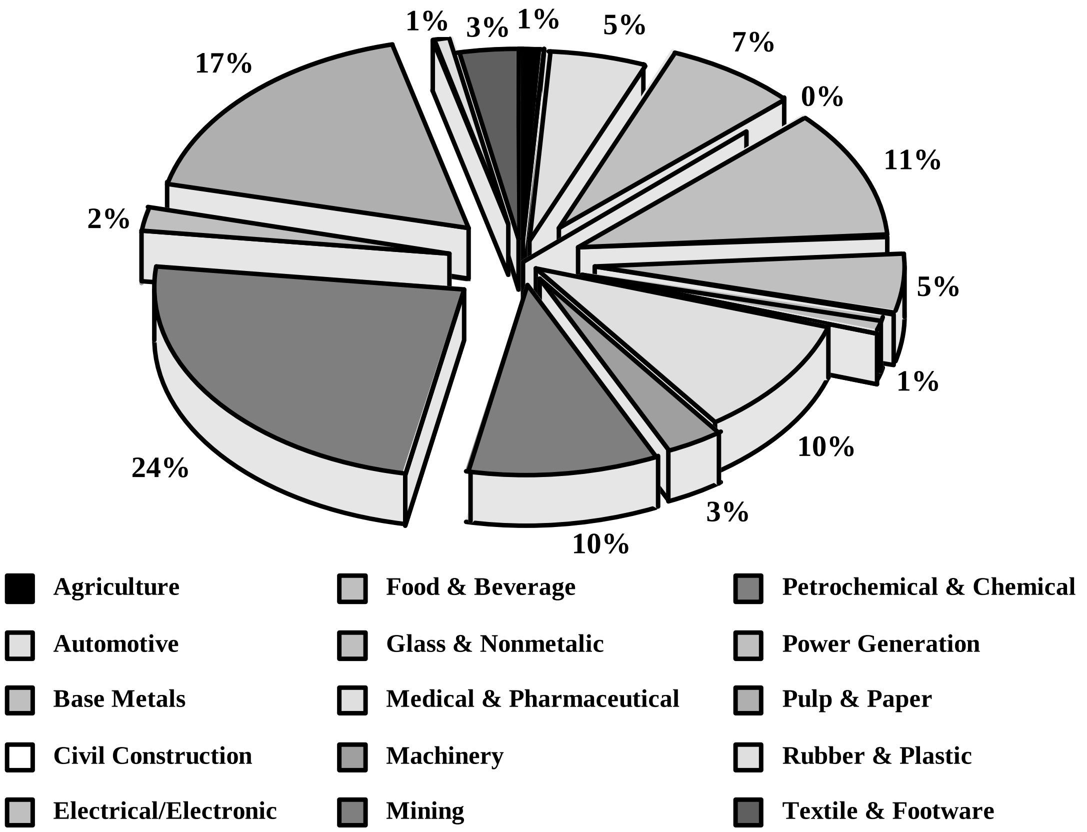
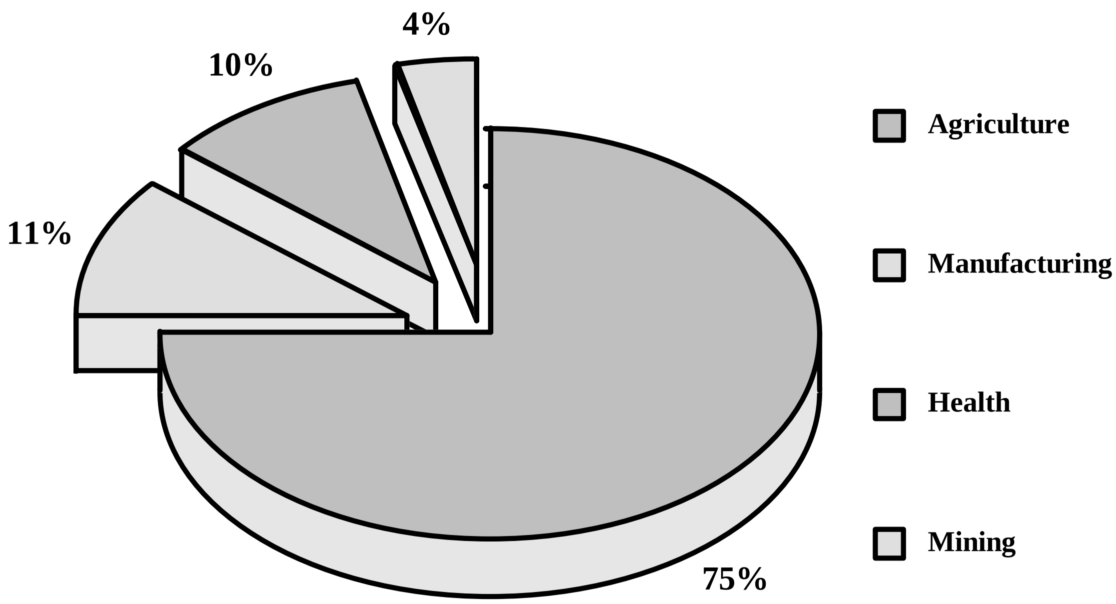


Figure: 4.11: Expenditure by sector (industry-based organisations): 1995/96



4.4.3 R&D output

In their survey of business companies, AMI distinguished between the following broad categories of output: academic type outputs (international and local journal articles), commercial outputs (trade articles, commercial books and conference papers) and patents. As is evident from Fig. 4.12, the largest category of outputs is of a commercial nature (48%, or 712 units), followed by academic output types (32%, or 468 units) and commercial patents (20%, or 298 individual patents). The fact that most publications are of a commercial nature, as well as the large proportion of patents, is not surprising. The substantial number of publications of an academic nature is somewhat surprising, however.

Figure: 4.12: Number of outputs by output category: 1995/96

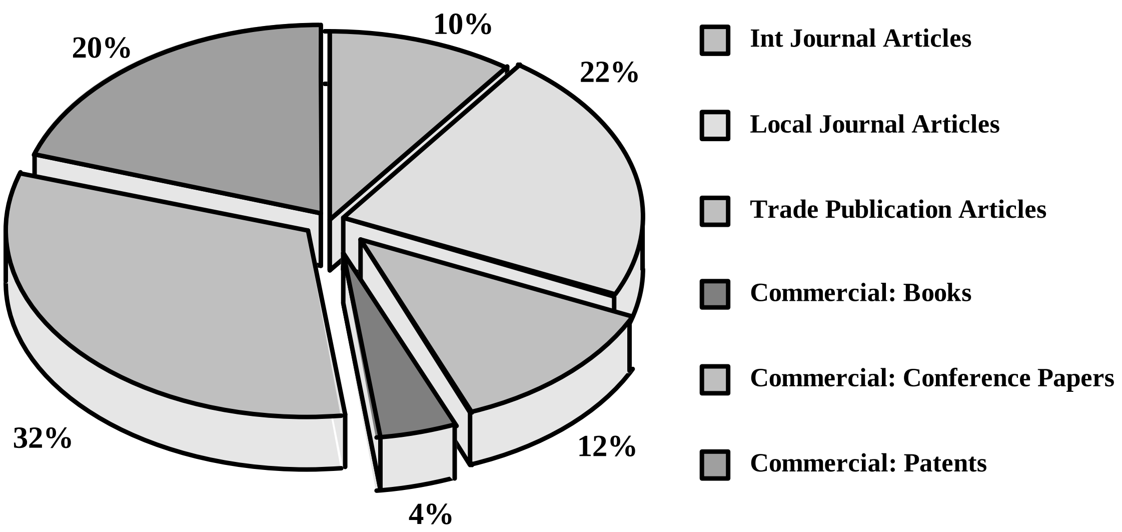


Figure 4.13 presents a breakdown of these three main categories (academic, commercial and patents) by industry sector and clearly shows different profiles, especially if one focuses on the proportion of academic: commercial publications. In sectors such as textile and clothing, rubber and plastics, medical and pharmaceutical, electrical and electronical, civil and construction and agriculture, more than 40% of all output was classified as academic. The figure also shows that sectors such as automotive and engineering, pulp and paper, petrochemical and chemical, and metal and machinery produced the highest proportion of patents compared with other types of output. [Note: One should bear in mind, however, that these outputs represent unweighted data that do not correct for any skewness in the sample].

Figure 4.13: Output categories by sector (business): 1995/96

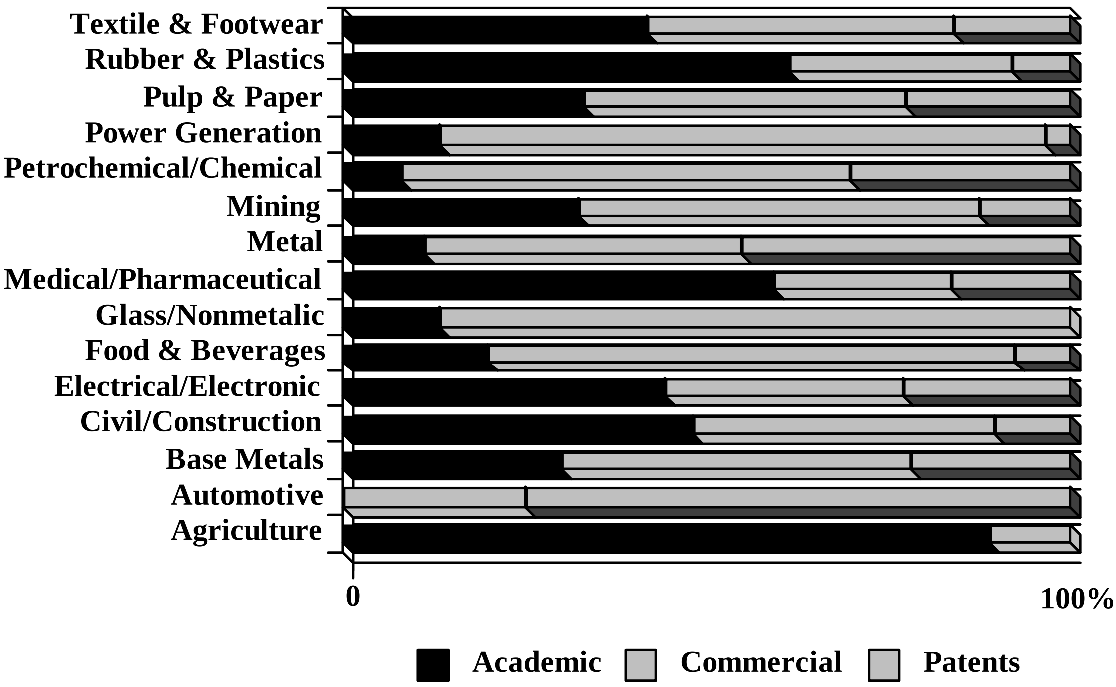


Table 4.20 summarises types of output for the seven industry-based organisations. The average per capita output of 3.1 scientific publications and papers is significantly less than the average for the HES (5.0), science councils (4.36) and museums (4.17) but higher than that of government departments (2.89). Because no data on the human resources involved in R&D for the business sector were available, a similar ratio could not be calculated.

Table 4.20: Output by main scientific field and human resources (industry): 1995/96

Scientific field	Scientists	Scientific publications	Unrefereed publications	Conference presentations	Per capita
Agricultural sciences	87 (54 %)	78 (30 %)	57 (43 %)	84 (75 %)	2.52
Medical sciences: basic	43 (26 %)	137 (53 %)	0 (0 %)	0 (0 %)	3.2
Technologies and applied sciences	14 (9 %)	10 (4 %)	49 (37 %)	7 (6 %)	4.7
Health sciences	4 (2 %)	20 (8 %)	6 (5 %)	4 (4 %)	7.5
Earth and marine sciences	14 (9 %)	14 (5 %)	20 (15 %)	17 (15 %)	3.6
TOTAL	**162**	**259**	**132**	**112**	**3.1**

4.5 Non-Government Organisations

4.5.1 Database

We conclude the overview of sectoral profiles with a brief discussion of the six NGOs surveyed. The database includes information on six of the fourteen NGOs approached as part of the survey.

4.5.2 Programmes and R&D expenditure

The six NGOs surveyed (CEPD, CPS, CASE, SAIRR, EDA and Western Cape Environmental Monitoring Group) employed 62 researchers and spent approximately R15 million on R&D in 1995. The breakdown per organisation is presented in Table 4.21.

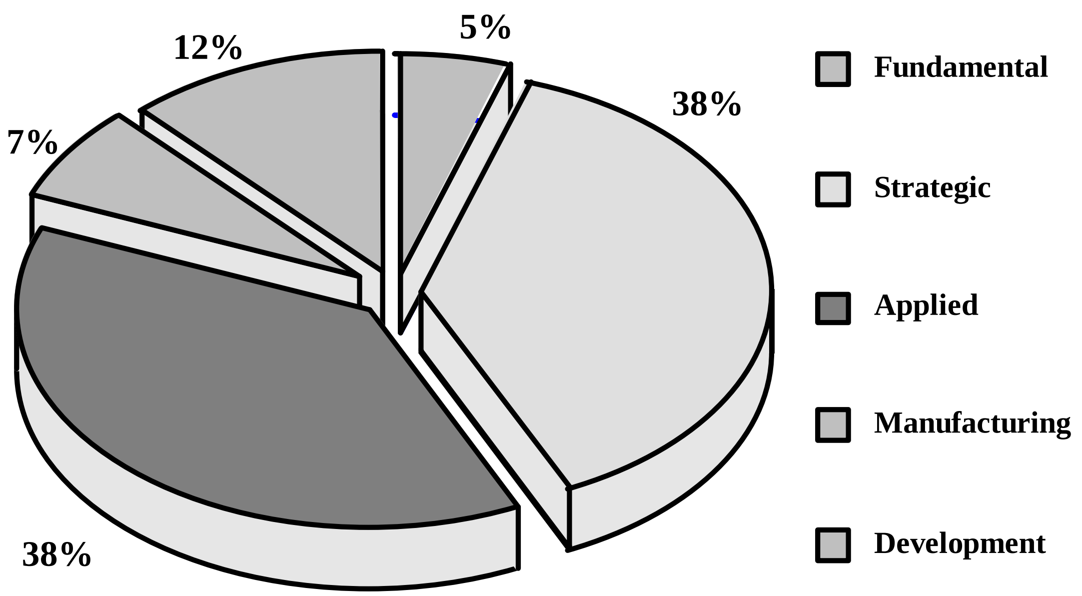
Table 4.21 Human resources and expenditure, by organisation (NGO): 1995/96

Organisation	Scientists	Expenditure R
Centre for Education Policy Development, Evaluation and Management	2	2 017 334
Centre for Policy Studies	13	1 370 782
Community Agency for Social Enquiry	25	5 908 504
Environment and Development Agency	3	538 961
South African Institute of Race Relations	12	4 105 977
Western Cape Environmental Monitoring Group	7	1 350 000
	62	15 291 558

4.5.3 Type of R&D

The biggest volume of research done by these NGOs is of an applied and developmental nature, although an equally significant component is devoted to strategic research. The latter can also be ascribed to the fact that some of the NGOs surveyed (for example, SAIRR and WCEMG) have strong links with universities or other academic institutions.

Figure 4.14: Type of R&D (NGOs): 1995/96



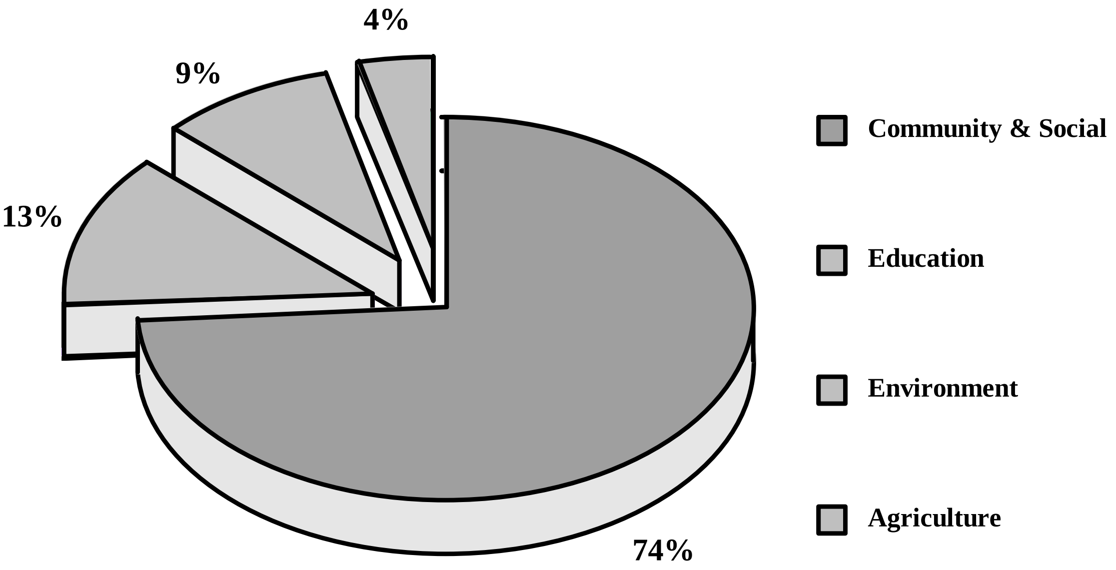
4.5.4 R&D output

All the R&D investment of these six NGOs falls within the field of the social and economic sciences. The 62 researchers surveyed produced a total of 52 scientific publications, 130 unrefereed reports and 69 conference papers. This constitutes an average output of 4.0, which compares favourably with most of the other sectors in the audit.

4.5.5 Expenditure by sector of application

As one would expect, most of the research finds application in the socio-economic and educational spheres. Figure 4.15 below presents the breakdown.

Figure: 4.15: Expenditure by sector of application (NGOs): 1995/96



This concludes our discussion of the NGO sector. The small sample of organisations surveyed does not constitute a sufficiently large base to enable us to draw any more general conclusions.

4.6 General conclusions

The following broad conclusions can be drawn on the basis of the sector overviews presented above:

?? The business and industrial sector dominates domestic investment in R&D (66%), followed by the science council sector (18%), higher education institutions (13%) and government (3%).

?? A wide variety of research cultures is represented in most of the sectors reviewed. Although the HES devotes the biggest proportion of its R&D to basic research, there are also clear signs of shifts towards more contract-based, application-driven research in most scientific fields. The science council sector clearly focuses on applied work, especially the development and improvement of technology, but there are a number of significant sites (MRC units, national facilities) where one finds a capacity in basic research, especially strategic research. The same varied picture is found within government, where more traditional Mode 1 knowledge production is a feature of most of the museums and institutes, for example, the Africa Institute. It appears to have become impossible to speak of clear divisions of labour or divides between sectors: there is no such thing as a monolithic research sector anymore. Research and development have become a fully distributed and interwoven industry.

?? The surface level picture that presents itself at first glance needs to be heavily qualified once one digs deeper. Historical factors (the establishment of the science councils, the legacy of apartheid as it impacts on the university and technikon system and contextual factors, such as changing socio-economic, environmental and global demands) all play a role in producing the specific mix of R&D present in South Africa. Further research is certainly needed to provide more context-specific profiles that will show how more exactly how these factors influence research productivity and output.

?? It is with some degree of caution that we compared "research productivity" across sectors. Using certain very rough indices of research "productivity", we were at least able to show how the main sectors compare with each other. In Table 4.22, we have calculated the following four measures:

?? Per capita output: The average number of scientific publications, unrefereed reports and conference papers per scientist

?? Average cost of technology: total R&D expenditure divided by the total number of patents produced in this sector

?? Average cost per technology: total R&D expenditure divided by the total number of technologies produced in the sector

?? Average cost per publication: total R&D expenditure divided by the total number of scientific publications, papers and reports

Table 4.22: A comparison of "R&D productivity" across sectors: 1995/96

Sector	Per capita output	Average cost per patent R	Average cost of technology output R	Average cost per publication R
HES	5.00	5 040 000	383 562	16 862
Science councils	4.36	10 258 735	1 432 600	74 520
Museums	4.17	None	None	35 803
NGOs	4.0	None	None	60 924
Industry-based organisations	3.1		2 217 391	102 392
Government departments	2.89	None	4 645 620	140 950

Business	n/a	4 697 986	n/a	947 225

This concludes our discussion of the results of the SSRD by sector. Chapter Five is devoted to an overview of the main findings across sectors, as well as comparing selected results with trends abroad.

Chapter Five

Comparative Findings

5.1 Introduction

The aim of the Survey on Scholarship, Research and Development has been to develop a fine-grained analysis of the South African S&T system at the level of research programmes and research fields. At the same time, the authors of the report have also set themselves the task of drawing conclusions about significant patterns and larger trends that are supported by the wealth of data collected.

The previous chapter presented and discussed the main findings of the survey by sector of performance. In Chapter Five, we compare significant findings across sectors, present certain international comparisons and draw more future-oriented conclusions.

The discussion is organised under the following headings:

?? Type of R&D
?? R&D expenditure
?? Human resources and R&D
?? Scholarship, R&D output
?? Conclusions

5.2 Type of R&D

In our discussion of type of R&D we address two issues: distribution across sectors and distribution across main scientific fields.

5.2.1 Type of R&D by performance sector

Table 5.1 summarises the overall distribution of results for the five category types of R&D for all sectors surveyed.

Table 5.1: Type of R&D by sector: 1995/96

Sector surveyed	Fundamental %	Strategic %	Applied %	Experimental development %	Incremental development %
Higher education	23	27	37	6	7
Science councils	2	22	38	17	21
Government & museums	3	26	41	14	16
NGOs (sample)	5	41	41	2	11
Industry-based organisations	7	35	37	9	12
TOTAL	**9**	**30**	**38**	**10**	**13**

The following points are worth noting:

?? The overall proportion of basic (fundamental and strategic) to applied and development (exploratory and incremental) research is 39:38:23. This proportion differs significantly between sectors:.

?? HES 50:37:13

?? SC 24:38:38

?? Government/museums 29:41:30

?? NGOs 46:41:13

?? Industry 42:37:21

?? As expected, the HES spends a larger proportion of its time on basic research (and almost equal amounts on fundamental and strategic research) than any other sector.

?? The HES also devotes – as has traditionally been the case – a significant proportion of time to fundamental research. None of the other sectors compare with this.

?? The science council sector recorded the highest proportion of time spent on development (38%). This is mainly due to the focus on technology development at the ARC, Mintek and the CSIR.

?? Perhaps surprisingly, the proportion of time spent on development within industry-based organisations is relatively low (21%).

If one combines the profiles of the science council and government sectors (to make comparison with previous R&D surveys possible), the following picture emerges:

Figure 5.1: Type of R&D for HES and Government: 1993–1995/6

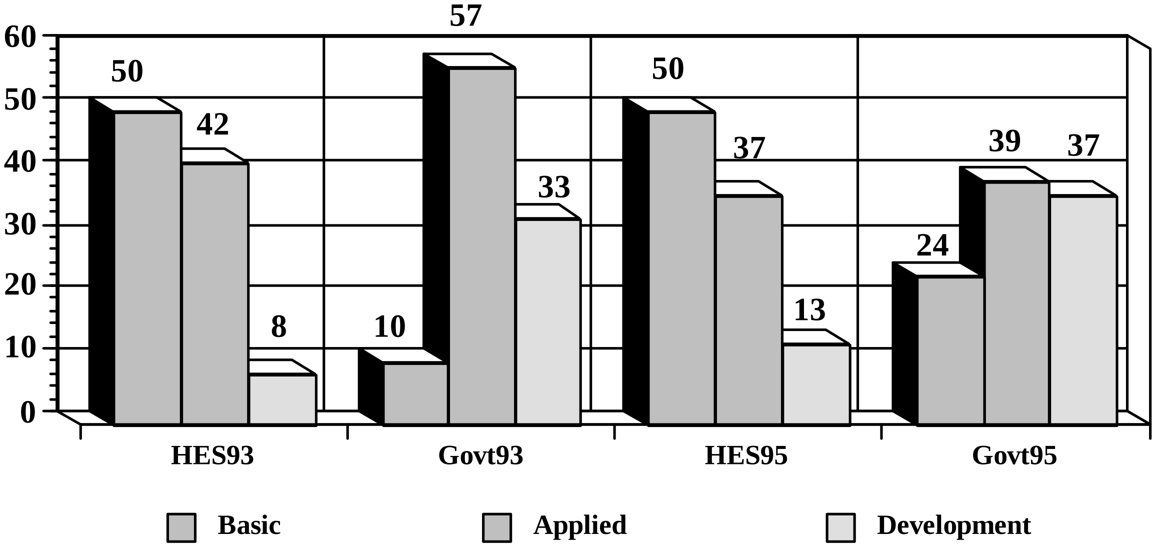


Figure 5.1 shows that:

?? The comparison over time shows a small but significant shift within the HES towards increased development-related work (from 8% to 13%).

?? The 1995/6 profile for the government sector looks quite different from that for 1993. The increase from 10% to 24% in basic research could perhaps best be explained by the inclusion of the category of "strategic research" under the heading of "basic research". This probably means that a significant proportion of what used to be classified as "applied research" has now been categorised as "strategic research". Secondly, the shift towards development work that is evident in the HES is repeated here in the government sector, although on a smaller scale.

The comparisons thus far have been based on the profiles of the sectors surveyed. Table 5.2 presents the same data from the perspective of "type of research" over the past five years. Column percentages of the amounts expended by the various sectors are included.

The salient findings are:

?? *Basic research:* There has been a steady decline in the proportion of basic research undertaken within the HES, with a concomitant increase in the amount of time spent on basic research (specifically, strategic research) within the government sector. In 1991, 75% of all basic research in the public sector (HES, government and science councils) was done at universities and technikons. This declined to 68% in 1993 and to 55% in 1995/1996.

Table 5.2: Type of R&D over time, by sector: 1991/92–1995/96

Type of R&D	Sector	1991/1992 (R 000)	Column %	1993/1994 (R 000)	Column %	1995/1996 (R 000)	Column %
Basic	HES	359 788	75	207 319	68	321 500	55
	Govern-ment	98 081	20	82 414	27	254 426	44
	NGO	19 747	5	15 162	15	7 034	1
	Subtotal	479 607	100	306 888	100	582 960	100
Applied	HES	273 757	38	172 351	26	237 921	38
	Govern-ment	384 481	56	464 640	71	381 640	61
	NGO	23 289	6	14 484	3	6 269	1
	Subtotal	681 527	100	651 475	100	625 830	100
Development	HES	56 895	17	35 978	12	83 594	19
	Govern-ment	269 966	82	263 564	87	352 283	80
	NGO	2 461	1	1 969	1	1 682	1
	Subtotal	329 322	100	301 511	100	437 559	100
TOTAL		**1 488 000**		**1 258 000**		**1 646 349**	

?? *Applied research:* The pattern with regard to applied research has remained more stable, with the HES contributing slightly more than a third and government just less than two-thirds.

?? *Development work:* The picture with regard to development work has also remained fairly constant over the past five years, with government performing more than 80% of all development work. At the same time, a significant proportion (20%) of this type of work is now done within the HES.

5.2.2 Conclusions

?? Although the HES spends the largest proportion (50%) of its direct costs on basic research, it is noteworthy that the larger part of this is devoted to strategic, rather than fundamental, research. This means that pure curiosity-driven research, or so-called blue-sky research, currently accounts for less than a quarter of all research within the HES and less than 5% of all R&D in the public sector.

?? The fact that the HES devotes such a large proportion of its resources to basic research makes it the biggest overall player in this category in the public sector. However, because of the large proportion of resources devoted to strategic research within the government sector (22%), the overall distribution of expenditure in the domain of basic research is now much more evenly balanced (55:44).

?? All performers in the public sector devote more than a third of their expenditure to applied research. The range is between 37% and 41%. As expected, the government sector (especially the science councils) produces the biggest chunk of applied research (61%), which is in line with their role as problem-oriented research institutions.

?? There has been an overall increase in expenditure devoted to development work. This is particularly true of the HES, where there was an increase of 4% between 1993 and 1995/1996. A comparable trend is evident in the government sector. Although these are not large percentages, they signify a shift to more development-oriented and technology-driven research.

5.2.3 Type of R&D by main scientific field

Because of different disciplinary histories, methodologies and traditions, the nature of scientific research and development differs quite considerably between main scientific fields. It is reasonable to expect the more "basic sciences" (for example, laboratory-based disciplines) to devote more time to fundamental and strategic research. Similarly, one would expect scientific fields which have developed to address particular applied problems and which tend to be context-bound (for example, agricultural sciences) to be inclined to focus more on applied research. Table 5.3 summarises these results. Data are presented both as column and row percentages. (For example, according to the column percentage, 10.4% of all basic research is done in the biological sciences, and according to the row percentage, 59% of all research in the biological sciences is classified as "basic research").

Table 5.3: Type of R&D by main scientific field (column and row percentages)

Main scientific field	Basic research %	Applied research %	Development %	Number of projects %
Agricultural sciences	3.2 37	6,3 52	3.7 11	263
Arts	1.9 64	1,0 24	1.3 12	87
Biological sciences	10.4 59	8,3 35	4.0 6	521
Chemical sciences	3.6 54	3,1 35	2.8 11	195
Earth and marine sciences	4.2	4,3	3.1	244

	52	39	9	
Economic sciences	3.4 42	4,7 41	5.2 17	251
Engineering sciences	3.8 30	6,6 43	13.8 27	386
Health sciences	0.8 27	2,2 59	1.6 14	85
Humanities	28.4 67	14,4 25	12.1 8	1256
Information and computer sciences	1.7 33	2,5 35	6.3 31	155
Mathematica l sciences	4.6 65	2,5 27	2.1 8	202
Medical sciences: basic	3.3 46	4,3 45	2.5 9	210
Medical sciences: clinical	3.7 30	8,6 52	8.1 18	363
Physical sciences	3.3 58	2,2 30	2.6 12	166
Social sciences	21.8 47	26,0 38	28.7 15	1500
Technologies and applied sci ences	0.8 28	2,0 49	2.6 12	87
TOTAL **Column percentage**	**3011** **50**	**2192** **37**	**768** **13**	**5971***

** The total number of projects adds up to 5 971, but only just over 4 200 unique projects are included in the database. This discrepancy is due to the fact that respondents could classify a project into more than one of these categories.*

Table 5.3 reveals that:

?? Ranked in descending order, the following five scientific fields devote more than 50% (the average) of their resources to basic research:

- Humanities (67%)
- Mathematics (65%)
- Arts (64%)
- Biological sciences (59%)
- Physical sciences (58%)
- Chemical sciences (54%)
- Earth and marine sciences (52%)

?? Ranked in descending order, the following five fields were rated highest on applied research:

- Health sciences (59%)
- Medical sciences: clinical (52%)
- Agricultural sciences (52%)
- Technologies and applied sciences (49%)
- Medical sciences: basic (45%)

?? Ranked in descending order, the following five fields scored highest on development work:

- Information and computer sciences (31%)
- Engineering sciences (27%)
- Medical sciences: clinical (18%)
- Economic sciences (17%)
- Social sciences (15%)

5.2.4 Summary and conclusions

?? The results are mostly in line with what we expected, with the "core disciplines" in the natural sciences, (such as mathematics, physics and chemistry) scoring high on basic research. Similarly, the humanities and arts, which have traditionally not rated high on applied and problem-solving research, scored high on basic research. Perhaps the least expected finding relates to the medical and health sciences, with the basic medical sciences scoring equally high on basic and applied research. This might suggest that the distinction between basic medical research and clinical medical research is itself problematic or that the actual boundaries between these types of research in the medical field are becoming increasingly blurred.

?? If one takes the view that most, if not all, scientific fields should have a strong grounding in basic research, at least within the HES, the relatively low ratings on basic research for the information and computer sciences, economic sciences, engineering sciences and even the social sciences are cause for concern.

?? As far as development work is concerned, fields such as engineering, information and computer sciences, and clinical medical sciences scored high rankings for applied research and technology-driven fields, as expected. The biggest surprise was the low percentage (12%) devoted to experimental work in the category of technologies and applied sciences. Equally surprising is the fact that the economic sciences and social sciences recorded significantly high proportions (17% and 15% respectively) for development work. One explanation could be (and this requires further analysis) that a fair amount of the research in these fields is aimed at developing and evaluating social programmes and policies that could be classified as development work.

5.3 R&D expenditure

The discussion on R&D expenditure that follows focuses on four issues:

- ?? Sources of funding by sector
- ?? Expenditure by sector
- ?? R&D expenditure over time
- ?? International comparisons

5.3.1 Sources of funding by sector

Table 5.4: Source of funding by performance sector: 1995/96

Sector	Internal funding R (000)	Government funding R (000)	Agency funding R (000)	External funding R (000)	Income (sales & services) R (000)	Total funding R (000)
Higher education	-	398 157 (GUF)	63 828	181 046	-	643 031
Science councils	-	488 218 (Baseline)	-	364 350	18 000	870 568
Government. & museums	-	125 604	1 994	8 263	-	135 861
NGOs (sample)	3 305	-	-	12 200	-	15 505
Industry-based organi-sations	38 085	-	1 985	11 313	10 976	62 359
TOTAL	**41 390 2.4%**	**1 011 979 58.5%**	**67 807 3.9%**	**577 172 33.4%**	**28 976 1.7%**	**1 727 324**

The salient findings include:

?? Government is the largest source of funding in the public sector. If one combines its direct and indirect contribution (agency funding), the amount totals more than 60% of all R&D expended.

?? Government also funds R&D indirectly through contracts awarded to science councils and universities. The amount of R577 million reflected under external funding includes both government contracts and private sector funding. Unfortunately, respondents in the science council sector (which makes the largest contribution to this amount) did not specify sources of external funding.

?? Previous R&D surveys (1991/1992 and 1993/1994) show that government's contribution to the public sector is very high (88% in 1991 and 90% in 1993) with the remainder coming from the private sector.

?? A rough estimate would be that government's contribution to R&D expenditure in the public sector is between 75% and 85%.

5.3.2 Expenditure by sector

Table 5.5: Expenditure by sector of application: 1995/96

Sector of Application	HES R (000)	Science councils R (000)	Government R (000)	NGOs R (000)	Industry R (000)	TOTAL R (000)	Column %
Agriculture	100 652	347 274	81 504	539	38 953	568 922	36.9
Mining & quarrying	26 177	146 439	0	0	0	172 616	11.2
Manu-facturing	57 224	96 209	10 000	0	5 606	169 039	11
Health	106 076	46 317	0	0	5 000	157 393	10.2
Commun-ity	65 127	39 373	13 039	11385	0	128 924	8.3
Education	75 064	15 402	592	2017	0	93 075	6
Defence	2 981	60 641	0	0	0	63 622	4
Transport	2 522	53 346	0	0	0	55 868	3.6
Communi-cation	12 461	15 692	0	0	0	28 153	1.8
Environ-ment	0	0	26 405	1350	0	27 755	1.8
Construc-tion	12 250	15 412	0	0	0	27 662	1.8
Energy	17 628	7 522	0	0	0	25 150	1.6
Financial	11 716	213	0	0	0	11 929	0.8
Wholesale trade		0	0	0	0	7 427	0.5
Private house-holds		0	0	0	0	3 441	0.2
Hospitality		0	0	0	0	1 234	0.1
	489 878	843 840	131 540	15 291	49 559	1 542 210	

The most salient issues are:

?? The most striking feature of Table 5.5 is the fact that more than half of public sector expenditure is directed at three sectors – agriculture, mining and quarrying, and manufacturing. This is due to the dominance of three large science councils (CSIR, ARC and Mintek) in this sector. Although this highly skewed picture has identifiable historical roots (the traditional importance afforded to the agricultural sector and the mining industry in the SA economy, for example), the result is proportionately low spending on areas that are high priorities in GEAR, such as health, community services, housing and energy.

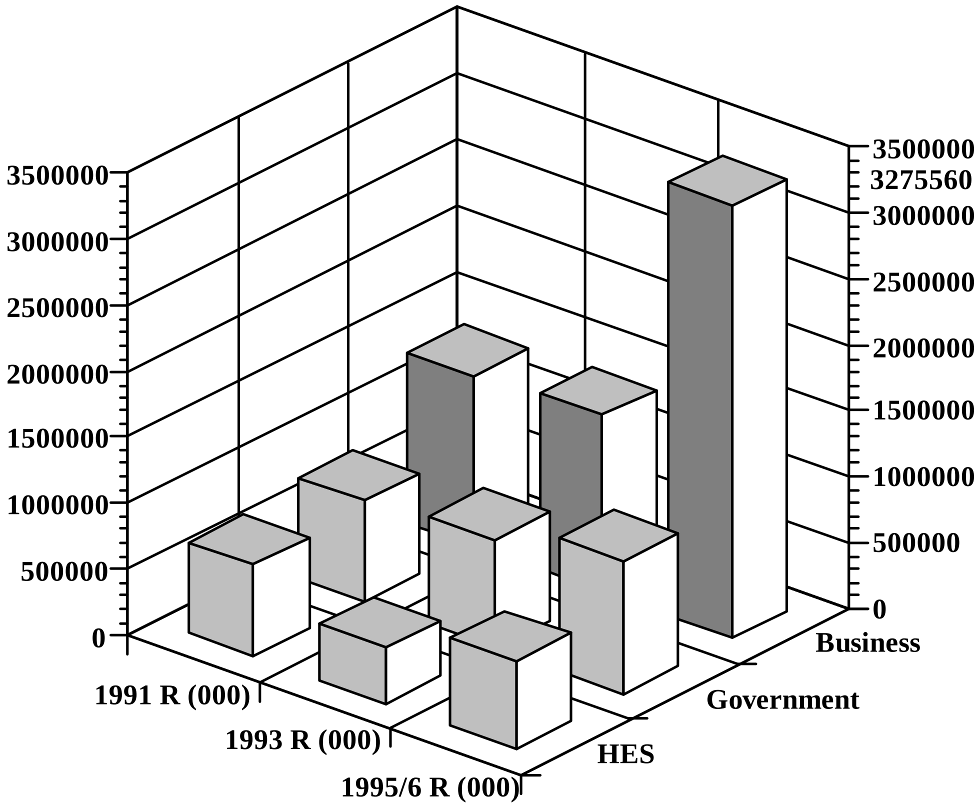
?? Although expenditure within the HES is slightly more evenly spread, with a greater emphasis on education and social services, there are also a number of areas that receive very little benefit from R&D, such as communication and information services, energy, the hospitality sector and tourism.

?? The overarching image that one is left with is that the priorities that were revealed in Table 5.5 express the socio-economic goals of the past and that a major reshaping is required to bring expenditure more in line with current and future national priorities.

5.3.3 R&D expenditure over time

Figure 5.2 below summarises the trends in R&D expenditure for the 1991/1992 and 1993/1994 R&D surveys in comparison with the NRTA results for 1995/1996.

Figure 5.2: Expenditure by sector: 1991–1995/6



	1991 R (000)	1993 R (000)	1995/6 R (000)
Business	1 298 000	1 336 000	3 275 560*
Government	755 000	811 000	1 005 290
HES	690 000	416 000	663 030

* Estimate may include innovation expenditure (ed.)

The salient issues are:

?? The longitudinal picture clearly shows that the results of the 1995/1996 survey are highly consistent with the 1991/1992 survey, especially if one accepts (as claimed by AMI) that the business sector was under-surveyed in previous surveys. It also reveals the deficiencies in the 1993/1994 survey. AMI estimates may include innovation expenditure [ed.]

?? The total estimated R&D expenditure of R4.9 billion in 1995/1996 constitutes 1.15% of gross domestic product (R430 billion). This finding is significant because it means that estimates of R&D expenditure that have been used in the past have grossly misrepresented the true state of affairs.

?? However, although the results show an increase in R&D expenditure over the past five years (as expressed as a percentage of GDP), one should be cautious to interpret this as proof of a real increase. It is much more likely that the figures cited for the business sector in previous R&D surveys always under-estimated true expenditure.

?? The fact that R&D expenditure amounts more than 1.0% of total GDP is a positive finding. Although it does not compare favourably with the proportionate expenditure of highly industrialised countries, such as Germany and the USA, it signifies a bigger national investment in and commitment to R&D than previously thought. The real challenge, of course, is to ensure that this expenditure is applied to meet the true needs of the South African society.

5.3.4 International comparisons

In order to provide an international comparison of R&D expenditure, Table 5.6 plots data from the SSRD against previous data for South Africa (1991/1992) and selected countries extracted from UNESCO's *1996 Statistical Yearbook*. Countries selected for this purpose include three of similar economic status to South Africa (upper-middle-income economies according to GNP figures provided by the World Bank), namely, the Czech Republic, Hungary and Mexico, as well as three high-income economies, namely, Australia, Germany and the USA.

In UNESCO's terms, t*otal R&D expenditure* comprises *current expenditure* (including overheads, labour and other current costs) and *capital expenditure*. *Sectors of performance* refer to the areas of the economy in which R&D work is performed. These include:

?? *Higher education sector*: Establishments of education at the third level as well as organisations such as the research institutes and experimental stations that serve them.

?? *General service sector*: Various public or government establishments that serve the community as a whole.

?? *Productive sector*: Domestic and foreign industrial and trading establishments that produce and distribute goods and services for sale.

For comparative purposes, we have included under the g*eneral service sector* those institutions and/or organisations included in the government and science council sectors covered by the SSRD. Data for the business sector, as provided by AMI, have been included in the *productive sector*.

Table 5.6: R&D expenditure by sector of performance: international comparisons: 1995/96

Country (Currency)	Year	Total Expenditure (R 000)		
		Higher education sector	General service sector	Productive sector #
South Africa (Rand)	1995/96	663 031 13.4 %	1.005.290 20.3 %	3 275 559 66.3 %
South Africa (Rand)	1991	690 439 24.8 %	798 025 28.6 %	1 297 622 46.6 %
Czech Republic (Koruna)	1994	580 000 4.5 %	3 704 000 28.5 %	8 699 000 67 %
Hungary (Forint)	1993	7 843 000 28 %	8 923 000 31.8 %	11 273 000 40.2 %
Mexico (Peso)	1993	1 485 696 41.7 %	1 794 274 50.3 %	286 188 8 %
Australia (Dollar)	1990	1 350 800 26.6 %	1 719 400 33.8 %	2 017 400 39.7 %
Germany (D.Mark)	1991	12 169 000 16.3 %	10 673 000 14.3 %	51 675 000 69.3 %
USA (Dollar)	1993	26 900 000 15.7 %	22 700 000 13.3 %	121 400 000 71 %

AMI estimates may include innovation expenditure

The salient issues are:

?? In comparing the 1995/1996 SSRD data with 1991/1992 data for South Africa, the significant increase (19.7 %) in productive (business) sector expenditure on R&D, and the concomitant decrease in the HES (11.4 %), is most noteworthy. Of the upper-middle-income economies listed, South Africa's business sector currently ranks alongside that of the Czech Republic as spending the largest proportion of national R&D funding (South Africa 66.3%, Czech Republic 67%). At the same time, both countries rank comparatively low in terms of the proportion of R&D expended within the HES (South Africa 13.4 %, Czech Republic 4.5 %).

?? In terms of the overall proportion of expenditure across sectors – from the HES to the general service (government) sector, to the productive (business) sector – the SSRD data for South Africa reveals a profile similar to that of two highly industrialised, high-income economies, namely Germany and the USA. In drawing this comparison, one obviously has to allow for the discrepancy in target dates on which the data are based. Nevertheless, the following picture of expenditure emerges on the basis of the latest information available:

- ?? South Africa (1995/1996): 13.4 : 20.3 : 66.3
- ?? Germany (1991) : 16.3 : 14.3 : 69.3
- ?? USA (1993) : 15.7 : 13.3 : 71.0

?? The picture that emerges from Table 5.6 suggests that the South African S&T system shares certain structural similarities with modern industrialised economies rather than with third-world countries. Although this is certainly true at one level, the picture at the macro-level conceals internal distortions and imbalances within and between sectors. These would include the huge differences in R&D expenditure between sectors of application, imbalances in output between higher education institutions and also between the university and technikon sectors, as well as the overall dominance of white male scientists and scholars in all sectors. It is imperative that all these "distortions" be addressed to ensure a more balanced S&T system, while at the same time increasing our competitiveness within the global arena.

??

5.4 Human resources and R&D

The following issues are addressed in this section:

- ?? The overall numbers of human resources by sector
- ?? A comparison of labour costs over time and by sector
- ?? The distribution of human resources by main scientific field
- ?? Patterns in research collaboration across main scientific fields

5.4.1 Human resources by sector

How many professional scientists and research scholars are involved in R&D in the public sector? Table 5.7 summarises the distribution across performance sectors.

Table 5.7: Human resources by sector (FTE) (excluding business sector): 1995/96

Sector	Total researchers/ scientists (R&D)	Column %
HES	6 684#	66
Science councils	2 749	27
Government & museums	452	4
NGOs (sample)	62	1
Industry-based organisations	162	2
TOTAL	10 109	100

 # This figure represents the upper estimate of the number of scientists. It is based on the assumption that the total population of scientists/researchers at universities and technikons (an estimated 16 300) spends on average approximately 41% of their time on research (the proportion recorded in the survey). A more moderate estimate, based on the assumption that the average time spent is closer to 33%, will produce a figure of 5 380. A lower estimate based on even more conservative assumptions (distinguishing between productive and less productive scientists), would put the number at around 4 200. Although we continue to use the upper estimates in the remainder of the chapter, it follows that the use of the lower estimates might lead to differences in interpretation.

5.4.2 International comparisons

Table 5.8 provides an international comparison of human resources by sector of economic performance. Data from the SSRD is plotted against previous data for South Africa (1991/1992) and selected countries extracted from UNESCO's *1996 Statistical Yearbook*. These countries are:

?? Three upper-middle-income economies, namely, Argentina, the Czech Republic and Hungary

?? Three high-income economies, namely, Australia, Germany and the USA

Human resource figures presented here refer to total numbers of scientists and engineers. In UNESCO's terms, the latter are defined as "persons working in those capacities, i.e. as persons with scientific or technological training (usually completion of third level education) in any field of science who are engaged in professional work on R&D activities, administrators and other high-level personnel who direct the execution of R&D activities" (p. 5.1).

Table 5.8: Human resources by sector of performance: (international comparisons)#

Country	Year	Total Scientists/Engineers (R&D)		
		HES	General service sector	Productive sector
South Africa *	1995/1996	6 684 48.4	3 200 23.4	3 800# 27.8%
South Africa **	1991	5 984 49.5 %	2 723 22.5 %	3 395 28 %
Argentina	1988	5.602 50.5%	3.192 28.8%	2 294 20.7%
Czech Republic	1994	1 731 12.9 %	4 966 37.2 %	6 628 49.7 %
Hungary	1993	4 546 38.4 %	3 769 31.8 %	3 503 29.6 %
Australia	1990	20 666 49.3 %	9 496 22.7 %	11 675 27.9 %
Germany	1991	62 171 25.8 %	37 548 15.6 %	141 084 58.5 %

USA	1993	128 000 13.3 %	60 000 6.2 %	764 500 79.4 %

Source: UNESCO Statistical Yearbook 1996 (pp. 5.1–5.42)

 # Estimate calculated on the basis of a 12 % increase between 1991 and 1995/1996 in the other two sectors. However, if the business sector was under-surveyed in 1991/1992, the 1995/1996 human resources figures would have to be fundamentally revised.
** SSRD Audit*
*** FRD, South African Science and Technology Indicators 1996*

The salient issues are:

?? SSRD data reveal that, in the case of South Africa, the proportionate distribution of human resources across sectors of performance has remained constant since 1991/1992. Of the other upper-middle-income countries listed, the South African profile is most similar to that of Argentina. It reveals an even closer similarity to Australia, classified by the World Bank as an upper-income economy. The proportion of human resources across sectors (from the HES to the general service [government] and productive [business] sectors) for these three countries is as follows :

?? South Africa (1995/1996): 48.4 : 23.4 : 27.8
?? Argentina (1988): 50.5 : 28.8 : 20.7
?? Australia (1990): 49.3 : 22.7 : 27.9

?? Compared to the above, the profile for the Czech Republic displays a reverse trend, with the highest proportion of human resources located in the productive sector and the lowest in the HES. This profile is also reflected in the data for Germany and the USA. The proportionate distribution of human resources across sectors for these three countries is as follows :

?? Czech Republic (1994): 12.9 : 37.2 : 49.7
?? Germany (1991): 25.8 : 15.6 : 58.5
?? United States (1993): 13.3 : 6.2 : 79.4

?? What is noteworthy in this comparison is that the high proportion of human resources in the productive or business sector, especially in Germany, does not occur at the expense of the HES (within which the German system of autonomous research institutes is renowned), but rather because of a very small numbers of human resources (15.6%) in the government sector. This is even more striking in the case of the USA where only 6.2% of human resources are found in the government sector. Interestingly enough, the high proportions of human resources in government for the eastern European countries (37.2% in the Czech Republic and 31.8% in Hungary 31.8%) is probably the result of the dominance of the academies of science in these countries. Most of these academies have recently been drastically down-sized, and one would therefore expect more recent statistics to reveal a changing picture.

5.4.3 Labour costs by sector (1991–1995/1996)

Tables 5.9 and 5.10 present data on human resources and labour costs for the HES and government sector between 1991/1992 and 1995/1996.

Table 5.9: Human resources and labour costs for the HES: 1991/92–1993/94

	1991/1992	**1993/1994**	**1995/1996**
Persons	14540	9916	16300
Person years	5984	4096	6684
Labour costs	R323 376	R220 381	R357 505
Per capita costs	R54 040	R53 804	R53 487

Table 5.10: Human resources and labour costs for the government sector: 1991/92–1993/94

	1991/1992	1993/1994	1995/1996
Persons	3116	3113	3200
Person years	2420	2303	2400
Labour costs	R184 977	R216 432	R403 922
Per capita costs	R 76 436	R 93 978	R168 300

The salient findings are:

?? A comparison of the data over the past five years for the HES reveals a high degree of consistency between the 1991/1992 R&D survey and the 1995/1996 SRD. The 1993/1994 survey was undertaken using a new methodology which makes comparison difficult, if not impossible. (see *SA Science and Technology Indicators*, 1996, p. 105 for a discussion of this issue).

?? The findings for the government sector are less consistent. The only obvious constant is the number of persons involved in research and the estimated person years. The huge variance in labour costs from survey to survey is caused by big differences in per capita costs. We would contend that the 1995/1996 figures are more accurate for two reasons: (i) These findings are based on first-hand verified information provided by the organisations and not on any sample estimates. (ii) If one were to calculate the total labour costs of a scholar in the HES (in other words, compute labour costs for 100% of their time), the result would be an average of R133 000. This amount is more in line with the R168 000 that we found in the 1995/1996 survey.

5.4.4 Human resources by main scientific field

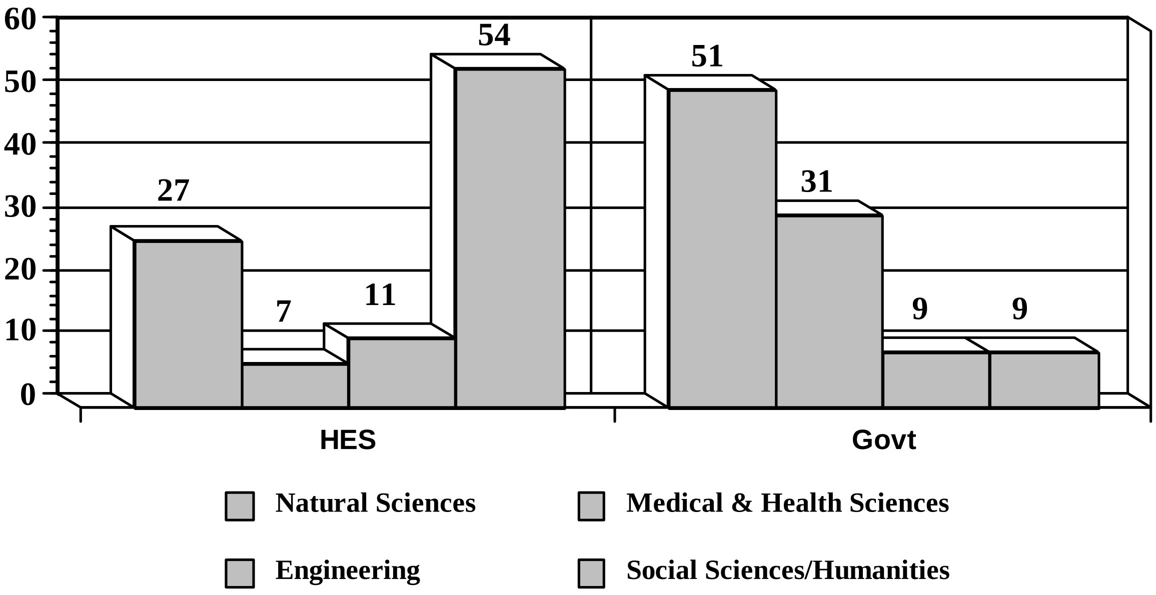
Table 5.11: Human resources by main scientific field: 1995/96

Main scientific field	Total scientists	Column %
Social sciences	1887	18.7
Humanities	1437	14.2
Engineering sciences	1021	10.0
Agricultural sciences	1017	10.1
Biological sciences	831	8.2
Earth and marine sciences	759	7.5
Technologies and applied sciences	635	6.3
Medical sciences: clinical	354	3.5
Economic sciences	345	3.4

Medical sciences: basic	330	3.3
Information and computer sciences	318	3.1
Chemical sciences	308	3
Health sciences	288	2.8
Mathematical sciences	263	2.6
Physical sciences	235	2.3
Arts	81	1
	10109	100

We decided to aggregate these 16 fields into four "main science cultures": the natural sciences, engineering sciences and technologies, medical and health sciences and social sciences and humanities. The resultant picture is presented in Fig. 5.3.

Figure 5.3: HR by main scientific field: 1995/96



The salient issues are:

?? Table 5.11 and Fig. 5.3 present an overview of human resources by main field and science culture. Looking at the macro picture suggests a fairly even distribution of human resources by main field. However, even at this level, the "dominance" of the natural and social sciences is evident.

?? Perhaps the most striking pattern emerges when one compares the HES with the government sector (predominantly science councils). Whereas the social sciences and humanities make up more than half (54%) of all human resources in the HES, this picture is completely reversed in the government sector, where the natural sciences constitute more than half (51%). The small proportion of human resources in the engineering sciences and technology in the HES (7%) is "corrected" in the government sector (31%).

?? These results form an interesting background to current debates about encouraging more human resources investment in the fields of the natural sciences and technology. Government has over time clearly "shaped" (in a more interventionist way through the science council sector) the supply of natural science, engineering and technology human resources in order to "compensate" for the lack of supply in these areas within the HES. Although this is understandable, it does suggest that the internal dynamics of the S&T system need major rethinking in order to have a more "natural" and equal distribution of human resources across sectors. It also raises the question of whether the fact that basic research is predominantly done within the HES means that the intellectual base for such research in the natural sciences and engineering fields is not too small to carry the weight for all sectors. Stated differently, we need a greater capacity for basic research in the natural sciences and engineering within the HES in order to support and rejuvenate the volume of applied research and development work done in other sectors.

?? Conversely, for the social sciences, the small resource base of "applied social scientists" in the government sector should be a cause of concern. This issue has clear implications for the future role of the HSRC, the only major social science player in the government sector.

?? The comments made thus far should not lead one to conclude that any "restructuring" or "rightsizing" of the South African S&T system be done in a mechanistic manner. It does, however, require innovative strategies to ensure better utilisation of existing human resources. As we will emphasise in the following section, any future strategies for deploying and redeploying existing human resources must take into account the extent and nature of collaborative efforts within and between sectors.

5.4.5 Patterns of research collaboration within the HES

Previous research has shown that patterns of research collaboration vary considerably between science cultures and also between main scientific fields. The reasons for these variations include differences in research methodology, intellectual styles and funding policies. The 1995/1996 SSRD provides us, for the first time, with extensive empirical data on patterns of research collaboration in the South African science system (data only available for the HES).

Four "indicators" of research collaboration are explored in this section:

(1) Research collaboration as evidenced through co-authorship of publications listed.

(2) Research collaboration as evidenced by the amount of joint funding procured (as a proportion of total funding).

(3) Research collaboration across disciplinary boundaries as evidenced by the discipline(s) indicated for co-workers.

(4) Degree of inter-institutional research collaboration as evidenced by the institutional affiliations of co-workers.

The summary results for these four "indicators" of research collaboration by main scientific field are presented in Tables 5.12–5.15.

Table 5.12: Extent of research collaboration by main scientific field: multiple authorship: 1995/96

Main scientific field	Authors	Co-authors	Row %
Agricultural sciences	114	47	41
Arts	51	2	4
Biological sciences	218	89	41
Chemical sciences	99	48	48
Earth and marine sciences	94	39	41
Economic sciences	190	34	18
Engineering sciences	170	40	24
Health sciences	51	15	29
Humanities	611	25	4
Information and computer sciences	93	21	23

Mathematical sciences	117	31	26
Medical sciences: basic	110	36	33
Medical sciences: clinical	182	59	32
Physical sciences	74	30	41
Social sciences	114	47	41
Technologies and applied sciences	42	12	29
	2330	575	29%

(Methodological note: The total number of 2 330 "authors" constitutes the results from the first wave of data collection in which questions where included on publication titles for 1994 and 1995. Information about co-authorship (which could refer to articles, books or chapters in books) from 1995 was used.).

Table 5.13: Extent of research collaboration by main field (fund-raising): 1995/96

Main scientific field	**Self funding R**	**Joint funding R**	**%**
Agricultural sciences	8 809 720	2 086 890	19
Arts	328 507	32 000	9
Biological sciences	16 220 889	2 669 844	14
Chemical sciences	6 283 396	3 761 407	37
Earth and marine sciences	8 696 182	1 393 448	14
Economic sciences	6 456 727	500 130	7
Engineering sciences	14 324 989	6 180 734	30
Health sciences	1 541 424	562 000	27
Humanities	5 925 216	1 850 391	24
Information and computer sciences	2 291 541	1 065 100	32
Mathematical sciences	3 408 250	5 636 799	62
Medical sciences: basic	7 376 440	3 595 536	33
Medical sciences: clinical	7 671 040	1 278 889	14
Physical sciences	3 287 812	5 427 537	62
Social sciences	11 716 131	9 467 844	45
Technologies and applied sciences	3 602 700	806 099	18
	107 940 964	46 314 657	28%

(Note: The column percentage in the last column expresses the amount of joint funding as a proportion of total funding.)

In Table 5.14, the extent of inter-disciplinary research collaboration was measured in the following way:

?? Where the respondent did not list a co-worker, the project was rated as "no collaboration".

?? Where co-workers listed were all from the same discipline as the project leader, the project was rated as "discipline-based collaboration".

?? Where one of the co-workers listed was from a discipline different from that of the project leader, the project was rated as "weak inter-disciplinary collaboration".

?? Where at least two of the co-workers listed were from disciplines other than that of the project leader, the project was rated as signifying "strong inter-disciplinary collaboration".

It should be added that this categorisation does not allow for distinctions between "type" of co-workers (for example, post-graduate students, colleagues or visiting fellows).

Table 5.14: Extent of research collaboration by main scientific field: inter-disciplinary collaboration: 1995/96

Main scientific field	Projects	No collaboration %	Discipline based collaboration %	Weak collaboration %	Strong collaboration %
Agricultural sciences	162	25	36	43	13
Arts	58	78	14	7	1
Biological sciences	312	34	36	20	10
Chemical sciences	113	19	40	31	10
Earth and marine sciences	136	36	31	21	11
Economic sciences	178	82	10	8	0
Engineering sciences	213	37	40	18	5
Health sciences	65	37	29	23	11
Humanities	891	79	13	5	3
Information and computer sciences	88	52	25	18	5
Mathematical sciences	145	48	34	15	3
Medical sciences: basic	135	22	34	30	14
Medical sciences: clinical	247	38	26	22	14
Physical sciences	105	26	55	16	3
Social sciences	902	60	24	10	6
Technologies and applied sciences	51	43	24	22	12
	3801	45	29	19	8

The final table on the "extent of research collaboration" examines the extent of inter-institutional collaboration. Four categories are distinguished:

?? "No collaboration" means that the project leader did not list any co-worker(s).

?? "HES only" means that all co-workers listed were from the HES, including both own institution and other universities.

?? "HES and government" means that co-workers came from another higher education institution as well as from a government department or science council.

?? "Multi-sector" means that co-workers were from various sectors, including business and institutions abroad.

Table 5.15: Extent of inter-institutional research collaboration by main scientific field: 1995/96

Main scientific field	Projects	No collaboration %	HES only %	HES and government %	Multi-sector %
Agricultural sciences	160	23	44	17	16
Arts	57	81	16	2	2
Biological sciences	308	31	34	15	19
Chemical sciences	113	19	60	6	15
Earth and marine sciences	135	32	36	4	27
Economic sciences	178	81	13	0	6
Engineering sciences	197	39	42	5	15
Health sciences	66	36	32	18	14
Humanities	1000	81	14	1	4
Information & computer sciences	88	50	42	1	7
Mathematical sciences	143	47	41	0	13
Medical sciences: basic	142	18	45	18	19
Medical sciences: clinical	256	30	37	18	15
Physical sciences	104	15	52	11	22
Social sciences	982	59	31	4	6
Technologies & applied sciences	51	37	45	10	8
	3980	42	37	8	13

The salient issues were:

?? The top five fields that ranked highest on co-authorship were:

? Chemical sciences

? Agricultural sciences

? Earth and marine sciences

? Physical sciences

? Social sciences

?? The top five fields rated highest on the proportion of joint funding procured were:

?? Mathematics

?? Physical sciences

?? Social sciences

?? Chemical sciences

?? Medical sciences: basic

?? The fields that scored highest on inter-disciplinary co-operation (adding "weak" and "strong" collaboration together) were:

?? Agricultural sciences

?? Medical sciences: basic

?? Chemical sciences

?? Medical sciences: clinical

?? Health sciences/technologies and applied sciences

?? The five top fields in terms of inter-institutional collaboration (adding together the last two columns) were:

?? Medical sciences: basic

?? Biological sciences

?? Physical sciences

?? Agricultural sciences

?? Medical sciences: clinical

?? As far as the issue of multiple authorship is concerned, the high rankings of fields such as the chemical sciences and agricultural sciences are not unexpected. However, the fairly high ranking of the social sciences is. One should note that co-authorship and co-editorship of books are more prevalent within the social sciences. This is arguably a weaker form of collaboration than co-authoring an article.

?? The finding that the social sciences scored high on the proportion of joint funding raised is equally surprising. This means that we might have to revise some traditional conceptions about the nature of research practices in this field. Its profile is closer to some natural science fields than it is to the humanities and arts, and this is surely due to the increasing commercialisation of research in the social sciences research.

?? As far as interdisciplinary collaboration is concerned, three fields stand out as not being involved in any significant interdisciplinary work. These are arts, the humanities and the economic sciences. Methodological styles and disciplinary traditions would clearly account for the uni-disciplinary focus in the arts and humanities, but not necessarily for the result with regard to the economic sciences. This requires further analysis.

?? The most noteworthy result as far as inter-institutional collaboration is concerned is that we found very low degrees of inter-sectoral co-operation (only 21%). The macro picture suggests that university scholars prefer to work with university colleagues within their own institutions or in other universities. Again, one has to add that further more detailed analysis might reveal interesting patterns at lower levels. It would be interesting to find out, for example, whether the more productive scientists (see our discussion in Chapter Three), are involved in more interdisciplinary and inter-institutional collaboration than the "average" university scholar.

5.5 Scholarship, R & D output

5.5.1 Some conceptual distinctions

It is useful to distinguish between the "outcomes" and "outputs" of human actions and endeavours. "Outcomes" may be defined as the less tangible consequences of human decision-making. They are usually "events" or "actions" of some sort. Karl Popper distinguished between the "intended" and "unintended" outcomes of human actions, a distinction which is useful when talking about human interventions (such as programmes and policies) in general. A new training programme or policy will (hopefully) have certain intended (desirable) outcomes, such as better trained staff, more competent workers or improved performance. It also usually has certain unintended (both positive and negative) outcomes.

The concept of "output" has its origins in systems theories. Within such theories, "outputs" are the measurable (and observable) end-products of an input–output process. It could refer to a production process (in other words, a manufacturing process where a new product is the output) or an information processing system (with data as input and information as output) or even to political processes (where legislation and new bills are the outputs of a policy-making process).

Against the background of these preliminary remarks, the outcomes of the research and development process that one could list would include better trained students, more competent and experienced scholars and a culture of learning within an institution. Regarding outputs, one would distinguish between various categories.

The following five categories were distinguished in the SSRD:

?? Scientific publications, namely, peer-evaluated articles (local and overseas journals), books, chapters in books and published conference proceedings.

?? Unrefereed reports: both in-house technical reports and commissioned contract reports for clients.

?? Scientific presentations: papers delivered at local and overseas conferences and seminars.

?? Technologies: product, process, support and information technologies.

?? Patents and licences.

The following two tables present the aggregate results for these five categories, first by sector (Table 4.19) and then by main scientific field (Table 4.20). In the presentation of the data in Table 4.19, the per capita output (in other words, the number of outputs per person year) has been included for each category. In Table 4.20, the expenditure per output has been included for each category.

The salient issues are:

?? The most important reason for tabulating output by type and sector in Table 4.19 is to establish certain benchmarks for future comparison. No previous data at this level are available for all sectors. Although certain universities take as the benchmark (and ideal) that a scholar produce at least one scientific publication per year, such a view represents institutional policies rather than national benchmarks.

?? The per capita output differs quite significantly across sectors, mostly in the expected direction. The highest per capita production of scientific publications occurs in the HES, the government and museum sectors and, rather surprisingly, in industry-based organisations. The small number of NGOs included in the survey make any strong conclusions about these results rather precarious.

?? The per capita output of unrefereed publications is highest in the science councils, where contract research is dominant, as well as at NGOs. Surprisingly, the comparable statistic for the HES is quite low (0.279), but this figure might mask large disciplinary and institutional variations.

?? The output of conference papers is high across the board, whereas the per capita output of technologies is highest in the science councils.

?? The overall picture that emerges from these findings is in line with the patterns of expenditure and type of research discussed above. The emphasis on basic research in the HES is manifested in the high per capita output of scientific publications and conference papers. Similarly, the emphasis on applied research and development work within the government sector results in higher per capita output of unrefereed reports and technologies.

Before discussing the main findings that emerge from Table 5.16, a methodological note is in order. All the data reported on refer to sampled data (in other words, unweighted data). The reason for this is that we focus on per capita output rather than total volume of output. We have not corrected for multiple authorship, as this would require a level of analysis that was beyond the scope of the study. An estimate, based on a cursory look at multiple authorship as reported in the survey, would suggest that scientific output across most categories should be weighted by a factor of 0.8. However, there are big differences between science cultures, which should also be taken into account.

The main purpose of Table 5.17 is to establish benchmarks across scientific fields. For this reason, comparisons between fields are more important than absolute values. Furthermore, expenditure does not include the costs of equipment or overheads. This fact, taken together with the effect of multiple authorship, implies that all estimates in Table 5.17 are probably an average of 15% to 20% less than the real values.

Table 5.16: Output by sector#: 1995/96

Sector	Scientists	Scientific publications	Per capita	Unrefereed publications	Per capita	Conference papers	Per capita	Technologies	Per capita
Higher education	3059	7332	2.4	1948	0.64	6010	1.96	556	0.18
Science councils	2749	1673	0.61	8389	3.05	1915	0.70	623	0.23
Government & museums	452	640	1.42	480	1.06	438	0.97	29	0.06
NGOs (sample)	62	52	0.84	130	2.10	69	1.11	1	0.02
Industry-based organisations	162	259	1.60	132	0.81	112	0.69	23	0.14
TOTAL	**6484**	**9956**	**1.54**	**11079**	**1.71**	**8544**	**1.32**	**1232**	**0.19**

 # Output for the HES was weighted by a factor of 0.8 to account for multiple authorship.

Table 5.17: Output by main scientific field: 1995/96

Main scientific field	R (000]	Scientific publications	R 000 per output	Unrefereed reports	R (000) per output	Confe-rence papers	R (000) per outpu
Agricultural sciences	356312	1032	345	1539	232	1136	314
Arts	5277	47	112	10	527	31	170
Biological sciences	131439	1195	110	411	320	1113	118
Chemical sciences	49393	331	149	43	1149	324	152
Earth and marine sciences	176086	823	214	1008	175	576	306
Economic sciences	39318	422	93	10	3932	220	179
Engineering sciences	205907	726	284	1883	109	545	378
Health sciences	31512	277	114	64	492	336	94
Humanities	94782	1839	52	367	258	1223	77
Information and computer sciences	52070	229	227	303	172	245	213
Mathematical sciences	31061	368	84	90	345	293	106
Medical sciences: basic	40116	526	76	35	1146	376	107
Medical sciences: clinical	54002	904	60	143	378	838	64
Physical sciences	28794	443	65	39	738	300	96
Social sciences	165344	2057	80	960	172	1797	92
Technologies and applied sciences	226221	317	714	4433	51	357	634
	1687634	11536	146	11338	149	9710	174

[Note on interpreting the findings in Table 5.17: the cost per output was calculated by dividing expenditure by the nu
This means that the average cost of producing a scientific publication is R146 000, whereas the average cost of proc
one wants to look at the aggregate picture, one must, of course, divide total expenditure by the total number of outp
cost of producing a scientific output (with publications, unrefereed reports and conference papers taken together) w
+ 9710) = R51 793. I believe, however, that this is less useful than looking at each category of output separately and

The salient issues are:

?? As expected, the average cost of producing a scientific publication of some sort is significantly less than the average cost of producing a technology. Somewhat surprisingly, the average cost of producing a scientific publication (R146 000) is comparable to producing unrefereed reports (R147 000), whereas both are cheaper than the average cost of producing a conference paper (R174 000).

?? Huge variations across sectors are noticeable. At first glance, the following fields consistently produce scientific publications and conferences papers (technologies excluded) at below average costs:

- Biological sciences
- Chemical sciences
- Health sciences
- Humanities
- Arts
- Mathematical sciences
- Medical sciences: basic
- Medical sciences: clinical
- Physical sciences
- Social sciences

?? The less cost-effective fields as far as the production of scientific publications and conferences papers are concerned are:

- Agricultural sciences
- Earth and marine sciences
- Engineering sciences
- Information and computer sciences
- Technologies and applied sciences

?? One should add, however, that the latter fields ranked highest as far as the per capita costs of technologies were concerned.

?? The pattern that emerges from Table 5.17 again confirms earlier patterns of expenditure on type of research. It reveals a fairly clear division of labour across scientific fields and sectors regarding type of research and thus also type of R&D output.

5.6 Conclusions

The SSRD has generated a wealth of information about scholarship, research and development within the South African S&T system. The picture that emerges is of a system that comprises a diversity of research cultures and practices. It demonstrates strong capacity in a number of sectors and fields, clear divisions of labour with regard to type of research and research output across scientific fields and institutions, clear patterns of research collaboration, and established strengths in certain niche areas. It is also a picture of "imbalances" in capacity and output, huge variations in human capital across fields and sectors, significant differences in type of research and cost of output, and weak inter-institutional and inter-sectoral collaboration.

There were a number of surprising results. The study served to correct current wisdom on total R&D expenditure and several other trends over the past five years. It shows clear shifts in the type of research conducted, in line with international trends, such as the growing importance of Mode 2 forms of knowledge production. It suggests a growing rapprochement among scientific fields engaged in commercial contract-type research. It also suggests a growing rift between discipline-based fields and increased interdisciplinarity in other fields.

There are a number of danger signs that require attention: a decline in expenditure on basic research, weak inter-sectoral collaboration and non-alignment of expenditure with socio-economic priorities as far as application is concerned.
A more detailed discussion of these patterns and trends and their implications (including their implications for national S&T policy) is presented in Chapter Six. This discussion also includes a number of recommendations for future research.

****

Chapter Six

Setting a new research agenda

6.1 Introduction

In this final chapter, we explore some of the implications that flow from the results of the SSRD and offer a number of practical recommendations that we believe require the urgent attention of the Department of Arts, Culture, Science and Technology and other key policymakers in South Africa's S&T system. The discussion is divided into two sections: (i) implications and recommendations pertaining to substantive issues and (ii) further research priorities and methodological issues.

6.2 Substantive issues

The **first issue** we wish to raise relates to **the locus of R&D capacity** (in terms of human resources) of the two traditional science cultures, namely, the natural sciences (including engineering and technology) and the social sciences (including the humanities). Looking at the spread of capacity across sectors surveyed, one notices that the majority (54%) of scientists within the HES are social scientists and that the overwhelming majority (82%) within the government sector (including the science councils) are natural scientists and engineers.

One of the implications of this result is that the research career of a social scientist is largely confined to the HES, whereas natural scientists have far more work opportunities outside the HES. At the same time, however, this picture warns of a possible discrepancy between supply and demand. There is, on the one hand, an over-supply of social scientists with little demand for their expertise outside of the HES and, on the other hand, an under-supply of natural scientists from the HES to continue catering for the needs and demands of other sectors. This raises a number of related recommendations and further implications.

The **first recommendation** is that **the natural science capacity within the HES must be strengthened. Apart from strategies required to attract larger**

numbers of students to natural science disciplines, this would require existing natural scientists within the HES to become more involved in the training process. Given the current capacity of natural scientists within this sector, there is a strong possibility that this requirement could result in a drop in the rate of HES-based research outputs in the natural sciences. In this regard, it is interesting to note that SSRD results reveal a higher overall rate of scientific publications, both locally and internationally, for the natural than for the social sciences. This discrepancy can be partly explained in terms of the different methodologies and research practices applied in the two science cultures, with those of natural scientists lending themselves far more readily to the publication of shorter, less narratively oriented outputs. However, the SSRD also reveals that the per capita output of post-graduate students in the social sciences is almost double that of the natural sciences. Hence, an obvious implication of the imperative for natural scientists to become more involved in training is that there would be a concomitant decrease in their research outputs.

Turning more specifically to the social sciences, a **second recommendation** related to the locus of R&D capacity, as described above, is that **government should assume a stronger responsibility for supporting applied, policy-related and developmental social science work outside the HES**. Currently this type of social science activity occurs largely at the HSRC and within the NGO sector. It is well known that since the early 1990s, broader socio-political processes of democratisation have increasingly threatened the continued prosperity of NGOs. Unlike work in the natural sciences, which is supported by other sectors and has financial access to various industries, NGOs tend to rely primarily on funding from abroad, with virtually no support from the government or science councils and very limited linkages with industry. Yet the need for social scientists in applied, policy-related, development work continues to be emphasised in policy discussions at all levels. This imperative remains unrealistic unless measures are taken to provide social scientists with opportunities to become involved in such work outside the HES.

Closely related to this second recommendation is the observation that there is an increasing move among social scientists within the HES towards undertaking contract work. This not only implies a clear move towards more applied work, but it could also be seen as evidence of a shift towards a new mode of knowledge production – referred to by Gibbons et al. (1994; 1997) as Mode 2 – among social scientists. Very briefly, Mode 2 refers to a "socially distributed knowledge production system" characterised by the "increasing contextualisation of knowledge" and emphasising marketability, transdisciplinarity and the importance of hybrid forums – "groups constituted through the interplay of experts and non-experts as social actors" – in the shaping of knowledge (1997, p. 2). In essence, Mode 2 operates on the basis of research practices which are different from the current Mode 1 ethos of science still dominant in the HES. Given that the majority of social scientists are located within the HES, the move towards a new mode of knowledge production carries with it the potential of cognitive dissonance among these scientists. This refers to a discrepancy between research practices and the core beliefs (embracing ideals of truth) underlying modern science. According to Gibbons, such beliefs and practices are mutually supportive. It therefore follows that the introduction of new research practices may be seen as threatening the existing belief system of science.

Of concern here is that current socio-economic and political imperatives call for research practices associated with Mode 2 knowledge production. At the same time, there is the danger that the move among social scientists in this direction is not adequately facilitated and/or encouraged because they find themselves located in a sector still dominated by Mode 1 beliefs. The possibility that this may be the case serves to strengthen the second recommendation made above. However, it also necessitates a **third recommendation**, namely, that **research executives, policymakers and other key players (including funders) within the HES should take up the challenge of promoting research practices that are in line with the global trend towards new modes of knowledge production**. **This would entail a critical re-examination of the "vision of science" and, where appropriate, a revision based on empirical trends in the actual practice of science**. This recommendation specifically concerns the social sciences because of their concentration in the HES. However, the overall debate about new modes of knowledge production and their implications for the management of research within the HES clearly applies to all cultures of science.

Still focusing on the locus of R&D capacity across sectors, and the specific attention that needs to be paid to drawing more social scientists into applied and developmental areas of work, a **fourth recommendation** is that **the promotion of interdisciplinarity and transdisciplinarity should be effectively institutionalised through the specific earmarking of funds for this type of research activity by the National Research Foundation**. At the very least, this could take the form of a new funding category. Other more formal options, such as specific incentive mechanisms to promote interdisciplinary research, should be considered. Initiatives such as these would serve to meet the challenge of drawing social scientists into applied and development research activities and, further, would go a long way towards giving substance to an issue which, to a large extent, remains at the level of rhetoric.

A **second issue** to be addressed pertains to **the importance of basic research** in the South African R&D system. The emphasis placed thus far on promoting applied and development work should not be read as implying a negation of the importance of basic research, particularly fundamental research. The SSRD provides evidence of fairly low ratings on basic research in many scientific fields, including engineering sciences and the social sciences, as practised within the HES. Given that this is the sector which traditionally spends the largest proportion of its direct costs on basic research, this finding creates cause for some concern. The current trend – both locally and internationally - towards stressing greater involvement in applied and development work as the key to defining research "relevance" cannot be interpreted as a need to withdraw from long-term basic research.

On this issue, the authors of the *"Report of the Federal Government on Research: 1996"* in Germany, make the point succinctly:

> ***"It is necessary" they argue "to improve the dovetailing of basic research and application-oriented research and to translate scientific results into innovative applications. Technology-oriented research relies on broad basic research. They represent two sides of the same coin" (p. 11).***

The point is made again later on in the report:

> ***"Generating knowledge in the context of its later application does not detract from the importance of basic research; on the contrary, it creates a fruitful field of tension and stimulation. Traditional notions of 'transfer' as a linear process leading from basic research to application-oriented research to innovation seem to be less and less convincing" (p. 29).***

In line with these arguments, a **fifth recommendation** is that **government should spend more on basic research, particularly within the HES**.

The **third issue** to be raised is that of **research collaboration**. Apart from the need to promote inter- or transdisciplinarity (as discussed above), the importance of cooperation and collaboration across institutional and sectoral boundaries are increasingly being recognised. It is with particular reference to overcoming obstacles between the generation and application of knowledge that this issue has been raised. In Germany, this imperative has been translated into federal government initiatives to intensify contacts and promote "strategic co-ordination" between science and industry at all levels (1996 Report, p. 30).

In the absence of comparative data, both nationally and internationally, it is difficult to comment on the degree of institutional and/or sectoral collaboration as revealed by the SSRD. Whereas collaboration between institutions within the HES is clearly high (with an average of 37% across main scientific fields), it is much lower between institutions across sector boundaries (with an average of 13%). With regard to the latter, it is interesting to note that multi-sector collaboration is highest within the medical sciences. A possible reason for this may be the MRC's policy of decentralisation. Given the number of MRC research institutes located on various campuses, as well as the extent of co-operation between the MRC and industry-based organisations (such as the SAIMR) in terms of joint funding, this finding is not surprising.

In line with the above, a **sixth recommendation** we wish to make is that **mechanisms should be developed to encourage other science councils, but**

especially the HSRC, to establish or strengthen collaborative or joint ventures. A mechanism that government could consider would be to restructure the subsidy formula in such a way as to ensure that the HSRC moves towards a model of decentralisation as exemplified by the MRC. Being the only national social science research agency mandated to undertake applied work, the decentralisation of the HSRC would not only serve to strengthen multi-sector collaboration within the social sciences, but would also address those issues touched on by our second recommendation, namely, government's responsibility to promote the increased involvement of social scientists in applied and developmental work.

Regardless of the scientific field in question, the qualitative data gathered confirms that there are virtually no formal or informal structures in place to facilitate greater cooperation between institutions across sectoral boundaries. Within the HES, initiatives such as the Eastern Seaboard Association of Tertiary Institutions (ESATI) in KwaZulu-Natal and the Adamastor Trust in the Western Cape have been set up with the specific purpose of promoting inter-institutional co-operation. The extent of their success thus far has yet to be evaluated. Looking beyond regional, HES-based initiatives however, we would like to submit a **seventh recommendation,** that **DACST should organise a national workshop to which key research executives and policymakers from all sectors, including the business/private sector, would be invited in order to discuss obstacles to research collaboration and to identify practical solutions to overcoming these**. Such an event could also serve as an ideal opportunity to provide key players in South Africa's S&T system with detailed feedback on the outcomes of the audit.

Turning specifically to the HES, a **fourth issue** we wish to address is that of **institutional capacity building**. The attention paid (primarily by government) to historically disadvantaged institutions over the past few years has essentially focused either on research capacity building at the level of individual researchers or on infrastructural development. On the basis of SSRD data, we would claim that, although important, neither of these issues adequately addresses the problem of institutional capacity building.

In comparing institutional profiles according to two criteria – per capita outputs and expenditure – it is possible to argue that the distinction between historically disadvantaged and historically advantaged institutions is becoming increasingly untenable. In terms of per capita outputs for example, the University of the Western Cape performs better than Potchefstroom University or the universities of the Free State and South Africa. In terms of per capita expenditure, both the universities of the Western Cape and the North rank within the top ten institutions within the HES. From data gathered for the SSRD, we would argue that the "performance" of these two institutions is due to a number of crucial factors, among which geographical location (proximity to urbanised centres) is not insignificant. However, we believe that the question of institutional research management has not received nearly sufficient attention in this regard. We would, for instance, argue that the relative success of such "historically disadvantaged institutions" as the University of the Western Cape and to a lesser extent, the University of the North, is due to active and well-organised research management policies and structures, among other things. This leads us to make our **eighth recommendation**, namely that **the Department of Arts, Culture, Science and Technology should formulate various mechanisms to promote improved quality research management. We have in mind mechanisms such as training workshops in the principles and practices of effective institutional research management, setting up linkages between local and overseas bodies that promote such endeavours, and supporting scholarship in this area of specialisation.**

The **fifth issue** refers to **the alignment of publicly funded R&D with national socio-economic goals and priorities**. Government has a responsibility, not only to encourage and support basic research [see discussion above), but also to ensure that public funds for R&D are expended in such a way that they contribute meaningfully to socio-economic goals.

The new South African government has, over the past few years, embarked on ambitious initiatives to reformulate national policies in areas such as public health and welfare, education and land reform. The next challenge that government faces, along with other role-players, is to implement these policies effectively and efficiently. For this to happen, continuous monitoring, feedback and evaluation will be required – activities that require systematic and ongoing research.

The GEAR document, which spells out government's vision in terms of national priorities for the medium term, explicitly states that policy frameworks and institutional structures are now in place to ensure the following:

- "the delivery of housing and related services
- steady improvement in the quality of education
- universal access to primary health care
- land and agricultural support for emergent farmers
- electrification of all urban areas and an increasing number of rural communities
- reliable water supplies and an appropriate sanitation infrastructure
- improved postal and telecommunications services
- a broad social security net, comprising social grants and targeted welfare services" (GEAR, p. 20)

We believe that this list of national priorities embodies a significant paradigm shift that also defines a new research agenda for the country. Such an agenda has the following key features:

- It is self-evidently inter-disciplinary (if not transdisciplinary) in nature.
- It requires that the country's best available intellectual resources be mobilised.
- It is applied, policy- and evaluation-driven research.

One could take any one of the priorities listed above to further substantiate the argument. We will suffice with an example referring to education (Curriculum 2005). Here we would argue that for Curriculum 2005 to be successful, it is imperative that a national knowledge base be developed that draws on the expertise and experience of scholars in fields as diverse as educational management, macro-educational systems, the sociology and economics of education, curriculum development, development studies, communications and telecommunications, information literacy and management, and programme evaluation. Similar points could be made about each of the other priorities listed.

Given this, we make two final recommendations that require serious attention in order to ensure that the implementation, monitoring and evaluation of national socio-economic goals are adequately supported by R&D.

Our **ninth recommendation** is that **government should give serious consideration to the establishment of a national research initiative that has as its mandate the undertaking of interdisciplinary, policy and development-driven research**. Such an initiative should ideally operate in the public sphere (rather than as a parastatal), and should have the explicit aim of optimising collaboration across disciplines and sectors.

Following this recommendation, we wish to make a **tenth** and final **recommendation. In order to facilitate the establishment of such an initiative, we recommend that government should put together a national task team, drawing on the best available expertise in each of the priority areas listed in the GEAR document. The brief of such a task team would be to undertake a study of the feasibility of setting up the proposed national initiative or programme, as well as to make specific proposals about the terms of reference, operating structure and resourcing thereof**.

The last two recommendations both address the same issue (although they can be treated separately). We believe that this matter requires serious attention if government wishes to ensure that a changing, dynamic socio-economic agenda is adequately supported and informed by appropriate and cost-effective R&D.

In conclusion, national socio-economic priorities do not, as a matter of course, change frequently. However, the advent of a democratic political dispensation in South Africa, together with far-reaching international developments, has given rise to a major overhaul of South African society and has, therefore, necessitated a revision of national socio-economic priorities. **A revision of the national research agenda is equally necessary.** In the first and main section of this chapter, we identified the following as the ten key issues to be put on this new research agenda:

?? The natural science capacity within the HES should be strengthened.

?? Government should strengthen support for applied, policy-related and development social science work outside the HES.

?? Key players within the HES should manage the shift towards Mode 2 research practices.

?? The National Research Foundation should institutionalise the promotion of interdisciplinarity and transdisciplinarity.

?? Government should spend more on basic research, particularly within the HES.

?? Government should develop mechanisms to ensure that science councils, particularly the HSRC, enter into collaborative or joint ventures.

?? The Department of Arts, Culture, Science and Technology should organise a national workshop to address the question of research collaboration across sectors.

?? The Department of Arts, Culture, Science and Technology should develop mechanisms to promote quality research management.

?? Government should consider the launching of a national research initiative that would focus on interdisciplinary, policy and development-driven research.

6.3 Further research and methodological issues

Based on the lessons learned in conducting the SSRD, as well as impressions gained through the collection and analysis of the data, we wish to make the following seven recommendations related to further research and methodology.

Recommendation Eleven: In the light of the poor quality of information yielded by government departments (due partly to ongoing internal transformation and restructuring of this sector), a follow-up survey of R&D activities and outputs in this sector is essential.

Recommendation Twelve: The SSRD has gathered vast amounts of quantitative data which need to be supplemented by appropriate qualitative information, especially in areas such as the utility, relevance and impact of R&D, areas of growth in R&D and innovation. We would suggest that qualitative studies utilising

Delphi-type techniques, as well as expert focus groups, be employed to cover all sectors.

Recommendation Thirteen: The qualitative studies referred to above, together with the quantitative database that has been established, should be utilised to set in place a national framework for R&D evaluation. Given that there is no established tradition of R&D evaluation in South Africa, although there are currently initiatives to institutionalise quality promotion, this is deemed to be an essential exercise.

Recommendation Fourteen: To optimise our understanding of local conditions and trends in R&D, we recommend follow-up studies that focus specifically on international comparisons.

Recommendation Fifteen: We strongly recommend that the audit be repeated in two to three years' time. It is essential that the lessons learned from this audit be taken seriously and that certain mistakes be eliminated. Amongst these we would include:

- ?? More attention to the adequate conceptualisation of the project
- ?? The undertaking of sector-specific rather than thematic studies
- ?? More emphasis on qualitative data
- ?? Greater sensitivity by project management to factors of timing, overlap between sectors and proportional costing of sub-projects
- ?? Consideration of electronic data-gathering techniques

Recommendation Sixteen: The SSRD project team was struck by the general lack of institutional databases, as well as the inadequacy of existing information systems. We thus recommend that the Department of Arts, Culture, Science and Technology initiate a project aimed at developing, upgrading and standardising research management information systems across sectors.

Recommendation Seventeen: One of the positive (even unintended) outcomes of the audit has been the development of a national classification system for scientific fields, disciplines and areas of specialisation. Initially developed by a task team of the audit, and subsequently refined through empirical validation, we believe this system to be ideally suited to the South African context and would recommend that it be adopted as a national standard by the National Research Foundation.

****

SOUTH AFRICAN RESEARCH CLASSIFICATION SYSTEM [SARCS]

(As used in the National Research and Technology Audit surveys)

LIST A MAIN DISCIPLINES

1000 NATURAL SCIENCES AND ENGINEERING

1100 AGRICULTURAL SCIENCES
1101 Agricultural economics
1102 Agriculture
1103 Agricultural engineering
1104 Agrometereology
1105 Animal production
1106 Fisheries
1107 Food sciences and technology
1108 Forest science
1109 Horticulture
1110 Plant production
1111 Soil and water sciences
1112 Veterinary science
1113 Wood science
1114 Plant Pathology

1200 BIOLOGICAL SCIENCES
1201 Biology, General
1202 Biochemistry
1203 Bio-engineering
1204 Botany
1205 Fresh water biology and limnology
1206 Genetics
1207 Microbiology
1208 Molecular and cell biology
1209 Zoology

1300 CHEMICAL SCIENCES
1301 Analytical Chemistry
1302 Chemistry, General
1303 Inorganic Chemistry
1304 Physical Chemistry
1305 Organic Chemistry

1400 EARTH & MARINE SCIENCES
1401 Atmospheric science/ meteorology
1402 Ecology/ environmental science
1403 Geochemistry
1404 Geology
1405 Geophysics
1406 Geochemistry
1408 Hydrology
1409 Marine biology
1410 Marine engineering & naval architecture
1411 Oceanology
1412 Space/earth science
1413 Physical Geography

1500 INFORMATION AND COMPUTER SCIENCES
1501 Information systems and technologies
1502 Computer hardware
1503 Computer software
1504 Communication technologies
1505 Health informatics
1506 Other information/computer technologies

1600 MATHEMATICAL SCIENCES
1601 Applied mathematics
1602 Biometrics
1603 Pure mathematics
1604 Operations research
1605 Statistics and Probability

1700 PHYSICAL SCIENCES
1701 Astronomy
1702 Atomic, molecular and nuclear physics
1703 Biophysics
1704 Particle and plasma physics
1705 Phenomenological physics (incl. acoustics, optics, magnetism and electricity)
1706 Theoretical and condensed matter physics

1800 ENGINEERING SCIENCES
1801 Chemical engineering
1802 Civil engineering
1803 Electrical engineering
1804 Electronic engineering
1805 Engineering management
1806 Industrial engineering
1807 Mechanical engineering
1808 Metallurgical engineering
1809 Mining engineering
1810 Nuclear engineering

1811 Minerals engineering

1900 TECHNOLOGIES AND APPLIED SCIENCES
1901 Aerospace and aeronautical engineering
1902 Architecture
1903 Automotive engineering
1904 Food sciences and technology
1905 Health technology
1906 Industrial design
1907 Manufacturing and process technologies
1908 Material sciences and technologies
1909 Quantity surveying
1910 Textile/clothing technologies
1911 Mining studies
1912 Energy studies
1913 Ergonomics

2000 MEDICAL AND HEALTH SCIENCES

2100 MEDICAL SCIENCES: BASIC
2101 Anatomical Pathology
2102 Chemical Pathology
2103 Endocrinology - basic
2104 Haematology - basic
2105 Immunology - basic
2106 Morphology
2107 Neuroscience
2108 Nutrition and Metabolism - basic
2109 Pharmacology
2110 Physiology
2111 Toxicology
2112 Pharmaceutics
2113 Anatomy

2200 MEDICAL SCIENCES: CLINICAL
2201 Anaesthesia and Pain Management
2202 Cardiovascular Diseases
2203 Dental Sciences
2204 Dermatology
2205 Diabetology
2206 Embryology and Fetal Development
2207 Endocrinology - clinical
2208 Gastrointestinal Diseases
2209 General Practice
2210 Genito-urinary Diseases, incl. Urology
2211 Geriatrics
2212 Gynaecology
2213 Haematology - clinical
2214 Immunology - clinical
2215 Infectious Diseases - clinical
2216 Intensive Care
2217 Metabolic Diseases
2218 Neurology
2219 Nuclear Medicine and Organ Imaging
2220 Obstetrics and Maternal Health
2221 Oncology
2222 Ophthalmology
2223 Orthopaedics
2224 Otorhinolaryngology
2225 Paediatrics and Child Health
2226 Psychiatry
2227 Rehabilitation Medicine (occupational + physiotherapy)
2228 Respiratory Diseases
2229 Rheumatology
2230 Sports Medicine
2231 Surgery
2232 Internal medicine
2233 Family medicine
2234 Radiography
2235 Optometry
2236 Hepatology
2237 Speech pathology

2300 HEALTH SCIENCES
2301 Biostatistics
2302 Environmental Health + occupational health
2303 Epidemiology, incl. Burden of Disease
2304 Health Promotion and Disease Prevention
2305 Health Systems Research
2306 Infectious Diseases
2307 Mental health and Substance Abuse
2308 Nutrition
2309 Trauma
2310 Paramedical sciences

3000 HUMAN SCIENCES

3100 SOCIAL SCIENCES
3101 Anthropology
3102 Communication and media studies (incl. journalism)
3103 Criminology
3104 Cultural studies
3105 Demography (population studies)
3106 Development studies
3107 Education
3108 Environmental studies
3109 Geography
3110 Home economics

3111	Industrial psychology/sociology	3112	Information and library science
3113	Nursing science	3114	Political sciences and public policy
3115	Psychology	3116	Social work
3117	Sociology	3118	Town and urban planning
3119	Human movement science (+ sport)	3120	Science and Technology Studies

3200	ECONOMIC SCIENCES		
3201	Accounting	3202	Business economics
3203	Business administration/management	3204	Economics
3205	Financial management	3206	Public management + administration
3207	Administrative + secretarial studies	3208	Business studies

3300	HUMANITIES		
3301	Archaeology	3302	Classics
3303	Historical studies / History	3304	Languages and literature
3305	Law	3306	Linguistics
3307	Philosophy	3308	Religious studies
3309	Theology		

3400	ARTS		
3401	Decorative arts	3402	Design studies
3403	Dramatic arts	3404	Fine arts
3405	Musicology	3406	Painting
3407	Photography + video technology	3408	Performing arts
3409	Sculpture	3410	Theater

LIST B: AREAS OF SPECIALISATION

1000 NATURAL SCIENCES, ENGINEERING AND TECHNOLOGY

100101	ABORICULTURE	100102	ACOUSTICS
100103	AERODYNAMICS	100104	AERONAUTICS
100105	AGRICULTURAL ENERGY	100106	AGRICULTURAL MATERIALS
100107	AGRICULTURAL STORAGE	100108	AGRICULTURAL TRANSPORTATION
100109	AGRICULTURAL WASTE	100110	AIR FRAME STRUCTURES
100111	AIR POLLUTION CONTROL	100112	ALGEBRA
100113	ALGEBRAIC GEOMETRY	100114	AMPHIBIANS
100115	ANIMAL BREEDING	100116	ANIMAL MANAGEMENT
100117	ANIMAL NUTRITION	100118	ANIMAL PHYSIOLOGY
100119	ANIMAL PRODUCTS	100120	ANIMAL VIROLOGY
100121	ANTENNAS & RADIATION	100122	APPLIED CHEMISTRY
100123	APPLIED PHYSICS	100124	APPLIED STATISTICS
100125	APPROXIMATION THEORY	100126	AQUACULTURE
100127	AQUATIC ECOLOGY	100128	ARACHNOLOGY
100129	ARCHAEOZOOLOGY	100130	ARCHITECTURAL DESIGN
100131	ARTIFICIAL INTELLIGENCE	100132	ASSOCIATIVE RINGS & ALGEBRAS
100133	ASTRONAUTICS	100134	ASTRONOMICAL INSTRUMENTS
100135	ASTROPHYSICS	100136	ASYMPTOTIC THEORY
100137	ATMOSPHERIC CHEMISTRY	100138	ATMOSPHERIC PHYSICS
100139	ATOMS & MOLECULES	100140	AUTECOLOGY
100141	AVIAN MEDICINE	100142	AGRICULTURAL CHEMISTRY
100143	ANIMAL SURGERY		

100201	BACTERIOLOGY	100202	BIODIVERSITY
100203	BIOENERGETICS	100204	BIOGEOGRAPHY
100205	BIOINORGANIC CHEMISTRY	100206	BIOMATERIALS
100207	BIOMECHANICS	100208	BUILDING MANAGEMENT
100209	BUILDING SCIENCE	100210	BIOTECHNOLOGY
100211	BREWING TECHNOLOGY		

100301	CADASTRAL SURVEYING	100302	CARBOHYDRATES
100303	CARTOGRAPHY	100304	CASTING TECHNOLOGY
100305	CATALYSIS	100306	CATEGORY THEORY
100307	CELL BIOLOGY	100308	CERAMICS
100309	CHROMATOGRAPHY	100310	CIRCUIT THEORY
100311	CIRCUITS	100312	CLASSICAL DYNAMICS
100313	CLIMATOLOGY	100314	COAL CONVERSION
100315	COAL GEOLOGY	100316	COAL UTILIZATION
100317	COASTAL ENGINEERING	100318	COGNITIVE SCIENCE
100319	COLLOID CHEMISTRY	100320	COMBINATORICS
100321	COMMUTATIVE RINGS & ALGEBRAS	100322	COMPANION ANIMAL MED & SURGERY
100323	COMPLEX ANALYSIS	100324	COMPLEX VARIABLES / ANALYTIC SP.
100325	COMPOSITES	100326	COMPUTATIONAL CHEMISTRY
100327	COMPUTATIONAL FLUID DYNAMICS	100328	COMPUTATIONAL MECHANICS
100329	COMPUTATIONAL PHYSICS	100330	COMPUTER AIDED DESIGN AND MANUFACTURING
100331	COMPUTER ENGINEERING	100332	COMPUTER GRAPHICS
100333	COMPUTER HARDWARE SYSTEMS	100334	COMPUTER INTEGRATED MANUFACTURING
100335	COMPUTER LANGUAGES	100336	COMPUTER MODELLING
100337	COMPUTER NETWORKS	100338	COMPUTER OPERATIONS
100339	COMPUTER-HUMAN INTERFACE	100340	CONDENSED MATTER
100341	CONDITION MONITORING	100342	CONSERVATION BIOLOGY
100343	CONSERVATION ECOLOGY	100344	CONSTRUCTION & DESIGN
100345	CONSTRUCTION MANAGEMENT	100346	CONSTRUCTION MATERIALS
100347	CONTINUUM MECHANICS	100348	CONTROL SYSTEMS
100349	CONTROL THEORY	100350	COORDINATION CHEMISTRY
100351	CORROSION	100352	COSMOLOGY
100353	CROPS	100354	CRYSTAL CHEMISTRY
100357	CRYSTALLOGRAPHY	100356	CYBERNETICS
100359	CYTOGENETICS	100358	CYTOLOGY
100401	DAIRY TECHNOLOGY	100402	DATA COMMUNICATION
100403	DATABASE SYSTEMS	100404	DECISION THEORY
100405	DEMOGRAPHICS	100406	DESIGN & PLANNING
100407	DEVELOPMENTAL BIOLOGY	100408	DEVELOPMENTAL GEOGRAPHY
100409	DIFFERENTIAL EQUATIONS	100410	DIGITAL SYSTEMS
100411	DISCRETE MATHEMATICS	100412	DISTRIBUTION THEORY
100413	DOCUMENT PROCESSING		
100501	ECONOMIC GEOLOGY	100502	ECOPHYSIOLOGY
100503	ELECTRICAL DISCHARGES	100504	ELECTROCHEMISTRY
100505	ELECTRODYNAMICS	100506	ELECTROMAGNETICS
100507	ELECTROMECHANICAL ENERGY CONVERSION	100508	ELECTROMECHANICAL FIELDS
100509	ELECTROMETALLURGY	100510	ELECTRON MICROSCOPY
100511	ELECTRONIC MATERIALS	100512	ELEMENTARY PARTICLES
100513	EMBRYOLOGY	100514	ENERGY GENERATION
100515	ENERGY MANAGEMENT	100516	ENGINEERING ECONOMY
100517	ENGINEERING GEOLOGY	100518	ENGINEERING MECHANICS
100519	ENGINEERING SURVEYING	100520	ENTOMOLOGY
100521	ENVIRONMENTAL BIOTECHNOLOGY	100522	ENVIRONMENTAL CHEMISTRY
100523	ENVIRONMENTAL CONTROL	100524	ENVIRONMENTAL ENGINEERING
100525	ENVIRONMENTAL GEOLOGY	100526	ENVIRONMENTAL MANAGEMENT
100527	ENVIRONMENTAL PROTECTION	100528	ENZYMOLOGY
100529	ERGONOMICS	100530	ETHNOBOTANY
100528	ETHOLOGY	100532	EVOLUTION
100529	EXPERIMENTAL DESIGN	100534	EXPERT SYSTEMS
100531	EXTRACTIVE METALLURGY		
100601	FARM MACHINERY	100602	FARM STRUCTURES + MANAGEMENT
100603	FATIGUE	100604	FERMENTATION
100605	FISH BIOLOGY	100606	FISHERIES MANAGEMENT
100607	FLIGHT DYNAMICS	100608	FLUID DYNAMICS
100609	FLUID MECHANICS	100610	FLUIDISATION
100611	FLUIDS & PLASMAS	100612	FOOD MICROBIOLOGY
100613	FOOD PROCESSING + TECHNOLOGY	100614	FORENSICS
100615	FOREST ECONOMICS	100616	FOREST ENGINEERING TECHNOLOGY
100617	FOREST MANAGEMENT	100618	FOREST PRODUCTS

100619 FOREST PROTECTION
100620 FOREST UTILISATION
100621 FOUNDATIONS OF PHYSICS
100622 FRUIT PRODUCTION
100623 FRUIT TECHNOLOGY
100624 FUEL PRODUCTION
100625 FUNCTIONAL ANALYSIS
100626 FUNCTIONS OF COMPLEX VARIABLES

100701 GAME FARMING
100702 GAME THEORY
100703 GAMMA-RAY ASTRONOMY
100704 GAS DYNAMICS
100705 GENERAL BIOCHEMISTRY
100706 GENERAL MICROBIOLOGY
100707 GENESIOLOGY
100708 GENETIC ENGINEERING
100709 GEOARCHAEOLOGY
100710 GEOCHRONOLOGY
100711 GEOHYDROLOGY
100712 GEOMAGNETISM
100713 GEOMETRY
100714 GEOMORPHOLOGY
100715 GEOSTATISTICS
100716 GEOTECHNICAL ENGINEERING
100717 GIS
100718 GLACIOLOGY
100719 GRAIN TECHNOLOGY
100720 GRAPH THEORY
100721 GRAVITATION
100722 GREENHOUSE & NURSERY
100723 GROUND & AIR SUPPORT
100724 GROUP THEORY & GENERALISATION

100801 HEAT TRANSFER
100802 HERPETOLOGY
100803 HETEROCYCLIC CHEMISTRY
100804 HISTOLOGY
100805 HYDRAULIC ENGINEERING
100806 HYDRO METALLURGY

100901 ICHTHYOLOGY
100902 IMAGE PROCESSING
100903 INFERENCE
100904 INFORMATION MANAGEMENT
100905 INFORMATION SECURITY
100906 INFORMATION SYSTEMS
100907 INFORMATION THEORY
100908 INFRA-RED ASTRONOMY
100909 INSECT VIROLOGY
100910 INSTRUMENTATION
1009011 INTEGRATED CIRCUITS
100912 INTERNAL COMBUSTION ENGINES
100913 INVERTEBRATES
100914 IRONMAKING
100915 IRRIGATION

101001 KINETICS

101201 LABORATORY ANIMAL MEDICINE
101202 LAND RECLAMATION
101203 LANDSCAPING
101204 LICHENOLOGY
101205 LIE GROUPS
101206 LIMNOLOGY
101207 LOGIC & FOUNDATIONS
101208 LEATHER SCIENCE + TECHNOLOGY

101301 MACRO-MOLECULAR CHEMISTRY
101302 MAGNETISM
101303 MALACOLOGY
101304 MAMMALOGY
101305 MANUFACTURING PROCESSES
101306 MARINE CHEMISTRY
101307 MARINE ECOLOGY
101308 MARINE EQUIPMENT
101309 MARINE GEOSCIENCE
101310 MARINE POLLUTION
101311 MARINE PROPULSION
101312 MATERIALS
101313 MATHEMATICAL METEOROLOGY
101314 MATHEMATICAL MODELLING
101315 MATHEMATICAL PHYSICS
101316 MATHEMATICAL PROGRAMMING
101317 MEAT TECHNOLOGY
101318 MECHANICAL DESIGN
101319 MECHANICAL METALLURGY
101320 MECHANICS
101321 MEMBRANES
101322 MEMORY STRUCTURES
101323 METABOLISM
101324 METAL CASTING
101325 METAL FORMING
101326 METALS
101327 METAMORPHIC PETROLOGY
101328 METEORITICS
101329 METEOROLOGY
101330 MICROBIAL GENETICS
101331 MICROELECTRONICS
101332 MICROMETEOROLOGY
101333 MICROSCOPY
101334 MICROWAVES
101335 MIDDLE & UPPER ATMOSPHERE
101336 MINE CLIMATIC CONTROL
101337 MINE DESIGN
101338 MINE VALUATION
101339 MINERAL BENEFICIATION
101340 MINERAL ECONOMICS
101341 MINERAL PROCESSING
101342 MINERALOGY
101343 MINING GEOLOGY
101344 MINING METHODS
101345 MOLECULAR GENETICS
101346 MORPHOLOGY
101347 MYCOLOGY

101401 NATURAL PRODUCTS CHEMISTRY
101402 NAVIGATION
101403 NEMATOLOGY
101404 NEURAL NETWORKS
101405 NEUROBIOLOGY
101406 NON-ASSOCIATIVE RINGS & ALGEBR A
101407 NONDESTRUCTIVE TESTING
101408 NON-FERROUS METALS

101409 NONPARAMETRIC STATISTICS
101410 NUCLEAR CHEMISTRY
101411 NUCLEAR INSTRUMENTATION
101412 NUCLEAR MEDICINE
101413 NUMBER THEORY
101414 NUMERICAL ANALYSIS
101415 NUMERICAL COMPUTATION
101416 NUMERICAL MATHEMATICS
101417 NURSERY TECHNOLOGY

101501 OFFSHORE ENGINEERING
101502 OPEN CAST MINING
101503 OPERATING SYSTEMS
101504 OPERATIONAL DESIGN
101505 OPERATIONS MANAGEMENT
101506 OPERATOR THEORY
101507 OPTICAL AND PHOTONIC SYSTEMS
101508 OPTICAL ASTRONOMY
101509 OPTICS & LASERS
101510 OPTIMISATION
101511 OPTOELECTRONICS
101512 ORCHARD PHYSIOLOGY
101513 ORE DEPOSITS
101514 ORGANOMETALLICS
101515 ORNAMENTAL PLANTS
101516 ORNITHOLOGY
101517 OZONES STUDIES
101518 OENOLOGY (WYNKUNDE)
101519 OXIDATION

101601 PALAEONTOLOGY
101602 PALYNOLOGY
101603 PARALLEL COMPUTATION
101604 PARALLEL PROCESSING AND ARCHITECTURE
101605 PARASITOLOGY
101606 PARKS
101607 PARTICLE TECHNOLOGY
101608 PASTURES
101609 PEDOLOGY
101610 PESTS & DISEASES
101611 PETROCHEMICALS
101612 PETROLOGY
101613 PHOTOCHEMISTRY
101614 PHYCOLOGY
101615 PHYSICAL METALLURGY
101616 PHYSICAL OCEANOGRAPHY
101617 PHYSICAL PHARMACY
101618 PHYSIOLOGICAL CHEMISTRY
101619 PLANETARY GEOLOGY
101620 PLANETARY SCIENCE
101621 PLANT BREEDING
101622 PLANT CONTROL
101623 PLANT NUTRITION
101624 PLANT PHYSIOLOGY
101625 PLANT PRODUCTS
101626 PLANT REPRODUCTION
101627 PLANT VIROLOGY
101628 PLASMAS
101629 PLASTICS
101630 POLYMERS
101631 POPULATION DYNAMICS
101632 POSITIONAL ASTRONOMY
101633 POWER ELECTRONICS
101634 POWER ENGINEERING
101635 POWER SYSTEMS
101636 PRIMATOLOGY
101637 PROBABILITY THEORY
101638 PROCESS CONTROL
101639 PRODUCT DEVELOPMENT
101640 PRODUCTION ANIMAL MED & SURGERY
101641 PRODUCTION MANAGEMENT
101642 PRODUCTION SYSTEMS
101643 PROGRAMMING SYSTEMS
101644 PROGRAMMING TECHNIQUES
101645 PROJECT MANAGEMENT
101646 PROPAGATION
101647 PROPULSION SYSTEMS
101648 PROTOZOOLOGY
101649 PULP & PAPER
101650 PYROMETALLURGY
101651 PLANT PATHOLOGY
101652 PHYTOCHEMISTRY / PLANT CHEMISTRY

101701 QUALITY ASSURANCE
101702 QUANTUM CHEMISTRY
101703 QUANTUM FIELDS
101704 QUANTUM PHYSICS
101705 QUATERNARY GEOLOGY

101801 RADIATION CONTROL
101802 RADIATION DAMAGE
101803 RADIO ASTRONOMY
101804 RADIO COMMUNICATION AND BRAODCASTING
101805 RADIOBIOLOGY
101806 RADIOLOGY
101807 RADIOPHARMACY
101808 RADURISATION
101809 REACTOR DESIGN
101810 REACTOR ENGINEERING
101811 REACTOR OPERATION
101812 REAL ANALYSIS
101813 REAL FUNCTIONS
101814 REAL-TIME COMPUTING
101815 REGIONAL GEOGRAPHY
101816 REGRESSION & CORRELATION
101817 RELATIVITY
101818 RELIABILITY THEORY
101819 REMOTE SENSING
101820 RENEWABLE ENERGY
101821 REPRODUCTION
101822 RESOURCE ECOLOGY
101823 ROAD ENGINEERING
101824 ROBOTICS
101825 ROCK BORING
101826 ROCK BREAKING
101827 ROCK MECHANICS
101828 ROCK SUPPORT SYSTEMS
101829 RAINFALL STUDIES
101830 RADIOTHERAPY
101831 RADIO ISOTOPES
101832 RADIATION PHYSICS
101833 REGIONAL GEOLOGY
101834 REFRIDGERATION
101835 RUBBER TECHNOLOGY

101901 SAMPLING
101902 SANITATION SYSTEMS
101903 SAWMILLING
101904 SEA-KEEPING CHARACTERISTICS
101905 SEDIMENTOLOGY
101906 SEED SCIENCE
101907 SEEDBEARING PLANTS
101908 SEISMOLOGY
101909 SEPARATIONS
101910 SET THEORY
101911 SHAFT SINKING
101912 SHIP STRUCTURES
101913 SIGNAL PROCESSING
101914 SILVICULTURE
101915 SIMULATION
101916 SOFTWARE ENGINEERING
101917 SOFTWARE METHODOLOGY
101918 SOIL & WATER RESOURCES
101919 SOIL BIOLOGY
101920 SOIL CHEMISTRY
101921 SOIL CLASSIFICATION
101922 SOIL CONSERVATION
101923 SOIL FERTILITY
101924 SOIL PHYSICS
101925 SOIL WATER
101926 SOLAR ENERGY
101927 SOLAR SYSTEMS
101928 SOLAR TERRESTRIAL PHYSICS
101929 SOLID STATE CHEMISTRY
101930 SOLID STATE PHYSICS
101931 SOLID WASTE
101932 SPACE SCIENCE
101933 SPATIAL STATISTICS
101934 SPECTROSCOPY
101935 SPEECH RECOGNITION
101936 STARS & STELLAR SYSTEMS
101937 STATISTICAL MODELLING
101938 STATISTICAL PHYSICS
101939 STEELMAKING
101940 STOCHASTIC PROCESSES
101941 STRATA CONTROL
101942 STRATIGRAPHY
101943 STRUCTURAL CHEMISTRY
101944 STRUCTURAL ENGINEERING
101945 STRUCTURAL GEOLOGY
101946 SUPERCONDUCTORS
101947 SURFACE CHEMISTRY
101948 SURFACE PHYSICS
101949 SYNECOLOGY
101950 SYNTHESIS
101951 SYSTEMATICS
101952 SEA POLLUTION CONTROL
101953 SURVEYING + MAPPING

102001 TAXONOMY
102002 TECTONICS
102003 TERRESTRIAL ECOLOGY
102004 TEXTILES
102005 THEORETICAL ASTROPHYSICS
102006 THEORETICAL CHEMISTRY
102007 THEORETICAL COMPUTER SCIENCE
102008 THEORETICAL PHYSICS
102009 THERMAL SCIENCES
102010 THERMODYNAMICS
102011 TIME SERIES ANALYSIS
102012 TISSUE CULTURE
102013 TOPOLOGY
102014 TRAFFIC ENGINEERING
102015 TRANSMISSION SYSTEMS
102016 TRANSPORT PHENOMENA
102017 TRANSPORTATION ENGINEERING
102018 TRIBOLOGY
102019 TUNNELLING

102101 UNDERWATER TECHNOLOGY
102102 URBAN GEOGRAPHY

102201 VASCULAR CRYPTOGAMS
102202 VEGETABLE PRODUCTION
102203 VEGETABLE TECHNOLOGY
102204 VEHICLE DYNAMICS
102205 VEHICLE GUIDANCE
102206 VEHICLE STRUCTURES
102207 VELD MANAGEMENT
102208 VERTEBRATES
102209 VETERINARY ANATOMY
102210 VETERINARY PATHOLOGY
102211 VETERINARY PUBLIC HEALTH
102212 VIROLOGY
102213 VIRTUAL REALITY AND RELATED SIMULATIONS
102214 VACINOLOGY
102215 VOLCANOLOGY
102216 VITICULTURE

102301 WASTE MANAGEMENT
102302 WASTE REPROCESSING
102303 WASTE WATER
102304 WATER QUALITY
102305 WATER RESOURCES
102306 WATER TREATMENT
102307 WAVES
102308 WEED CONTROL
102309 WELDING
102310 WILDLIFE BIOLOGY
102311 WILDLIFE MANAGEMENT
102312 WILDLIFE MEDICINE
102313 WINE TECHNOLOGY
102314 WOOD DRYING
102315 WOOD PROPERTIES
102316 WOOD TECHNOLOGY
102317 WEAPON SYSTEMS

102401 X-RAY ASTRONOMY

102501 YEASTS

2000 MEDICAL AND HEALTH SCIENCES

200101 AIDS/HIV
200102 ALGAE AND FUNGI
200103 AMINO ACIDS
200104 ANESTHESIA AND ANALGESIA
200105 ANIMAL DISEASES
200106 ANIMAL TERMS
200107 ANTI-ALLERGIC AGENTS
200108 ANTI-INFECTIVE AGENTS
200109 ANTI-INFLAMMATORY AGENTS
200110 ANTI-RHEUMATIC AGENTS
200111 ANTI-NEOPLASTICS

200201 BACTERIA
200202 BACTERIAL AND FUNGAL DISEASES
200203 BEHAVIOURAL DISORDERS
200204 BIO-ETHICS
200205 BIO-INFORMATICS
200206 BIOMEDICAL AND DENTAL MATERIALS
200207 BIOMEDICAL SYSTEMS
200208 BIOPHARMACEUTICS
200209 BIOPHYSICS
200210 BIOSTATISTICS
200211 BIOSYNTHESIS
200212 BIOSYSTEMATICS
200213 BODY REGIONS
200214 BONE RESEARCH

200301 CARBOHYDRATES
200302 CARDIOVASCULAR AGENTS
200303 CARDIOVASCULAR DISEASES
200304 CARDIOVASCULAR SYSTEM
200305 CELLS
200306 CENTRAL NERVOUS SYSTEM AGENTS
200307 CLINICAL INFORMATION SYSTEMS
200308 COENZYMES
200309 CLINICAL TRIALS
200310 CARDIOTHORACIC SURGERY
200311 CHIROPRACTICS

200401 DENTAL TECHNOLOGY
200402 DENTISTRY
200403 DERMATOLOGIC AGENTS
200404 DERMATOPHARMACY
200405 DIAGNOSIS
200406 DIGESTIVE SYSTEM
200407 DIGESTIVE SYSTEM DISEASES

200501 EMBRYONIC STRUCTURES
200502 ENDOCRINE DISEASES
200503 ENDOCRINE SYSTEM
200504 ENVIRONMENTAL HEALTH
200505 ENVIRONMENTAL POLLUTANTS
200506 ENZYMES
200507 ENZYME INHIBITORS
200508 EPIDEMIOLOGY
200509 EYE DISEASES

200601 FEMALE GENITAL DISEASES
200602 FLUIDS AND SECRETIONS

200701 GROWTH SUBSTANCES

200801 HEALTH INFORMATION STANDARDS
200802 HEALTH INFORMATION SYSTEMS
200803 HEMATOLOGIC, GASTRIC, RENAL AGENTS
200804 HEMIC AND IMMUNE SYSTEMS
200805 HEMIC AND LYMPHATIC DISEASES
200806 HETEROCYCLIC COMPOUNDS
200807 HORMONES, SUBSTITUTES, ANTAGONISTS
200808 HOSPITAL INFORMATION SYSTEMS
200809 HUMAN PHYSIOLOGY
200810 HYPOGLYCEMIC AGENTS
200811 HEALTH ECONOMY
200812 HOMEOPATHY

200901 IMMUNOSUPPRESSIVES
200902 IMMUNOLOGIC AND BIOLOGIC FACTORS
200903 IMMUNOLOGIC DISEASES
200904 INDUSTRIAL PHARMACY
200905 INJURY, POISONING
200906 INORGANIC CHEMICALS
200907 INVERTEBRATES
200908 LIPIDS AND ANTILIPEMIC AGENTS

201301 MALARIA
201302 MENTAL DISORDERS
201303 MENTAL HEALTH
201304 MUSCULOSKELETAL DISEASES
201305 MUSCULOSKELETAL SYSTEM
201306 MEDICAL PHYSICS
201307 MEDICAL GENETICS
201308 MEDICAL MICROBIOLOGY
201309 MEDICAL BIOCHEMISTRY
201310 MEDICAL VIROLOGY

201401 NEONATAL DISEASES
201402 NEOPLASMS
201403 NERVOUS SYSTEM
201404 NERVOUS SYSTEM DISEASES
201405 NEUROTRANSMITTERS
201406 NOXAE
201407 NUCLEIC ACIDS
201408 NUCLEOTIDES
201409 NUCLEOSIDES
201410 NUTRITIONAL AND METABOLIC DISEASES
201411 NUTRITIONAL PHYSIOLOGY

201501 OCCUPATIONAL HEALTH + DISEASES
201502 ORGANIC CHEMICALS
201503 OTORHINOLARYNGOLOGIC DISEASES

201601 PARASITIC DISEASES
201602 PEPTIDES

201603 PERIPHERAL NERVOUS SYSTEM AGENTS
201604 PESTICIDES
201605 PHARMACEUTICAL BIOCHEMISTRY
201606 PHARMACEUTICAL CHEMISTRY
201607 PHARMACEUTICS
201608 PHARMACOGNOSY
201609 PHARMACOKINETICS
201610 PIGMENTS
201611 POLYCYCLIC HYDROCARBONS
201612 PROTEINS

201801 REPRODUCTIVE CONTROL AGENTS
201802 RESPIRATORY SYSTEMS
201803 RESPIRATORY TRACT DISEASES

201901 SENSE ORGANS
201902 SKIN AND CONNECTIVE TISSUE DISEASES
201903 STD's
201904 STOMATOGNATHIC DISEASES
201905 STOMATOGNATHIC SYSTEM
201906 SUBSTANCE ABUSE
201907 SURGERY, OPERATIVE
201908 SYMPTOMS AND GENERAL PATHOLOGY
201909 SOMATOLOGY / BEAUTY SCIENCES

202001 TELEMATICS
202002 TELEMEDICINE
202003 THERAPEUTICS
202004 TISSUE TYPES
202005 TRAUMA
202006 TUBERCULOSIS

202101 UROGENITAL SYSTEM
202103 UROLOGIC AND MALE GENITAL DISEASES

202201 VERTEBRATES
202202 VIRUS DISEASES
202203 VIRUSES
202204 VITAMINS

3000 HUMAN SCIENCES

300101 ACADEMIC DEVELOPMENT
300102 ADMINISTRATIVE LAW
300103 ADULT EDUCATION
300104 ADVERTISING
300105 AESTHETICS
300106 AFRICAN LANGUAGES AND LITERATURE
300107 AFRIKAANS LANGUAGE AND LITERATURE
300108 AGRARIAN GUIDANCE
300109 AGRICULTURAL DEVELOPMENT
300110 AGRICULTURAL ECONOMICS
300111 APPLIED ETHICS
300112 APPLIED LINGUISTICS
300113 ARABIC LANGUAGE AND LITERATURE
300114 ARAMAIC LANGUAGE AND LITERATURE
300115 ARCHIVES
300116 ART - HISTORY OF
300117 ARTIFICIAL INTELLIGENCE
300118 AUDITING AND ACCOUNTABILITY
300119 ACTUARIAL SCIENCE
300120 AFRICAN STUDIES

300201 BANKS AND BANKING
300202 BIO-KINETICS
300203 BIOLOGY EDUCATION
300204 BUDDHISM
300205 BUILDING MANAGEMENT
300206 BUSINESS COMMUNICATION
300207 BUSINESS ETHICS
300208 BUSINESS INFORMATION SYSTEMS
300301 CAREER GUIDANCE
300302 CHILD PSYCHOLOGY
300303 CHRISTIAN THEOLOGY
300304 CHURCH HISTORY
300305 CITY PLANNING
300306 CIVIL PROCEDURE
300307 CLASSICAL LANGUAGES AND LITERATURE
300308 CLINICAL PSYCHOLOGY
300309 COGNITIVE STUDIES
300310 COMMERCE
300311 COMMERCIAL LAW
300312 COMMUNITY DEVELOPMENT
300313 COMMUNITY HEALTH
300314 COMMUNITY PSYCHOLOGY
300315 COMPANY LAW
300316 COMPARATIVE EDUCATION
300317 COMPARATIVE LAW
300318 COMPUTER GRAPHICS
300319 COMPUTER-ASSISTED INSTRUCTION
300320 CONFLICT STUDIES
300321 CONSTITUTIONAL LAW
300322 CONSUMER BEHAVIOUR
303023 CONTRACTS LAW
300324 CORRECTIONAL SERVICES
300325 COST ACCOUNTING
300326 COUNSELLING PSYCHOLOGY
300327 CRIMINAL LAW
300328 CROSS-CULTURAL STUDIES
300329 CULTURAL HISTORY
300330 CURRICULUM DEVELOPMENT
300331 CUSTOMARY LAW
300332 CRIME STUDIES
300333 CONSTITUTIONAL STUDIES

300401 DEVELOPMENT ECONOMICS
300402 DEVELOPMENTAL PSYCHOLOGY
300403 DIACONOLOGY
300404 DIDACTICS
300405 DISCOURSE ANALYSIS
300406 DISTANCE EDUCATION
300407 DOGMATOLOGY
300408 DUTCH LANGUAGE AND LITERATURE

300501 ECCLESIASTICAL LAW
300502 ECONOMETRICS
300503 ECONOMIC HISTORY
300504 ECONOMIC MODELS AND FORECASTING
300505 ECONOMIC SYSTEMS
300506 ECONOMIC THEORY
300507 EDUCATION - HISTORY OF
300508 EDUCATION - PHILOSOPHY OF
300509 EDUCATION - SOCIOLOGY OF
300510 EDUCATIONAL ADMINISTRATION + MANAGEMENT
300511 EDUCATIONAL POLICY
300512 EDUCATIONAL PSYCHOLOGY
300513 EGYPTOLOGY
300514 ENGLISH LANGUAGE AND LITERATURE
300515 ENGLISH SECOND LANGUAGE TEACHING
300516 ENTREPRENEURSHIP
300517 ENVIRONMENTAL EDUCATION
300518 ENVIRONMENTAL LAW
300519 ENVIRONMENTAL
300520 ETHICS
300521 ENVIRONMENTAL ECONOMICS
300522 ETHNOLOGY
300523 ETHNICITY AND RACE RELATIONS
300524 EXPERT SYSTEMS
300525 EVALUATION RESEARCH

300601 FAMILY LAW
300602 FAMILY STUDIES
300603 FINANCE, PUBLIC
300604 FINANCIAL ECONOMICS
300605 FORENSIC PSYCHOLOGY
300606 FRENCH LANGUAGE AND LITERATURE
300607 FUNDAMENTAL PEDAGOGICS
300608 FUTURE STUDIES

300701 GENDER STUDIES
300702 GENEALOGY
300703 GERMAN LANGUAGE AND LITERATURE
300704 GERONTOLOGY
300705 GRAPHIC ARTS
300706 GREEK LANGUAGE AND LITERATURE

300801 HARMONY
300802 HEALTH PSYCHOLOGY
300803 HEBREW LANGUAGE AND LITERATURE
300804 HERMENEUTICS
300805 HIGHER EDUCATION STUDIES
300806 HINDUISM
300807 HISTORICAL LINGUISTICS
300808 HISTORIOGRAPHY
300809 HISTORY: AFRICAN
300810 HISTORY: ANCIENT
300811 HISTORY: ASIAN AND THE PACIFIC
300812 HISTORY: EUROPEAN
300813 HISTORY: AMERICAN
300814 HISTORY: SOUTH AFRICAN
300815 HUMAN MOVEMENT SCIENCE
300816 HUMAN RESOURCES MANAGEMENT
300817 HUMAN RIGHTS
300818 HOSPITALITY STUDIES (HOTELS, CATERING)

300901 INDIAN LANGUAGES AND LITERATURE
300902 INDIGENOUS LAW
300903 INDUSTRIAL LAW
300904 INDUSTRIAL RELATIONS
300905 INFORMAL LOGIC
300906 INFORMAL SETTLEMENTS
300907 INFORMATION MANAGEMENT
300908 INFORMATION RETRIEVAL
300909 INFORMATION SERVICES
300910 INFORMATION SYSTEMS
300911 INFORMATION TECHNOLOGY
300912 INHERITANCE AND SUCCESSION
300913 INSOLVENCY LAW
300914 INSURANCE LAW
300915 INTERCULTURAL COMMUNICATION
300916 INTER-GROUP RELATIONS
300917 INTERIOR DESIGN
300918 INTERNATIONAL ECONOMICS
300919 INTERNATIONAL LAW
300920 INTERNATIONAL RELATIONS
300921 INTERNATIONAL TRADE
300922 ISLAMIC STUDIES
300923 ITALIAN LANGUAGE AND LITERATURE
300924 IMPACT ASSESSMENT
300925 INDUSTRIAL DEVELOPMENT
300926 INDUSTRIAL POLICY

301001 JOURNALISM
301002 JURISPRUDENCE
301003 JUVENILE DELINQUENCY

301201 LABOUR ECONOMICS
301202 LABOUR LAWS AND LEGISLATION
301203 LAND LAW
301204 LAND REFORM
301205 LANGUAGE ACQUISITION
301206 LANGUAGE PLANNING
301207 LANGUAGE TEACHING
301208 LATIN LANGUAGE AND LITERATURE
301209 LAW - PHILOSOPHY OF
301210 LAW OF DELICT
301211 LAW OF PERSONS
301212 LAW OF SUCCESSION
301213 LEADERSHIP STUDIES
301214 LEARNING DISABILITIES
301215 LEGAL HISTORY
301216 LEXICOGRAPHY
301217 LIBERATION THEOLOGY
301218 LITERACY
301219 LITERARY THEORY
301220 LOCAL GOVERNMENT
301221 LOGIC
301222 LAW REFORM
301223 LOGISTICS MANAGEMENT

301301 MACRO-ECONOMICS
301302 MANAGEMENT ACCOUNTING
301303 MARITIME LAW
301304 MARKETING
301305 MATHEMATICS EDUCATION
301306 MEDIEVAL STUDIES
301307 MEMORY
301308 METAPHYSICS

301309 MIDDLE EASTERN STUDIES
301310 MIGRATION
301311 MILITARY HISTORY
301312 MILITARY SCIENCE
301313 MISSIONOLOGY
301314 MOTIVATION
301315 MULTICULTURAL EDUCATION
301316 MUNICIPAL GOVERNMENT
301317 MUSEUM SCIENCES
301318 MUSIC - HISTORY
301319 MUSIC EDUCATION
301320 MARITIME STUDIES

301401 NARRATION (RHETORIC)
301402 NEURO-PSYCHOLOGY
301403 NEW TESTAMENT STUDIES
301404 NON-FORMAL EDUCATION
301405 NORTHERN SOTHO LANGUAGE AND LITERATURE

301501 OLD TESTAMENT STUDIES
301502 ONOMASTICS
301503 ONTOLOGY
301504 OPERATIONAL MANAGEMENT
301505 ORAL HISTORY
301506 ORGANIZATIONAL STUDIES
301507 ORTHOPEDAGOGICS

301601 PAINTING
301602 PASTORAL PSYCHOLOGY
301603 PASTORAL THEOLOGY
301604 PENOLOGY
301605 PERCEPTION
301606 PERSIAN LANGUAGE AND LITERATURE
301607 PERSONALITY
301608 PERSONNEL MANAGEMENT
301609 PERSONS (LAW)
301610 PHILOSOPHY - HISTORY OF
301611 PHILOSOPHY OF ART
301612 PHILOSOPHY OF MIND
301613 PHILOSOPHY OF RELIGION
301614 PHILOSOPHY OF SCIENCE
301615 PHOTOGRAPHY
301616 PHYSICAL EDUCATION
301617 POLICE SCIENCE
301618 POLITICAL ECONOMICS
301619 POLITICAL PHILOSOPHY
301620 POLITICAL SOCIOLOGY
301621 PORTUGUESE LANGUAGE AND LITERATUR
301622 PRACTICAL THEOLOGY
301623 PREHISTORY & PHYSICAL ANTHROPOLOGY
301624 PRE-SCHOOL EDUCATION
301625 PRIMARY EDUCATION
301626 PRIMARY HEALTH CARE
301627 PRIVATE INTERNATIONAL LAW
301628 PRIVATE LAW
301629 PROCEDURE (LAW)
301630 PROPERTY (LAW)
301631 PSYCHIATRIC NURSING
301632 PSYCHOPEDAGOGICS
301633 PSYCHO-LINGUISTICS
301634 PSYCHOMETRICS
301635 PSYCHOPATHOLOGY
301636 PSYCHOTHERAPY
301637 PUBLIC ADMINISTRATION
301638 PUBLIC LAW
301639 PUBLIC RELATIONS
301640 PUBLIC POLICY STUDIES
301641 PRODUCTIVITY

301701 QUALITATIVE RESEARCH METHODS
301702 QUANTITATIVE RESEARCH METHODS
301703 QUANTITY SURVEYING

301801 READING
301802 RECREATION AND LEISURE
301803 REGIONAL DEVELOPMENT
301804 REGIONAL ECONOMICS
301805 RELIGION - SOCIOLOGY OF
301806 RESEARCH METHODOLOGY
301807 ROCK ART
301808 ROMAN LAW
301809 ROMANCE LANGUAGES AND LITERATURE
301810 RURAL DEVELOPMENT
301811 RUSSIAN LANGUAGE AND LITERATURE
301812 RISK ASSESSMENT

301901 SANSKRIT LANGUAGE AND LITERATURE
301902 SCHOOL GUIDANCE
301903 SCIENCE EDUCATION
301904 SCIENCE AND TECHNOLOGY POLICY
301905 SCULPTURE
301906 SEMANTICS
301907 SEMITIC LANGUAGES AND LITERATURE
301908 SHONA LANGUAGE AND LITERATURE
301909 SMALL BUSINESS
301910 SOCIAL PROBLEMS
301911 SOCIAL PSYCHOLOGY
301912 SOCIAL THEORY
301913 SOCIO-LINGUISTICS
301914 SOCIOLOGY OF EDUCATION
301915 SOCIOLOGY OF RELIGION
301916 SOUTHERN SOTHO LANGUAGE AND LITERATURE
301917 SPANISH LANGUAGE AND LITERATURE
301918 SPATIAL ARCHAEOLOGY
301919 SPECIAL EDUCATION
301920 SPEECH PATHOLOGY AND AUDIOLOGY
301921 STRATEGIC MANAGEMENT
301922 STRATEGIC STUDIES
301923 STRESS
301924 SWAZI LANGUAGE AND LITERATURE
301925 SYRIAC LANGUAGE AND LITERATURE
301926 SYSTEMATIC THEOLOGY
301927 SOCIAL INDICATORS
301928 SA STUDIES
301929 SECURITY MANAGEMENT

302001 TAX LAW
302002 TEACHER TRAINING
302003 TEACHING
302004 THINKING SKILLS

302005 TOURISM
302006 TOWN AND REGIONAL PLANNING
302007 TRANSLATION
302008 TSWANA LANGUAGE AND LITERATURE
302009 TELEVISION STUDIES
302010 TRANSPORT ECONOMICS

302101 URBAN GEOGRAPHY
302102 URBANIZATION STUDIES
302103 URDU LANGUAGE AND LITERATURE

302201 VEDIC LANGUAGE AND LITERATURE
302202 VENDA LANGUAGE AND LITERATURE
302203 VICTIMOLOGY
302204 VISUAL ARTS
302205 VIOLENCE
302206 VALUE STUDIES

302301 WOMEN'S STUDIES

302401 XHOSA LANGUAGE AND LITERATURE

302501 YIDDISH LANGUAGE AND LITERATURE

302601 ZULU LANGUAGE AND LITERATURE

LIST C SECTORS OF RESEARCH

?? Agriculture, Hunting, Forestry And Fishing
?? Mining And Quarrying
?? Manufacturing
?? Electricity, Gas And Water Supply
?? Construction
?? Wholesale And Retail Trade/Personal And Household Goods
?? Transport And Storage
?? Financial And Business Institutions
?? Community And Social
?? Private Households
?? Defence
?? Educational Services
?? Hospitality Sector
?? Health Sector
?? Communication And Telecommunications

****