Engineers in a Developing Country

The Profession and Education of Engineering Professionals in South Africa

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PREFACE

This monograph on the engineering profession, and the education of engineering professionals, is the third in the Human Sciences Research Council (HSRC) series on professions and professional education. It was preceded by monographs on medical doctors[1] and social workers.[2] A further monograph on nursing is in the pipeline and one on artisans is in progress.

The overall study addresses the following broad question: How are professions and professional education programmes responding to the needs and challenges of a transforming South Africa? It is recognised that many of the hopes and aspirations for South Africa's new democracy depend upon the production of professionals who have globally competitive knowledge and skills, but are also prepared – in all senses of the word – to live and work in this country and to contribute to the national development effort and social transformation.

Each profession is examined through two theoretical lenses:

- Its professional labour markets, both national and international, as well as the markets of other competing professions.
- Its national and international professional milieu, defined as the multiple socio-economic and political conditions, structural arrangements and professional and educational discourses that shape what it means to be a professional, behaving professionally, at a particular juncture in history.

The first task in each of the professional studies is to conduct a preliminary scoping exercise, reviewing major current literature and secondary research, and conducting preliminary analysis of available statistics and preliminary interviews with key stakeholders. Key issues are identified and subsequently explored in greater depth, usually combining quantitative analysis of statistics relating to supply and demand with qualitative research at selected education institutions, at which the identified issues are further explored. In this engineering study, the major issues are the shortage of engineers, the changing demographics of engineering students, and the impact of increasing numbers of women in engineering education.

One of the features of the professional studies is that statistics are disaggregated by race as well as gender wherever possible. International literature on professions barely touches on race issues although the feminisation of professions is addressed. With our history of enforced racial segregation, it is important to see whether the racial profiles of the professions are changing. Unfortunately, to do so requires one to perpetuate the use of the racial classifications that were employed to separate and discriminate against people during the apartheid era. One can only hope that we will soon reach the stage where such categorisation is no longer necessary. Certainly the categories are becoming more difficult to monitor as fewer people are prepared – or able – to identify themselves racially. In this monograph, we use the terms African, coloured, Indian and white to denote the different population groups indicated in the data sources. We use the term black to refer to all population groups other than white, taken together.

Dr Mignonne Breier
Project Leader

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1 Breier M with Wildschut A (2006) *Doctors in a divided society: The profession and education of medical practitioners in South Africa*. Cape Town: HSRC Press.
2 Earle N (2007) *Social work in social change: The profession and education of social workers in South Africa*. Cape Town: HSRC Press.

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ACRONYMS AND ABBREVIATIONS

ASGISA	Accelerated and Shared Growth Initiative for South Africa
BEng	Bachelor of Engineering
BSc (Eng)	Bachelor of Science in Engineering
BTech	Bachelor of Technology
CESA	Consulting Engineers South Africa
DoE	Department of Education
DST	Department of Science and Technology
EASA	Engineering Association of South Africa
ECSA	Engineering Council of South Africa
ESGB	Engineering Standards Generating Body
FET	Further Education and Training
HEMIS	Higher Education Management Information System
HEQC	Higher Education Quality Committee
HSRC	Human Sciences Research Council
JIPSA	Joint Initiative on Priority Skills Acquisition
LFS	Labour Force Survey
MoU	Memorandum of Understanding
NDip	National Diploma
NQF	National Qualifications Framework
NSFAS	National Student Financial Aid Scheme
OHS	October Household Survey
pa	per annum
Prof B	Professional Bachelor's
R&D	Research and Development
SAACE	South African Association of Consulting Engineers
SAICE	South African Institution of Civil Engineering
SAIMC	South African Institute of Measurement and Control
SAIRR	South African Institute of Race Relations
SET	science, engineering and technology
SET4WRG	Science, Engineering and Technology for Women Reference Group
SETA	Sector Education and Training Authority
UCT	University of Cape Town
UNISA	University of South Africa
Wits	University of the Witwatersrand

CHAPTER 1

The South African engineering labour market and professional milieu

Introduction

This monograph on the work and education of engineering professionals has been produced at a crucial juncture in the history of engineering in South Africa. The country is embarking on a massive and very expensive expansion in infrastructure, partly in preparation for its hosting of the FIFA World Cup in 2010, and is also investing in upgrading power stations; building roads, airports and harbours; improving other services at municipal level; and constructing the Gautrain. There is also a boom in the construction industry. At the same time South Africa is facing a shortage of engineering capacity, particularly in the public sector, that has been described as one of the worst capacity and scarce-skills crises in years. As an indication of the dilemma, it can be noted that South Africa, which is to be sole host of the 2010 World Cup, has 473 engineers[3] per million citizens while Japan, which co-hosted the 2002 World Cup along with South Korea, has 3 306. Even compared to other upper-middle-income countries (developing countries), like Chile (1 460 engineers per million citizens) and Malaysia (1 843 engineers per million citizens), South Africa's engineering capacity is low (Lawless 2005). There are many factors contributing to our situation, including the status and image of the engineering professions in relation to other, more lucrative careers; the shortage of Grade 12 school leavers who meet the criteria to gain entry to engineering degree programmes; and the high quality of engineering education (South Africa is one of the countries that has joined the Washington Accord, which recognises the substantial equivalence of accreditation systems to assess that the graduates of accredited programmes are prepared to practise engineering at the professional level) (Jones 2006). The high quality of engineering education in this country, as also indicated by Professor Beatrys Lacquet (first female dean of the Faculty of Engineering at the University of the Witwatersrand [Wits]),[4] and Professor Kader Asmal (then South African minister of education),[5] ironically ensures that our graduates are in great demand internationally.

These and many other facets of the engineering professions in South Africa come under the spotlight in this study, which is one of a number of professional case studies that form part of the HSRC's research project on professions and professional education in South Africa. Each study investigates the major current issues in the profession concerned and considers the ways in which they are being addressed in educational programmes. The monographs present syntheses of these issues for public and policy attention.

This study drew on the following sources of data: employment data from Quantec Research (Pty) Ltd (2007),[6] which includes the October Household Survey (OHS) for the period 1996–1999, and the September Labour Force Survey (LFS) for the period 2000–2005; vacancy data from the Department of Labour for the period April

3 This figure includes engineers who are not registered.
4 Meer werk as mense, sê ingenieurs se eerste vroue-dekaan [More work than people, according to first female dean in engineering], *Rapport*, 25 March 2007.
5 South Africa's brain drain dilemma, *BBC News*, 19 April 2004.
6 Hereafter, simply Quantec.

2004–March 2007 (these data were gleaned from all South African vacancies published weekly in the Business Times Careers section of the *Sunday Times*, and compiled for the Department of Labour by Erasmus [2007]); and enrolment and graduation figures for engineering students from the annual databases of the Higher Education Management Information System (HEMIS) of the Department of Education (DoE 1996–2005).

It should be noted that there are three main types of engineering professionals in South Africa: engineers, engineering technologists and engineering technicians. A fourth designation – of 'certificated engineer' – refers to particular certificates that need to be held for specific roles in mining and industry, and is not discussed here in further detail. The designation depends first and foremost on the higher education qualification that has been attained. Engineers hold a four-year Bachelor of Science in Engineering (BSc [Eng]) or Bachelor of Engineering (BEng) from a university; technologists hold a Bachelor of Technology (BTech) from a university of technology; and technicians hold a National Diploma (NDip) from a university of technology. Throughout this monograph the term 'engineering professional' is used to refer to this collective group, while the term 'engineer' refers only to those holding the four-year university degree.

The monograph begins by considering the broader international context, and drivers of change for engineering professionals in the South African labour market. This is followed by an analysis of the current employment situation and employment trends with regard to engineering professionals in this country. The professional milieu for engineering professionals in South Africa is then discussed. Chapter 1 concludes with a discussion of the demand for engineering professionals in the workforce, followed by general concluding remarks.

The educational context for engineering professionals is provided in Chapter 2, which starts with a consideration of the drivers of change in the education of engineering professionals, followed by a discussion of secondary education, reasons for studying engineering, and the supply of engineering professionals by higher education institutions (the latter section also provides data on transformation trends). This is followed by a more in-depth discussion of various engineering programmes and the accreditation process; challenges for higher education institutions that offer engineering programmes; issues of student access and mobility or articulation; engineering training by Further Education and Training (FET) colleges; engineering training through learnerships; and a concluding section.

Chapter 3 suggests strategies to enhance levels of female participation in engineering; discusses factors influencing women in choosing engineering as a career; cites barriers experienced by women in engineering in the labour market; discusses graduation trends and employment of women in engineering; and provides a concluding paragraph.

The monograph concludes with a discussion of progress achieved, as well as the challenges still to be addressed in engineering employment in South Africa. Chapter 4 also suggests possible interventions and makes recommendations aimed at overcoming some of the hurdles.

The labour market context

It is a worldwide trend that lack of engineering capacity is hampering development, as stated by, among others, Johan Pienaar, registration manager at the Engineering Council of South Africa (ECSA);[7] Robbie Venter, CEO of Altron;[8] Hugh Williams, chief executive of the International Marine Contractors Association;[9] and Sipho Nkosi, Chamber of Mines president and Exxaro CEO.[10] Japan is running out of engineers[11] and there is a shortage of engineering teachers in India.[12] The shortage of engineers in South Africa is specifically seen as one of the worst capacity and scarce-skills crises in years, with local municipalities being hit the hardest (Lawless 2005). South Africa is currently in a period of extensive expansion in state expenditure, partly in preparation for its hosting of the FIFA World Cup in 2010 and also in upgrading power stations, improving other services at municipal level, constructing the Gautrain, and responding to the boom in the construction industry. Given the new context of expanded expenditure, particularly in the public sector, there are key questions to investigate in terms of the demand for and supply of engineering professionals. Putting infrastructure (roads, power supply, water supply, building construction, telecommunication networks, and recreational and other assets) in place requires the input of all engineering fields of study, but particularly civil engineering skills.

In terms of the employment of and demand for engineering professionals in the South African labour market, two significant drivers have been identified over the past three decades (Steyn & Daniels 2003). The first driver was the reduction in agriculture and mining's share of the GDP, and the second was the relative changes within sectors with respect to labour productivity and capital intensity. There has been a reduction in the demand for agricultural and mining engineers and an increase in the demand for engineers with expertise in manufacturing and service-related technologies. Substitution shifts in employment took place, away from the traditional sectors such as agriculture and mining to the manufacturing sector. Historically, the gold mining industry has been a significant employer of engineers, but employment levels have decreased substantially in recent years. The negative growth in agricultural engineering graduations is a concern in a country like South Africa, where agricultural engineering can contribute to increased productivity to address food shortages and job creation (Berry 2006).

Steyn and Daniels (2003) also indicate that there was a gradual decrease in the percentage of engineering professionals in the total labour force between 1994 and 2001. This was in contrast to the expansion of the economy from the mid-1990s onwards, which should have led to an increase in engineering employment. However, since the data show employment rather than demand shifts, actual demand for engineering professionals could be masked by the impact of potentially significant emigration or changes in organisation of work, such as subcontracting, which would imply that an individual might not be recorded as an employed engineer but rather, for example, as a self-employed manager of a firm engaged in engineering work.

7 SA's wide engineering gap, *Fin24.com*, 21 October 2007.
8 Altron CEO Robbie Venter on the skills shortage in SA…, *EE Publishers*, 21 July 2008.
9 Tackling the offshore skills shortage, *SPG Media Limited*, 18 October 2007.
10 SA produces more mining skills, but can't keep up with growth, poaching, *Mining Weekly,* 22 July 2008.
11 Japan faces engineering shortage, *The New York Times*, 18 May 2008.
12 Offshore conundrum: India has dire shortage of engineering professors, *EE Times*, 17 December 2007.

Conversely, over the 1996–2005 period, the number of engineers and technologists showed an average annual growth of 5.91%, as opposed to the 0.74% average annual growth in formal employment in the total economy over this period (Quantec 2007).

It is, however, exceptionally difficult to come up with authoritative figures or even estimates with regard to skills shortages or demand for engineering professionals. The reasons are manifold: the quality of official statistics; double counting of especially engineering professionals in the Sector Skills Plans of Sector Education and Training Authorities (SETAs) in the face of infrastructure investment; absence of a comprehensive national register of qualified engineering professionals (it is not compulsory for engineering professionals to register with ECSA); the nature of the world of work for engineering professionals (they are easily absorbed into non-related industries); and unreliable emigration figures (engineering professionals maintain their registration status if registered, regardless of where they are working or what type of work they are doing, and do not necessarily indicate emigration when they are working overseas for any duration of time).

Employment is usually used as an indicator of the demand for an occupation or skills. In the absence of regular and consistent survey data based on the needs of companies that use engineering skills, LFS statistics are used here for the purpose of analysis of demand for employment. However, it is important to note that these data can only be used as a proxy for demand.

Current employment and employment trends

This section examines the major characteristics of employed engineering professionals and considers total employment of engineering professionals holding an engineering degree (engineers and technologists) or an engineering diploma (technicians); employment of engineering professionals across the economic sectors; engineering professionals working as managers; ratios of engineers to technologists to technicians; the demographic profile of this group in terms of race, gender and age; and remuneration trends for engineering professionals.

As mentioned, the data used are from the OHS of 1996–1999 and the LFS of 2000–2005 (Quantec 2007). Both of these surveys are designed and administered by the South African government's national statistics agency, Statistics South Africa (Stats SA). The reason why data from two different data sources (the OHS and the LFS) are used is because Stats SA terminated the OHS after 1999. The methodology of the two surveys could have differed slightly, such as in the sampling or the weighting of data. As a result of the transition from one survey dataset to another, some discontinuity may be expected between trends expressed in the OHS data (1996–1999), and trends expressed in the LFS data (2000–2005).

Both the OHS and the LFS are based on samples of the national population. High annual fluctuations in the number counts are a product of small sample size and the process of weighting raw data obtained through a sample to approximate national parameters (Wilson, Woolard & Lee 2004). In order to smooth out fluctuations in employment trends over the 1996–2005 period, it was decided to calculate an employment average per annum over the whole period, as well as the averages for two-year periods over the 1996–2005 time frame to get a smoother graphical trend line.

The fluctuations in data are particularly evident when national employment totals are disaggregated to another category, such as race or gender. In order to smooth effects of fluctuations when disaggregating data, an average was calculated for the period covered by each survey. Thus, for the OHS, which ran for a period of four years (1996–1999), an annual average employment was calculated; the same was done for the six-year period 2000–2005. It should be apparent that there is not an even split in the number of years of data between the period before the millennium and the second period, post-millennium. This is because it was considered more important to retain the integrity of each series of survey data (OHS 1996–1999 and LFS 2000–2005) than to group one year of LFS data with the OHS series to create an even, five-year split for each period.

Total employment of engineering professionals in South Africa

Employment data on engineering professionals show huge fluctuations between 1996 and 2005 (Quantec 2007). To address fluctuations, an employment average per annum over a 10-year period (1996–2005) was thus calculated (Tables 1.1 and 1.2). An employment average for two-year periods over the 1996–2005 time frame was calculated to get a smoother graphical employment trend line (Figure 1.1).

Table 1.1 shows that on average 124 567 people were employed per annum in engineering professional positions in South Africa over the 1996–2005 period. Almost a third (39 686) were employed as engineers and technologists and more than two-thirds (84 881) as technicians. Among those employed as engineers and technologists, on average 60.98% (24 202) had degrees, 16.79% (6 667) had National Diplomas and 22.21% (8 817) had only a National Qualifications Framework (NQF) level 4 or lower qualification. Among those employed as technicians, 3.58% (3 047) had degrees, 27.91% (23 694) had National Diplomas and more than two-thirds (58 140) had qualifications at NQF level 4 or lower.

The large average number of 58 140 people who worked as engineering technicians without the required qualification is noteworthy. This trend relates to the difficulty that National Diploma students experience in finding industrial placements for their experiential training year (Interview 2006a; Lawless 2005). This means that such students do not get the opportunity to work for an employer for the required period of time in order to complete their experiential training and obtain the necessary qualifications (Interview 2006a; Interview 2006b). Over the 1996–1999 period, 56.51% of these underqualified engineering professionals were white and 47.86% were in the age category 65–69 years; while over the 2000–2005 period, 45.19% of these underqualified engineering professionals were white and younger than those in the earlier period (with a quarter in the age category 30–34 years) (Quantec 2007). For the 1996–1999 period, as these were predominantly older people, this trend could be explained in terms of people being appointed based on work experience already gained despite not having appropriate qualifications; while for the 2000–2005 period, as these were predominantly younger people, it would seem that they were probably still trying to gain experiential training in order to qualify.

Lawless (2005) found in her civil engineering study that about 60% of final-year National Diploma students who responded to her survey in October and November 2004 had not had experiential training and therefore could not graduate. The LFS data would suggest that such people are indeed working in the engineering labour

Table 1.1 Total employment of engineering professionals, by occupation and qualification level (1996–2005)

Engineering professionals employed as engineers & technologists	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average employed pa	Average annual growth (%)
Degrees	19 890	15 729	24 153	19 024	22 212	28 272	33 868	23 343	22 181	33 346	242 018	24 202	5.91
National Diplomas	167	10 146	16 977	6 580	7 343	2 813	2 862	2 224	5 818	11 743	66 672	6 667	60.41
NQF level 4 or lower	9 471	12 186	9 523	13 714	10 730	2 671	4 309	4 338	5 121	16 104	88 167	8 817	6.08
Total	**29 528**	**38 061**	**50 653**	**39 318**	**40 285**	**33 756**	**41 039**	**29 905**	**33 120**	**61 193**	**396 858**	**39 686**	**8.43**

Engineering professionals employed as technicians	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average employed pa	Average annual growth (%)
Degrees	2 257	3 089	1 902	3 016	1 107	1 723	2 717	5 810	2 052	6 798	30 471	3 047	13.03
National Diplomas	26 405	8 875	13 330	16 236	29 362	22 848	30 470	24 750	27 222	37 438	236 935	23 694	3.96
NQF level 4 or lower	71 684	10 292	6 958	68 212	52 174	63 623	61 903	68 362	100 549	77 646	581 404	58 140	0.89
Total	**100 346**	**22 256**	**22 190**	**87 464**	**82 644**	**88 194**	**95 090**	**98 922**	**129 822**	**121 881**	**848 810**	**84 881**	**2.18**

Total employed as engineering professionals	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average employed pa	Average annual growth (%)
Total	**129 874**	**60 317**	**72 843**	**126 782**	**122 929**	**121 950**	**136 129**	**128 827**	**162 942**	**183 074**	**1 245 668**	**124 567**	**3.89**

Source: Quantec (2007)

market. Thus, at this level the skills are available, but strategies need to be put in place to assist such workers to complete the experiential training that would allow them to obtain their National Diplomas and register as professional engineering technicians. In this case it is necessary to distinguish between a *scarce skill* and a *skill gap* – these people are almost qualified and working as technicians; they simply need the opportunity to do their experiential training in order to close the skill gap.

The LFS data further reveal that about 10 000 people with degrees and over 48 000 people with National Diplomas in an engineering-related field were working in occupational categories ranging from sales worker to machine operator, except for managers. Furthermore, about 1 600 people with degrees in an engineering-related field were unemployed, compared to over 10 000 with diplomas in an engineering-related field. Three-quarters (75.43%) of this unemployed group were black (i.e. African, coloured or Indian), and well over half (59.08%) were men. Although unemployment here refers to those who were unemployed with an engineering-related qualification (which also includes areas such as manufacturing and technology and not only engineering – as the unemployed in the OHS and LFS datasets cannot be identified according to purely engineering fields of study), it would be worthwhile to explore and research this unemployment further, to get a notion of the reasons why people with an engineering-related qualification are unemployed.

It is important to note that among those employed as engineers and technologists, a significant number (an average of 6 667 per annum) only had a National Diploma-level qualification. This finding could be as a result of poor data, coding problems or incorrect responses, or because an insufficient number of qualified engineers and/or technologists were available to be appointed, especially at municipal level. According to Gareth van Onselen, the Democratic Alliance's head of research in Parliament, South Africa's six major metropoles have 732 civil engineering professionals between them – not all qualified engineers – serving a population of about 15.6 million.[13]

For the purposes of the rest of this study we decided to include all National Diploma-qualified people along with the technicians, and not with the engineers and technologists. However, in this study technicians with degrees were kept as technicians. Further analysis in this monograph is based on the 24 202 annual average employed engineers and technologists with degrees, and the 33 408 annual average employed technicians with National Diplomas (23 694 plus 6 667) and degrees (3 047), over the 1996–2005 period.

Looking at the average number of engineers and technologists with degrees working in a specific year over the 1996–2005 period (Table 1.2), people with civil engineering degrees represented almost a third (29.30%), mechanical engineers a fifth (20.25%) and electrical engineers 15.97%. The category 'not elsewhere classified' represented 14.64% of total employment of engineers and technologists with degrees and included engineering fields such as agricultural, industrial and robotics engineering, according to the South African Standard Classification of Occupations. Electronics and telecommunications engineers and technologists accounted for 6.35%, while cartographers and surveyors, mining engineers, chemical engineers, metallurgists and related professionals represented 4.85%.

13 Engineering a response to SA's infrastructure woes, *Business Day,* 5 March 2007.

Table 1.2 Total employment of engineering professionals with degrees and National Diplomas, by field of study (1996–2005)

Engineers & technologists with degrees	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average employed pa	Average annual growth (%)
Civil	12 065	4 115	7 104	5 264	3 333	9 663	6 616	5 760	5 133	11 870	70 923	7 092	–0.18
Electrical	523	3 942	3 038	1 495	2 218	5 545	3 939	3 618	5 790	8 540	38 649	3 865	36.39
Electronics & telecommunications	1 804	2 211	0	794	5 416	470	2 911	1 756	0	0	15 361	1 536	* –0.38
Mechanical	1 992	556	7 389	5 026	4 522	7 446	10 327	3 608	5 172	2 959	48 997	4 900	4.49
Chemical	520	616	1 412	1 048	383	969	1 736	2 269	1 074	475	10 502	1 050	–1.00
Mining & metallurgy	0	679	0	890	2 871	801	1 914	1 980	1 058	210	10 403	1 040	** –13.64
Cartographers & surveyors	527	1 309	1 983	249	1 597	0	909	659	2 375	2 139	11 748	1 175	16.84
Not elsewhere classified	2 459	2 301	3 226	4 258	1 872	3 378	5 516	3 693	1 579	7 153	35 436	3 544	12.60
Total with degrees	**19 890**	**15 729**	**24 153**	**19 024**	**22 212**	**28 272**	**33 868**	**23 343**	**22 181**	**33 346**	**242 018**	**24 202**	**5.91**

Technicians with National Diplomas/degrees	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average employed pa	Average annual growth (%)
Civil	6 279	6 300	5 994	1 182	7 682	4 321	3 816	1 758	1 628	6 543	45 504	4 550	0.46
Electrical	7 529	3 420	7 749	4 124	4 052	3 565	8 868	4 155	6 319	8 772	58 552	5 855	1.71
Electronics & telecommunications	7 796	2 389	5 741	6 530	8 079	8 376	9 502	16 290	14 714	23 848	103 266	10 327	13.23
Mechanical	2 124	3 286	6 212	6 688	10 411	4 106	7 131	2 023	2 420	11 507	55 909	5 591	20.65
Chemical	0	0	583	1 794	0	676	1 943	0	395	0	5 391	539	*** –6.27
Acidiser	2 339	924	539	0	1 232	1 291	1 339	1 030	2 958	2 470	14 121	1 412	0.61
Draughtsperson	1 449	1 968	2 798	2 180	3 795	4 279	2 950	6 825	5 289	2 562	34 093	3 409	6.54
Not elsewhere classified	1 313	3 823	2 591	3 333	2 562	772	500	705	1 367	277	17 243	1 724	–15.87
Total with National Diplomas/ degrees	**28 829**	**22 110**	**32 208**	**25 831**	**37 813**	**27 384**	**36 049**	**32 784**	**35 091**	**55 978**	**334 078**	**33 408**	**7.65**

Source: Quantec (2007)

*Note: * 1996–2003; ** 1997–2005; *** 1998–2004*

Considering the annual average number of technicians with National Diplomas/ degrees over the same period, the picture looks very different. Almost a third (30.91%) held diplomas in electronics and telecommunications engineering, with electrical engineering technicians accounting for less than a fifth (17.53%), mechanical engineering technicians 16.74% and civil engineering technicians only 13.62%. This trend impacts on the ratios of engineers and technologists to technicians in the different fields. This is especially the case in civil engineering, where there is a shortage of technicians in proportion to civil engineers, which impacts on service delivery at municipal level.

Among the degree-qualified engineers and technologists, the number of electrical engineers and technologists achieved an encouraging average annual growth rate of 36.39%, cartographers and surveyors 16.84%, those not elsewhere classified 12.60%, and mechanical engineers and technologists 4.49% over the 1996–2005 period. Negative growth rates were reported over this period for engineers and technologists in the following categories: mining, metallurgy and related professionals (–13.64%); chemical (–1%); electronics and telecommunications (–0.38%); and civil (–0.18%).

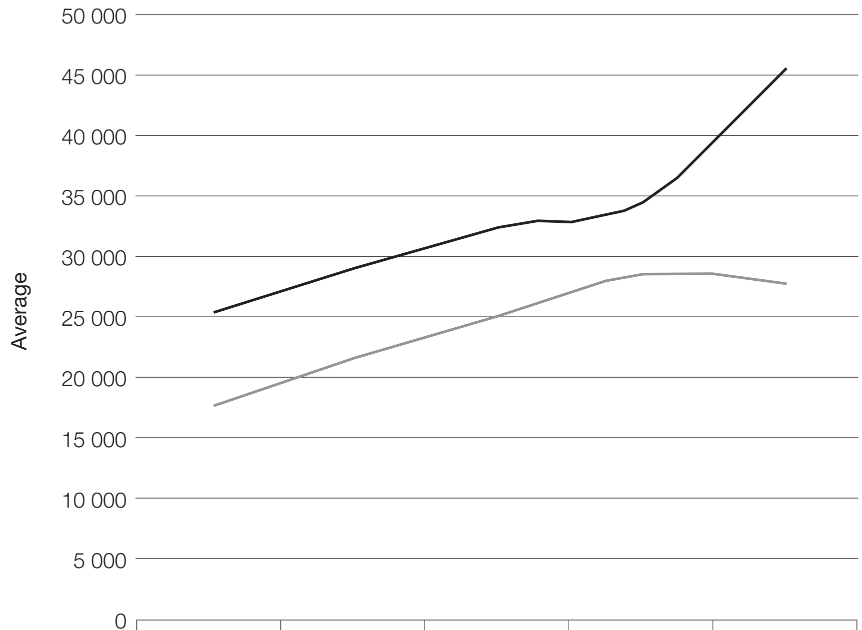
In contrast to the negative growth in employment for electronics and telecommunications engineers and technologists, there was an average annual increase of 13.23% in employment for technicians in this field. The reverse is evident for the electrical engineering field: slow growth in employment for electrical technicians compared to very positive growth for electrical engineers and technologists.

For engineers and technologists the electrical engineering field showed the biggest absolute employment gain over the 1996–2005 period, while for technicians the most growth was in the field of mechanical engineering.

Figure 1.1 provides a picture of the employment trends for engineers, technologists and technicians over the two-year periods (based on figures in Table 1.2). The figures show that the average annual growth rate of employment for engineers and technologists for the full period 1996–2005 was 5.91%. Technicians showed the same trend as engineers and technologists over the 1996/97 to 2002/03 period; however, over the 2004/05 period there was a drastic increase in the number of technicians, contrasting with a decrease in the number of engineers. The average annual growth in the number of technicians over the whole 1996–2005 period was 7.54% (from 28 829 in 1996 to 55 978 in 2005).

Table 2.2 in Chapter 2 shows that there was also a bigger increase in graduation of technicians at higher education institutions (2.50% average annual growth) than in graduation of engineers (1.00% average annual growth) over the 1996–2005 period, although graduation of technologists (3.73%) increased the most over this period.

Figure 1.1 Employment trends (averages per two-year period) for engineers and technologists, and technicians (1996–2005)



	1996/97	1998/99	2000/01	2002/03	2004/05
Engineers & technologists	17 810	21 589	25 242	28 606	27 764
Technicians	25 470	29 020	32 599	34 417	45 535

Source: Quantec (2007)

Employment of engineering professionals: public and private sectors

In order to understand the state of the engineering profession in South Africa, it is necessary to consider the sectors in which engineers engage. In a broader sense engineers are at the core of two key areas of development enterprise in the country: building and maintaining infrastructure in the public sector, and contributing towards economic growth in the private sector. These are fundamentally different contexts in terms of the kind of engineering work undertaken and the conditions of employment.

In the public domain, engineers in the employ of the parastatals have always been involved in the provision of transport, communication and electrification. Those specifically in the civil engineering field are involved in general urban development and upgrading of infrastructure and are by and large employed by local or provincial government. In the private sector, engineers are working in a wide range of commercial enterprises, including small consulting firms, medium-sized businesses and large multinational companies. There are also sizeable contingents of engineers who are not working in the traditional engineering sector. Many of these are active in the financial and general business sector, as reported in Table 1.3.

Employment distribution across the different economic sectors

Table 1.3 shows that there was substantial ebb and flow in the availability of engineering employment in the various sectors of the economy between 1996 and 2005. The shifts in employment of engineering professionals in the sectors of the economy are noteworthy. The dramatic fluctuation within sectors is a good illustration of the intra-sectoral factors affecting employment. These factors usually relate to the following: the effects of the business cycle; the free enterprise nature of society (South Africa does not have a planned economy and engineering professionals deploy themselves in sectors for various reasons); the type of employment arrangements that exist in the industry; and the nature of supply of skills from the higher education sector (Interview 2006c; Steyn & Daniels 2003). Stakeholders in the engineering industry have specifically raised concerns about the employment arrangements made through labour brokers, particularly for technicians (Interview 2006a; Interview 2006b). The experience is that labour brokers are not committed to ensuring training and continuity of work for the employees who are on their payrolls. In the 1990s, when the economy was going through an operating and maintenance phase, large numbers of technicians were retrenched from state-owned enterprises such as the power-supply company ESKOM. At the time labour brokers absorbed these employees, and the tendency is to place them on short contracts in different work environments across sectors (Interview 2007a).

Over the period 1996–2005 the majority of engineers and technologists worked in the manufacturing and financial and business services sectors. It makes sense for engineering professionals to work in manufacturing (24.99%), but it is significant that, on average, 25.17% worked in finance. The significant number of engineers employed in the financial and business services sector is an indication of the proportion of consulting engineers working either for large financial and management consulting companies or in smaller, independent engineering consulting operations. It is well known that management consultancies often recruit top engineering graduates. The South African Association of Consulting Engineers (SAACE)[14] reports that, over the years, its membership has grown from 30 individual members (in 1952) to 420 firms in 2002, employing more than 12 500 people in total (SAACE 2006). The large number of engineers working in the financial and business services sector may not apply their technical skills, but they assist the industry with risk management through consulting agencies (Interview 2006d). This is a controversial issue, which may contribute to the difficulties in dealing with the shortages in areas where engineers' skills could be employed more appropriately, such as in civil engineering, the local authorities and ESKOM.

Construction is a labour-intensive industry that is very dependent on the domestic market and in which the public sector is dominant. On average per annum only 9.02% of engineering professionals were employed in the construction industry over the 1996–2005 period. Construction declined throughout the 1990s because of the government's policy of curtailing expenditure. In 2005, however, the construction industry grew at a rate of 4.80% nationally. Table 1.3 reports an increase in employment from 2003–2005, and this trend continues into the present.

The Accelerated and Shared Growth Initiative for South Africa (ASGISA), with a capital investment of R372 billion for infrastructure work over the 2006–2010 period, will surely stimulate and ensure growth of the construction sector. According to Sam Amod, former president of the South African Institution of Civil Engineering (SAICE), 'The industry is faced with the prospects of a boom in infrastructure construction and industrial projects at a time when its skilled resources are reduced to critical levels and many of its civil engineering professionals are approaching retirement.'[15] Suitably

14 In August 2008 SAACE transformed itself into Consulting Engineers South Africa (CESA).
15 Civil engineering students in demand, *Express*, 31 March 2006.

Table 1.3 Distribution of engineers, technologists and technicians, by economic sector (1996–2005)

Engineers, technologists & technicians per economic sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average employed pa	Average annual growth (%)
Engineers & technologists	0	1 013	1 385	1 615	3 133	946	2 282	2 170	1 910	210	14 665	1 466	* –17.87
Technicians	1 852	1 626	2 327	1 256	2 271	2 136	3 053	1 078	734	2 300	18 632	1 863	2.44
Mining & quarrying: Total	**1 852**	**2 639**	**3 711**	**2 871**	**5 405**	**3 082**	**5 336**	**3 248**	**2 643**	**2 510**	**33 296**	**3 330**	**3.43**
Engineers & technologists	3 841	3 737	3 410	5 314	2 832	11 104	11 906	5 939	6 586	5 906	60 575	6 057	4.90
Technicians	4 951	4 204	4 528	7 454	6 382	7 694	13 251	8 071	8 365	12 360	77 260	7 726	10.70
Manufacturing: Total	**8 792**	**7 941**	**7 937**	**12 769**	**9 214**	**18 798**	**25 156**	**14 010**	**14 952**	**18 266**	**137 835**	**13 784**	**8.46**
Engineers & technologists	523	3 245	3 502	1 359	843	2 187	1 632	1 828	669	3 473	19 260	1 926	23.41
Technicians	3 720	2 624	7 109	312	1 234	1 056	2 816	648	2 433	2 333	24 284	2 428	–5.05
Electricity, gas & water supply: Total	**4 243**	**5 869**	**10 611**	**1 671**	**2 077**	**3 243**	**4 448**	**2 476**	**3 101**	**5 806**	**43 545**	**4 354**	**3.55**
Engineers & technologists	5 532	1 216	5 588	1 471	2 214	3 181	1 351	1 751	1 842	9 013	33 160	3 316	5.57
Technicians	1 327	1 223	3 231	890	3 335	0	1 510	0	4 290	765	16 572	1 657	–5.93
Construction: Total	**6 859**	**2 439**	**8 819**	**2 361**	**5 549**	**3 181**	**2 862**	**1 751**	**6 132**	**9 779**	**49 732**	**4 973**	**4.02**
Engineers & technologists	760	362	0	1 197	1 100	2 916	0	322	0	0	6 657	666	0.00
Technicians	3 663	1 196	569	1 523	2 948	3 218	4 710	2 105	1 581	6 155	27 667	2 767	5.94
Wholesale & retail trade: Total	**4 423**	**1 558**	**569**	**2 720**	**4 048**	**6 134**	**4 710**	**2 427**	**1 581**	**6 155**	**34 325**	**3 432**	**3.74**
Engineers & technologists	1 883	891	0	852	2 992	0	3 673	3 944	2 054	3 113	19 402	1 940	5.75
Technicians	7 105	3 107	3 111	6 730	7 506	6 068	3 467	5 566	2 561	6 886	52 107	5 211	–0.35
Transport, storage & communication: Total	**8 988**	**3 998**	**3 111**	**7 582**	**10 498**	**6 068**	**7 139**	**9 510**	**4 615**	**9 999**	**71 509**	**7 151**	**1.19**
Engineers & technologists	2 652	2 522	9 827	5 877	9 752	5 271	11 274	4 173	5 361	8 485	65 195	6 519	13.79
Technicians	1 528	3 338	7 951	5 428	11 208	6 429	5 941	11 977	8 699	11 091	73 590	7 359	24.64
Finance: Total	**4 180**	**5 860**	**17 778**	**11 305**	**20 960**	**11 700**	**17 215**	**16 150**	**14 060**	**19 576**	**138 785**	**13 878**	**18.71**
Engineers & technologists	1 065	1 715	442	634	370	2 302	1 750	2 101	3 760	3 144	17 283	1 728	12.78
Technicians	4 856	3 544	3 383	2 238	1 907	782	1 301	1 541	1 895	3 717	25 164	2 516	–2.93
Community, social & personal services: Total	**5 921**	**5 259**	**3 825**	**2 872**	**2 277**	**3 084**	**3 051**	**3 642**	**5 655**	**6 861**	**42 447**	**4 245**	**1.65**

Source: Quantec (2007)

*Note: * 1997–2005*

skilled people will be needed to drive the massive infrastructure programme under ASGISA, but current skills shortages in local government will impede the rollout of the programme.

A few initiatives are attempting to address this problem. ECSA and the civil engineering profession are assisting local governments by mobilising retired engineers to help the staff of local authorities prepare projects for implementation (Interview 2006c). SAICE and the Local Government SETA are involved in a programme that awards bursaries to technicians who work in local authorities (and there was quite a substantial increase in the number of technicians over the 2002–2005 period, as shown in Figure 1.1). SAICE has signed a Memorandum of Understanding (MoU) with the Department of Provincial and Local Government to provide capacity in the hardest-hit local authorities (Interview 2006d). The strategy is to marry an engineering firm with a local authority in order to build technical and management capacity.

Public–private distribution

A quarter (25.15%) of engineers, technologists and technicians worked in the public sector in 2000 and mostly for state-owned enterprises (Table 1.4). This figure decreased to 24.46% by 2005, as the private sector showed more growth than the public sector at that time. The average annual growth rate for employment of engineering professionals in the public sector for the period 2000–2005 was 7.68%, compared to 12.12% in the private sector.

The increase in employment at provincial (23.32% average annual growth) and local (10.30% average annual growth) government levels is heartening, although 2000–2005 is a short period in which to measure average annual growth. The expansion of infrastructure spending by government over the next few years will lead to further demand for engineering professionals in the public sector, but with the current rate of reported skills shortages it will not be easy to fill the vacancies. There are around 2 000 vacancies in municipalities in South Africa, according to Dawie Botha, speaking as executive director of SAICE.[16] It is recommended that these vacancies be filled by teams, each consisting of a recently retired senior engineer and two or three younger graduates (Lawless 2005).

Growth in both categories (engineers/technologists and technicians) is most probably as a result of more technologists and technicians (rather than engineers) being supplied by higher education intitutions, as the number of technologist graduations increased by an average annual rate of 3.73%, technician graduations by an average annual rate of 2.50% and engineer graduations by an average annual rate of only 1.00% over the 1996–2005 period (Table 2.2). Furthermore, over the past few years there has been a decline in ECSA engineer registration and an increase in technologist/technician registration.[17] Inexperienced technicians and at times non-technical staff are found running technical departments and project management units where there are no civil engineers; decisions are thus deferred, not made at all or made inappropriately (Lawless 2007). Delays in the supply-chain management process occur because procurement has become centralised rather than the duty of each department, according to engineers seconded to struggling municipalities.[18]

16 Universities running on empty, *The Star*, 9 August 2008.
17 SAIMC professional development and training, *SA Instrumentation and Control*, February 2005.
18 Engineers warn of dire straits in local councils, *Business Day,* 2 March 2007.

Table 1.4 Distribution of engineers, technologists and technicians, by public and private sector (2000 and 2005)

	2000			2005			Average annual
Sector	n	%		n	%		growth (%)
All engineering professionals (engineers, technologists & technicians)							
Central government	2 103	13.93		1 329	6.08		–8.77
Provincial government	1 107	7.34		3 159	14.46		23.32
Local government	1 240	8.22		2 025	9.27		10.30
State-owned enterprises	10 646	70.52		15 338	70.19		7.58
Total public sector	**15 097**	**100.00**	**25.15**	**21 851**	**100.00**	**24.46**	**7.68**
Private sector *	**38 088**		**63.45**	**67 473**		**75.54**	**12.12**
Unspecified	**6 840**		**11.40**	**0**		**0.00**	
Total	**60 025**		**100.00**	**89 324**		**100.00**	**8.27**
Engineers & technologists							
Central government	2 103	40.27		1 082	10.02		–12.45
Provincial government	370	7.08		828	7.67		17.50
Local government	0	0.00		809	7.50		
State-owned enterprises	2 750	52.65		8 075	74.81		24.04
Total public sector	**5 222**	**100.00**	**23.51**	**10 794**	**100.00**	**32.37**	**15.63**
Private sector*	**13 486**		**60.71**	**22 552**		**67.63**	**10.83**
Unspecified	**3 504**		**15.77**	**0**		**0.00**	
Total	**22 212**		**100.00**	**33 346**		**100.00**	**8.47**
Technicians							
Central government	0	0.00		247	2.24		
Provincial government	738	7.47		2 331	21.08		25.87
Local government	1 240	12.56		1 216	11.00		–0.40
State-owned enterprises	7 896	79.97		7 263	65.69		–1.66
Total public sector	**9 874**	**100.00**	**26.11**	**11 057**	**100.00**	**19.75**	**2.29**
Private sector *	**24 603**		**65.06**	**44 921**		**80.25**	**12.80**
Unspecified	**3 336**		**8.82**	**0**		**0.00**	
Total	**37 813**		**100.00**	**55 978**		**100.00**	**8.16**

Source: Quantec (2007)

Notes:
** Including private associations, private business, and self-employed*
Data for only 2000 and 2005 were compared, as data before 2000 were not available according to the above sector breakdown.

Engineering professionals working as managers

In the South African context, where there is a serious shortage of managers as indicated by Professor Eon Smit, quoted in his capacity as director of the University of Stellenbosch's Business School,[19] it is often found that engineering professionals become managers.[20] Following the initial training of engineering professionals, opportunities to occupy leadership positions usually arise very soon – in most cases this would involve either a continuation of the technical track or a move to a more managerial and business-focused position (Case 2006). Engineers are more suited than others to adapt to the highly pressurised environment of banks' trading floors, according to ABSA Capital's head of trading,[21] and industrial engineers especially are being snatched by the banking sector, according to Johan Pienaar, registrations manager at ECSA.[22] Historically, BSc (Eng) graduate engineers have tended to move more easily into management-level positions than have other engineering professionals (Case 2006). It is crucially important to note, however, that the management functions that engineering professionals perform are strongly rooted in the technical exposure that they received in the earlier years of their training (Case 2006). For example, three decades ago project management was seen mainly as a sphere of engineering and construction, argues Terry Deacon, an experienced engineering professional.[23]

The levels of leadership that an engineer displays tend to change over the course of a career (Case 2006). A good example is Danai Magugumela, the first black female CEO at BKS Consulting Engineers, who started off as a civil engineer with the Texas Department of Transportation, joined a consulting firm in Cape Town, and later another consulting engineering group, moved to the public sector for four years as project manager at the Municipal Infrastructure Investment Unit, and then moved on to the entrepreneurial environment.[24] Engineers with approximately 10 years' experience would be likely to be supervising specific technical work (according to Eddie Durant, Grinaker-LTA managing director),[25] while many of those with more experience would be at the helm of large corporate or public sector enterprises (Case 2006). As CEO of the Coega industrial development zone, Pepi Silinga is an example of a leader with an engineering qualification, an MBA and development programme experience who has successfully promoted co-operation between provincial and national government levels and parastatal enterprises by ensuring delivery to communities.[26] As shown in Table 1.5, on average just over a quarter of those with a professional engineering qualification worked as managers during the period 1997–2005; the number of engineers working as managers almost doubled over this period.

Only around half of those trained to be engineers end up doing engineering work, while the other half work in other industries, according to Alec Erwin, minister of public enterprises at the time.[27] Engineers are poached by other industries because of

19 A shortage of managers, *Mail & Guardian*, 11–17 April 2008.
20 The ten best-paid jobs in South Africa, *Citizen*, 28 November 2006.
21 ABSA Capital puts spanner in engineer booster plan, *Business Report*, 10 July 2008.
22 SA's wide engineering gap, *Fin24.com*, 21 October 2007.
23 Keeping things on track, *Mail & Guardian*, 1–7 August 2008.
24 Engineering transformation: 'Retain talent irrespective of race or gender', *Engineering News*, 23–29 June 2006.
25 Skills shortage is genuine threat to growth, say bosses, *Business Report*, 24 May 2007.
26 The captain of Coega's ship, *Enterprise*, 30 November 2005.
27 Regstel-aksie is dood, sê Erwin [Affirmative action no longer exists, says Erwin], *Beeld*, 12 July 2007.

their analytical skills, according to Johan Pienaar, registrations manager at ECSA.[28] This 'internal poaching' of engineers contributes to a shortage of experienced engineers.[29] The engineering profession has been neglected for years with regard to remuneration and lack of public sector investment,[30] but fortunately is currently making a comeback with increased infrastructure spending.[31] However, executive-level remuneration is still more attractive than that for technical workers, according to Sandra Burmeister, CEO of Landelahni Business Leaders,[32] and Dirk Hermann, general secretary of the trade union Solidarity.[33] Furthermore, appointment policies, especially at local government level, will have to change if more technical skills are to be attracted. According to Webster Ndodana, quoted in his capacity as first black president of SAACE and owner of a consulting engineering firm, technical staff are currently appointed at lower levels than previously and this creates the impression that there are no career paths in this sector for those with technical skills.[34] Young engineers are frustrated by the lack of both on-the-job training and opportunities to learn from others with more experience.[35] Career paths for engineers and continuing professional development need to be addressed in a bid to keep technical skills where they are most needed.[36]

Underutilisation of engineers could also contribute to frustration in a technical environment – engineering graduates were, for example, being deployed to building sites because construction companies could not find enough artisans, according to Carl Grim, CEO of Aveng.[37] According to Sigi Proebstl, chief executive at Siemens South Africa, the market requires one engineer to every four technicians and 16 artisans,[38] while currently the ratio stands at 1 engineer to every 1.38 technicians (Table 1.2) and two artisans.

A combination of factors thus contributes to engineering professionals leaving the technical environment. The adaptability of engineering skills to many different environments, insufficient incentives, appointment policies, lack of opportunities to gain the required experience, lack of continuing professional development, insufficient career paths, underutilisation of engineers (because of too few technicians and artisans available) in some environments, and underqualified engineering staff in other environments (such as at local government level due to a shortage of engineers) all contribute to migration of technical skills to more lucrative environments. Workplace culture, growth opportunities, flexible employment practices, valuing diversity, reward systems, employment equity, and broad-based black economic empowerment are among the means to address shortcomings in the working environment of technical staff, according to Professor Frank Horwitz, quoted in his capacity as director of the University of Cape Town's (UCT) Graduate School of Business.[39]

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28 SA's wide engineering gap, *Fin24.com*, 21 October 2007.
29 Carte D, The ten best-paid jobs in South Africa, *Citizen*, 28 November 2006.
30 Mars D, Engineering a response to SA's infrastructure woes, *Business Day*, 5 March 2007.
31 The ten best-paid jobs in South Africa, *Citizen*, 28 November 2006.
32 SA produces more mining skill, but can't keep up with growth, poaching, *Mining Weekly*, 22 July 2008.
33 Better pay, incentives may save SA from skills shortage, *Business Day*, 6 July 2007.
34 'Gebruik die kundige ingenieurs' ['Use the expert engineers'], *Rapport*, 22 January 2006.
35 Engineering transformation: 'Retain talent irrespective of race or gender', *Engineering News*, 23–29 June 2006.
36 Addressing skills shortage in engineering field, *The Star*, 23 May 2007.
37 Aveng hurt by skills lack, *Business Day*, 12 January 2007.
38 SETAs receive funds to address SA's skills crisis, *Sowetan*, 17 May 2007.
39 Need for skills shortage solution, *The Herald (EP Herald)*, 30 November 2006.

Managers with engineering-related qualifications include those who have studied in areas such as engineering, manufacturing and technology – and not purely engineering – because managers in the OHS and LFS datasets cannot be identified according to purely engineering fields of study. Managers with engineering-related qualifications, but who are not included among engineering professionals (those with 'pure' engineering degrees and National Diplomas, reflected in Tables 1.1. and 1.2), make up just over a quarter (27.44%) of engineering professionals (engineers, technologists, technicians and engineering managers) working in the engineering environment (Table 1.5).

Table 1.5 Percentage of people with engineering-related qualifications working as managers (1997–2005)

Engineering professionals & managers in engineering-related fields	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	(%)
Engineers & technologists (with degrees)	15 729	24 153	19 024	22 212	28 272	33 868	23 343	22 181	33 346	222 128	30.56
Technicians (with National Diplomas)	22 110	32 208	25 831	37 813	27 384	36 049	32 784	35 091	55 978	305 250	42.00
Managers *	15 247	12 163	12 506	24 292	24 309	30 165	23 829	28 449	28 449	199 410	27.44
Total employment	**53 086**	**68 524**	**57 362**	**84 317**	**79 965**	**100 082**	**79 956**	**85 721**	**117 773**	**726 788**	**100.00**

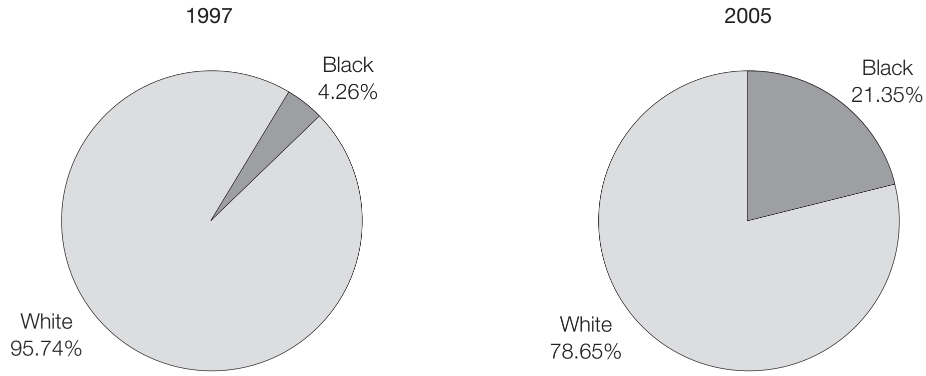
Source: Quantec (2007)

Notes:
** People working as managers with a qualification in an engineering-related field, and not counted with engineering professionals in Tables 1.1 and 1.2*
Numbers differ from Tables 1.1 and 1.2 as this table excludes 1996.

Figure 1.2 reports the distribution of managers according to race and Figure 1.3 according to gender. In 1997, 4.26% of people who had a qualification in an engineering-related field and who held a managerial position were black – the category 'black' comprising Africans, coloured people and Indians. (See the preface for an explanation of the racial analyses in this report.) This figure increased to just over a fifth (21.35%) in 2005.

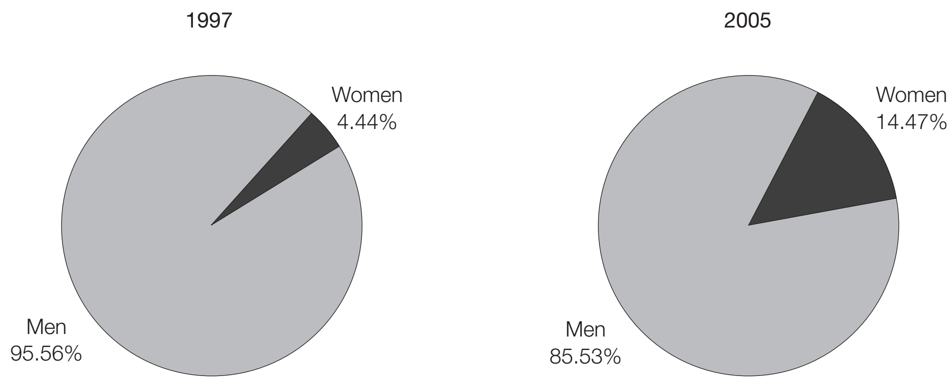
The trend was less favourable for women than for black people. In 1997 only 4.44% of managers were women and this figure increased to only 14.47% by 2005.

Figure 1.2 Distribution of managers with engineering-related qualifications, by race (1997 and 2005)



Source: Quantec (2007)

Figure 1.3 Distribution of managers with engineering-related qualifications, by gender (1997 and 2005)



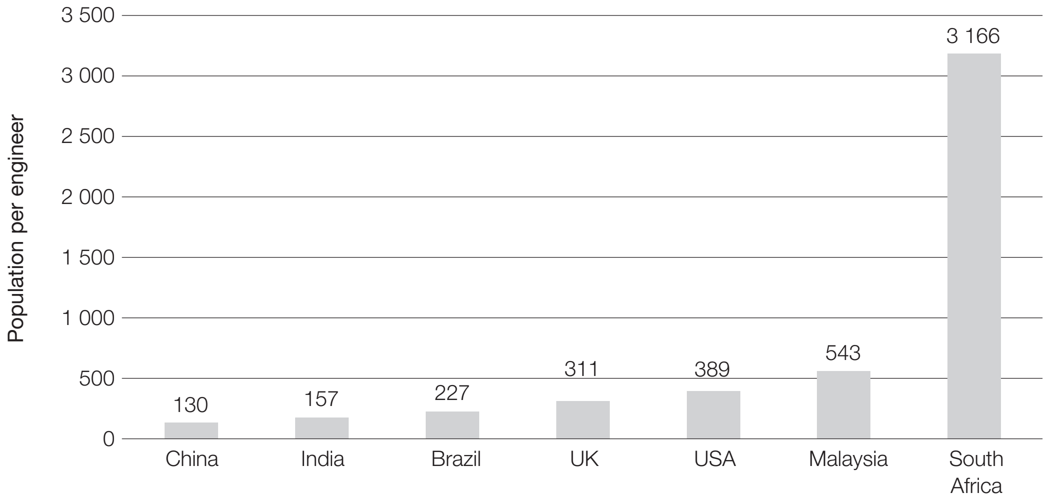
Source: Quantec (2007)

Employment ratios of engineering professionals

One measure of economic prosperity in a country is the number of engineers supplied per million citizens per annum. When international benchmarks such as the ratios of engineers to population are cited, they are usually based on figures supplied by the professional registering bodies of each country. Most of the registering bodies comparable to ECSA merely quote the number of professional engineers registered at a specific point in time.

Figure 1.4 provides the ratio of registered engineers to population in South Africa compared to the ratio of registered engineers to population in a few developed and developing countries (outside Africa), based on the ECSA number of 14 806 professional engineers registered at that time (2004). Figure 1.5 shows the ratio of registered engineers to population in South Africa in comparison to the ratio of registered engineers to population in some other African countries. Figures 1.4 and 1.5 indicate one registered engineer to every 3 166 citizens in South Africa – South Africa is regressing in this regard, as in 1972 there was one engineer to every 2 000 people (Interview 2006f). It is generally known that South Africa is technologically stronger than other African countries and it is thus not surprising that the ratio of registered engineers to population is more favourable in South Africa than in other African countries. Nevertheless, it is disquieting that the ratio of engineers to population in South Africa is not significantly better than in Zimbabwe, Namibia and Tanzania and other less developed countries, given that South Africa needs to develop and strengthen its infrastructure (Lawless 2005). It must, however, be kept in mind that the definition of engineer varies from one country to another and this makes it difficult to compare countries with regard to the number of engineers. The engineer to population figure would look better if real employment figures or counts of engineering professionals were used. For example, if the number of employed engineers in South Africa in 2004 according to the LFS is used (22 182), it translates into one engineer to every 2 113 people – obviously a more favourable ratio than one engineer to every 3 166 people, although still not much better than the ratios of other African countries. As indicated earlier, only half of the engineers trained end up in the engineering environment in South Africa (according to South Africa's minister of public enterprises at the time),[40] and this needs to be addressed through various incentives, as already mentioned in the section on engineering professionals.

Figure 1.4 Registered engineer to population ratios in South Africa, and in developed and non-African developing countries (2004)

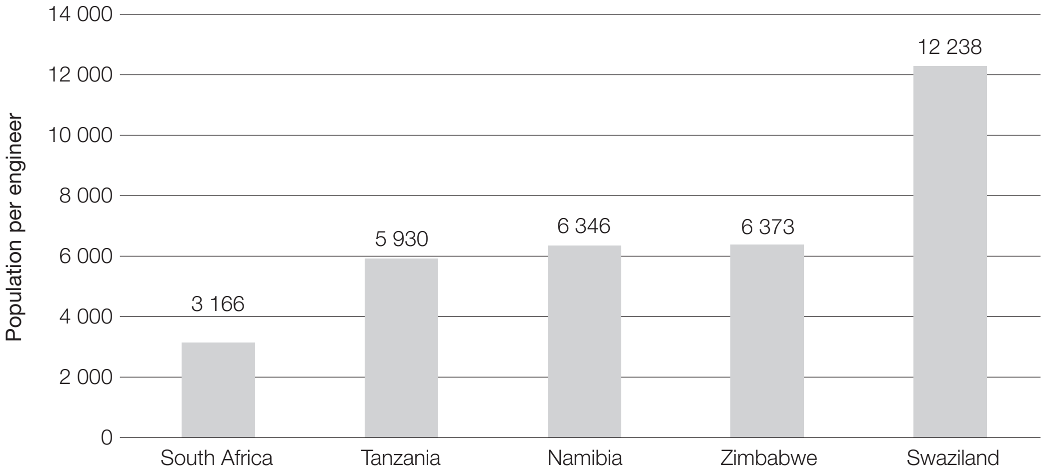


Source: Lawless (2005)

The ideal ratio of engineers to technologists to technicians to artisans has been debated for decades. For most developed countries the ideal ratio for the four categories is 1:2:4:16, according to the general secretary of the South African Institute of Measurement and Control (SAIMC).[41] ECSA and the Engineering Association of South Africa (EASA) propose a ratio for engineers, technologists, technicians and artisans of 1:1:4:16 for the South African context (ECSA & EASA 1995). According to Quantec (2007) employment data for the period 1996–2005, the ratio of engineers and technologists to technicians was about 1:1.4 (OHS and LFS do not differentiate between engineers and technologists).

40 Regstel-aksie is dood, sê Erwin [Affirmative action no longer exists, says Erwin], *Beeld,* 12 July 2007.
41 SAIMC professional development and training, *SA Instrumentation and Control,* February 2005.

Figure 1.5 Registered engineer to population ratios in some African countries (2004)



Source: Lawless (2005)

Supply data, however, do differentiate between engineer graduation and technologist graduation. If the supply (output) ratio of graduate engineers to graduate technologists at higher education institutions is applied to the Quantec data for the 1996–2005 period, the ratio of engineers to technologists to technicians is approximately 1:0.4:1. This means that to every technologist there are just over two engineers. Such a ratio implies that engineers are underutilised, doing the work of technologists or even technicians in some instances – a fact that is confirmed by several stakeholders in the engineering industry. The CEO of Aveng, Africa's biggest builder, mentioned that engineering graduates were being deployed to building sites because construction companies could not find enough welders and other workers.[42]

Indications are that technologists with BTech degrees are also frequently being underutilised, at least in the private sector, and are used in very similar positions to technicians. In the public sector there does seem to be some evidence that technologists are being fast-tracked to take up positions historically filled by graduate engineers, and as shown in Table 1.1 there seem to be quite a number of National Diploma graduates also employed to do work where engineers are absent. Concerns have been raised, however, about how appropriate this is (Lawless 2005).

Demographic profile of engineering professionals

As already noted, in order to smooth the effects of fluctuations in data, an average was created for the period covered by each survey. Thus, for the OHS, which ran for a period of four years (1996–1999), an annual average employment number was generated; the same was done for the period 2000–2005 (LFS).

Race and gender

The race profiles of employed engineers and technologists are presented in Figure 1.6 and those of technicians in Figure 1.7, while the gender profiles are presented in Figures 1.8 and 1.9. The averages for 1996–1999 (OHS) and 2000–2005 (LFS) data were used to get an indication of the transformation trends (Quantec 2007).

42 Aveng hurt by skills lack, *Business Day*, 15 January 2007.

Black people represented 15.47% of all engineers and technologists over the 1996–1999 period. This percentage almost doubled to just under a third (30.47%) of all engineers and technologists over the 2000–2005 period. Black technicians constituted over a quarter (28.58%) of all technicians over the period 1996–1999 and increased by slightly fewer percentage points (12.82%) than black engineers and technologists to 41.39% of all technicians over the 2000–2005 period.

The average number of Indian engineers and technologists increased by 1 625 (proportionally from 7.91% to 22.72%), coloured engineers and technologists by 797 (proportionally from 11.02% to 13.75%) and African engineers and technologists by 2 779; although within the overall category of black engineers and technologist, the average number of African engineers and technologists increased proportionally less than coloured and Indian engineers and technologists between the 1996–1999 and 2000–2005 periods.

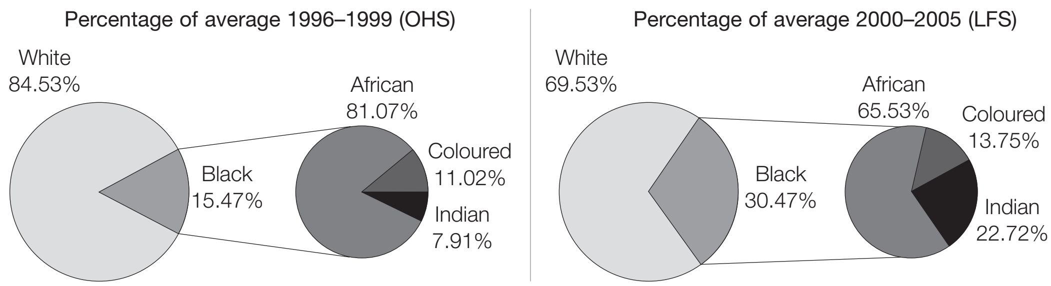
The average number of African technicians increased by 6 614 (proportionally from 59.98% to 72.60%). The average number of coloured technicians increased by 1 198 (although they decreased in proportion to the number of African technicians) and the average number of Indian technicians decreased by 45 between the 1996–1999 and 2000–2005 periods.

Although there has been a small average annual growth of 0.04% in the number of all female engineering professionals (engineers, technologists and technicians) over the 1996–2005 period, the proportion of women to men decreased from 11.70% in the 1996–1999 period to 8.64% in the 2000–2005 period. This was despite the fact that the supply of female graduates at higher education institutions increased at an average annual rate of 15.37% over the 2000–2005 period (DoE 1996–2005). It is worth mentioning that the decrease in the employment of white female engineers and technologists over this period is primarily responsible for this negative trend. Female to male technician proportions show a similar downward trend over this period (see Figure 1.9). Reasons for the low female employment in the engineering industry are discussed in Chapter 3.

Although the average number of white male engineers and technologists increased by as much as 3 041, as a proportion of all male engineers and technologists white engineers and technologists decreased in number from 84.45% to 71.20% over the 1996–2005 period. The average number of African male engineers and technologists increased by 2 000 (proportionally from 12.25% to 16.66%), while the average number of Indian male engineers and technologists increased by 1 625 (proportionally from 1.38% to 7.57%), and the average number of coloured male engineers and technologists increased by 797 (proportionally from 1.92% to 4.58%) over this period.

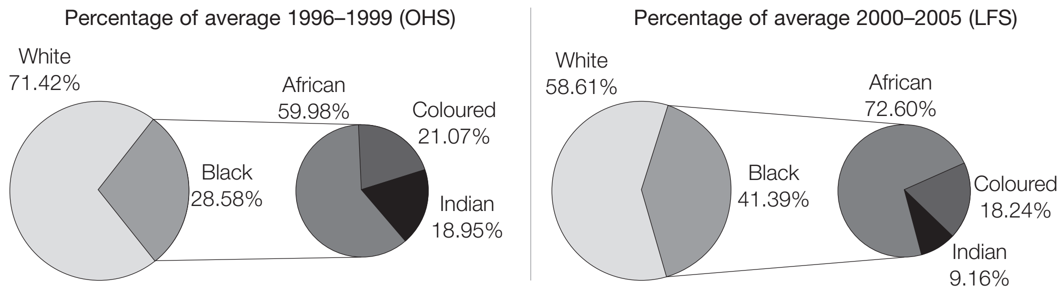
The average number of African male technicians increased by 6 679 (proportionally from 15.89% to 30.54%), coloured male technicians by 889 (proportionally from 6.31% to 6.96%), and Indian male technicians by 145 (although proportionally they dropped from 4.51% to only 3.54%), while the average number of white male technicians increased by 2 832 (but dropped proportionally from 73.30% to only 58.96%) over the same period.

Figure 1.6 Race profiles of engineers and technologists: average for 1996–1999 (OHS) and 2000–2005 (LFS)



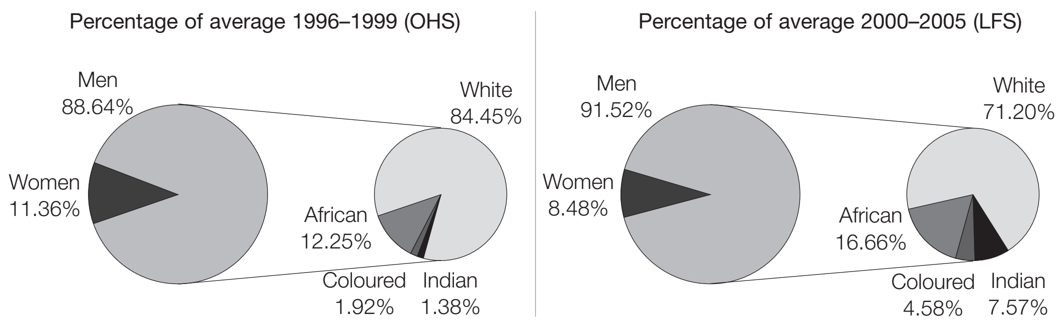
Source: Quantec (2007)

Figure 1.7 Race profiles of technicians: average for 1996–1999 (OHS) and 2000–2005 (LFS)



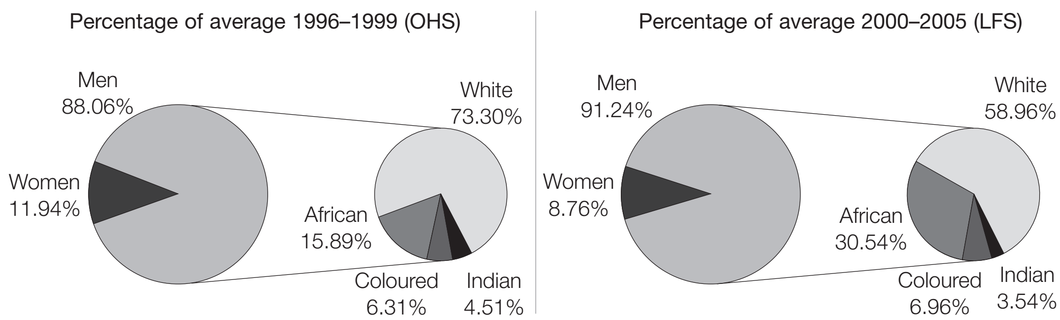
Source: Quantec (2007)

Figure 1.8 Gender profiles of engineers and technologists: average for 1996–1999 (OHS) and 2000–2005 (LFS)



Source: Quantec (2007)

Figure 1.9 Gender profiles of technicians: average for 1996–1999 (OHS) and 2000–2005 (LFS)



Source: Quantec (2007)

Age

Figure 1.10 shows the age profile of engineers and technologists, and technicians in the labour market in 2005. The greatest population density of engineers and technologists – more than half (55.70%) – is shown to occur between the ages of 35 and 39. These engineers and technologists (aged 35–39 in 2005) were students around 20 years ago (during the 1980s). Construction peaked in the 1970s and 1980s, according to Peter Squires, director at VKE,[43] and attracted engineering students at that time. From 1986–2003 civil engineering first-degree graduations declined (Lawless 2005) as construction slowed in the 1990s.[44] This may explain the concentration of engineers in the 35–39-year age category.

A major shortage of older and experienced professionals is evident in Figure 1.10 – only 13.01% of engineers and technologists are in the age category 50–60 plus. This has a major impact on the transfer of skills to the younger generation of engineering professionals, according to Vanesh Maharaj, a partner with Development Engineering and Consultants (DEC).[45]

The profile also indicates a shortage of mid-career professionals between the ages of 40 and 49. According to Lawless (2005), this low figure further shows that this middle group, having gained experience, are the ones sought after globally. Althea Povey, a former SAACE president, explains that it may be that industry does need more engineers but cannot afford to take on young graduates, who require time and money to train, and so the hunt is always on for the older, experienced engineers, who are scarce.[46] One of the key issues in the engineering industry at the moment is the lack of mentors, as indicated by Sean Flanagan, executive director of construction company Murray and Roberts.[47]

All engineering professionals start out in training positions that are largely technically oriented. Initially, workplace training would usually fulfil the requirement for professional registration, should it be sought (Hanrahan 2000). Lawless (2005) has found that in a substantial proportion of civil engineering contexts, engineering professionals in this training stage, especially graduates, are not getting basic supervision and assistance from older professionals. There are too few of the latter, and they have too much work to be able to pay attention to the transfer of skills. Anecdotal evidence suggests that this situation also pertains across other engineering disciplinary contexts. Most of the large corporate concerns used to operate substantial graduate training programmes for in-depth training, many of which now only exist in a very pared-down form. Graduates are now expected to 'add value' as soon as possible after their entry into the workplace (Adams 2006). Elsewhere in the world, the retirement ages are being raised to retain expertise in order to mentor younger engineers; this might well be an option for South Africa too.

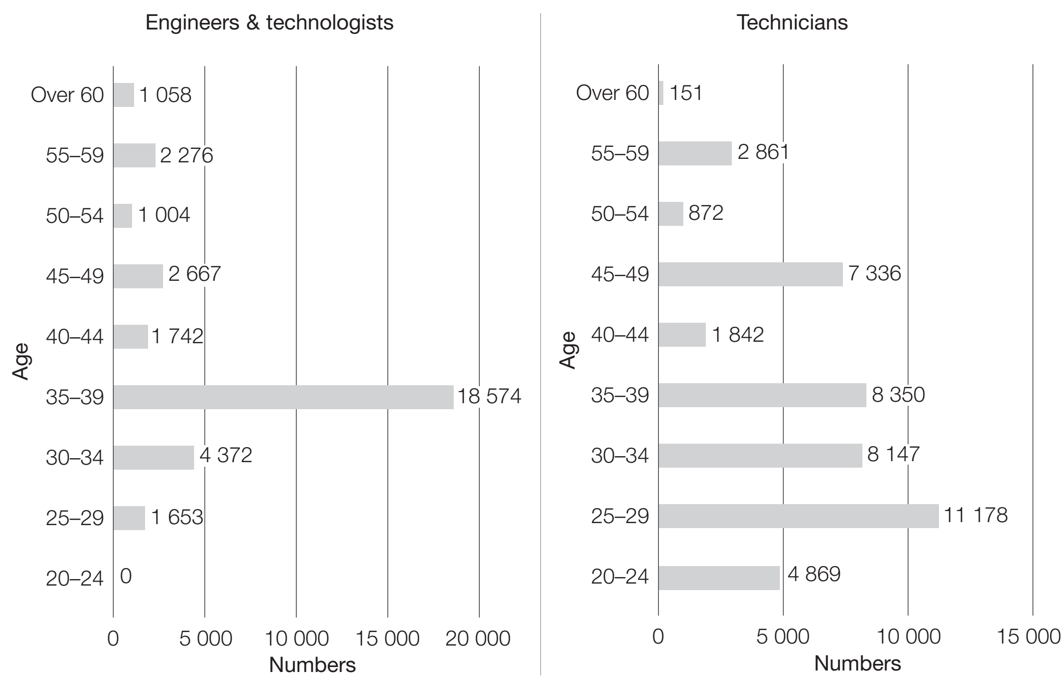
The very low number of engineers and technologists younger than 35 is noteworthy. Supply data from the Department of Education (DoE) indicate that on average about 2 048 graduates (engineers plus technologists) per annum were delivered for the period 1996–2005 – this equals just under 21 000 over this period (DoE

43 With bridge-building prospects improving, SA mulls skills-dearth challenge, *Engineering News*, 7 July 2006.
44 With bridge-building prospects improving, SA mulls skills-dearth challenge, *Engineering News*, 7 July 2006.
45 Hunt turns offshore for senior-professionals to fill SA's skills gap, *Sunday Independent*, 1 July 2007.
46 SAACE president questions assertions on the shortage of engineers, *Inside Track*, 3 March 2005.
47 Hunt turns offshore for senior-professionals to fill SA's skills gap, *Sunday Independent*, 1 July 2007.

1996–2005). This means that about 25 000 graduates should have entered the labour market since 1996. But where are they? One explanation could be low levels of professional registration, because some of these graduates could still be candidate engineers or technologists. LFS data for 2005 show, for instance, that about 8 000 people with engineering degrees were working as technicians, which is an example of underutilisation. Another possible explanation is that young graduates leave South Africa to gain experience abroad (Interview 2006f). International agreements, such as the Washington Accord for engineers (Jones 2006), the Sydney Accord for technologists, and the Dublin Accord for technicians have increased the opportunities for graduates (Interview 2006h).

In terms of the age profile of technicians, Figure 1.10 shows three-quarters (75.40%) of the technician workforce as being under the age of 45, which makes the task of the very few older technicians to transfer the necessary skills in the workplace virtually impossible. The age figures in Figure 1.10 reflect the fact that technicians start their working careers earlier than engineers and technologists; a technician graduates after a three-year National Diploma.

Figure 1.10 Age profile of engineers and technologists, and technicians (2005)



Source: Quantec (2007)

Remuneration trends for engineering professionals

Compared to other professions such as medicine and chartered accountancy, it is well known that those working in engineering traditionally earn less. Lower remuneration and an apparent lack of glamour associated with engineering are among the major factors influencing potential students when making career decisions.

Lawless (2005) reports that low salaries were seen as a key source of frustration, especially for engineers aged 35–55 years in the civil engineering sector. Her findings further show that salary disparities between civil engineers and other professionals appear to be most notable in younger groups, which contributes to the movement of young professionals to other industries. This trend is not unique to South Africa. Lawless refers to a recent study by the Higher Education Statistics Agency in the UK, which found that more than half of engineering graduates defect to other careers, citing money, status and image as the main reasons. According to Lawless, graduates in the UK could command double the starting salary offered to them in engineering by joining the finance and business sectors. In South Africa, too, this is a worrying trend in terms of engineering professionals, as an already alarming skills shortage is being exacerbated by the fact that local professionals are drawn by higher salaries to other markets and industries.

However, remuneration trends can be an indicator of the demand for certain skills and parity in terms of demographics, i.e. race and gender. Industry stakeholders are generally reluctant to provide salary data, and quantitative surveys on the matter are, as a rule, confidential and only available to participants. LFS data for the period 1997–2005 were therefore used to get an estimate of remuneration trends for engineering professionals. The data show an average annual increase in engineering technicians' salaries of 8.89% and for engineers and technologists an average annual increase of 12.88% over the period. The average annual growth in the salaries of female technicians over the same period was 17.23% compared to 7.41% for males, while female engineers and technologists had an average annual increase of 19.19% compared to 11.73% for males. The average annual growth in the salaries of black technicians compared to white technicians was the same – about 8%; but higher for black than for white engineers and technologists – 16.21% for black and 11.25% for white engineers and technologists.

The managing director of Engineering Work Solutions, a recruitment and placement agency for engineering professionals in the construction industry, indicated in 2007 that salaries had increased by 25% and more over the past year (Interview 2007a). Graham Pirie, CEO of SAACE, confirmed this by referring to the noticeable effect on profitability in the industry of an increase in salaries due to the apparent scarcity of skills in some areas.[48] In 2007, P-E Corporate Services reported that the shortage of technical, engineering and manufacturing staff increased the salaries for this group compared to other employees.[49] Attraction and retention of scarce and critical skills is still the single biggest driver of remuneration policy in private, public and state-owned enterprises, and the shortage of engineering professionals is compelling organisations to consider higher salaries, which has resulted in salaries increasing four or five times in three years, according to Vanesh Maharaj, partner with DEC.[50] Lawless (2005) emphasises that it is necessary to dramatically increase salaries in order to address the skills shortages, specifically for civil engineering professionals.

Within civil engineering, apart from the self-employed, civil professionals in JSE-listed companies are the highest earners, followed by contractors, with local government employees receiving the lowest average salaries. Local government and provincial remuneration levels have been identified as an area needing urgent attention, and there are large numbers of vacancies within provincial structures (Lawless 2005). Lawless suggests that engineering and other built-environment professions should

48 Can built-environment professionals now name their price? *Mining Weekly*, 7 April 2006.
49 Skills shortage 'drives up salaries', *Business Day*, 1 June 2007.
50 Hunt turns offshore for senior-professionals to fill SA's skills gap, *Sunday Independent*, 1 July 2007.

receive the same treatment as other comparable government employees – such as medical professionals – and be offered 'scarce-skills' and 'rural' allowances to make public sector employment more attractive.

In the mining sector, big contractors in 2007 were offering a sign-up bonus of R20 000 in an attempt to recruit skilled workers, according to trade union Solidarity's Dirk Hermann.[51]

The professional milieu

ECSA is a statutory body established in terms of the Engineering Profession Act (No. 46 of 2000) and is the entity that registers engineering professionals in South Africa. ECSA is authorised by the relevant legislation to carry out functions mainly in terms of the education, training and registration of engineering professionals, the protection of the public interest with regard to engineering activities, and the recognition of professional associations, such as engineering associations, institutes, institutions and societies.

Because of the important role of the formal qualification for professional registration, ECSA operates a system of accreditation of the various engineering qualifications offered by higher education institutions. ECSA is responsible for the setting and auditing of academic standards for purposes of registration through a process of accreditation of engineering programmes at universities and universities of technology, and setting and auditing professional development standards through the provision of guidelines that set out the post-qualification requirements for registration. ECSA further prescribes the requirements for continuing professional development and determines the period within which registered persons must apply for renewal of their registration.

ECSA is currently also engaged in the project Identification of Engineering Work. The main purpose of this project is to identify work in South Africa to ensure that work specific to the built environment is performed only by competent persons registered with a statutory council and accountable for their actions. This requires ECSA to consult with recognised voluntary associations, persons, bodies and industries that may be affected by any laws regulating the built-environment professions regarding the identification of the type of engineering work that may be performed by persons registered in any categories provided for in section 26(1) of the Act.

A further responsibility of ECSA is to ensure that the interests of the profession are promoted. This occurs through the Council's recognition of voluntary societies that are active in engineering. The various engineering institutions are principally CESA (formerly SAACE), SAICE, the South African Institute of Electrical Engineers, the South African Institution of Chemical Engineers, and the South African Institution of Mechanical Engineering.

Registration with ECSA is still voluntary. Engineering professionals may register with ECSA after completion of their three-year experiential training (in the case of engineers and technologists), or after their one-year experiential training (in the case of technicians). In terms of ECSA registration, the difference between engineers

51 Better pay, incentives may save SA from skills shortage, *Business Day*, 6 July 2007.

and technicians is that engineers graduate with a degree from a university and then work for a period of three years before registering as professional engineers at ECSA; technicians complete two years of theoretical training at a university of technology and are then required to do one year of experiential training before obtaining their National Diplomas and registering with the Council as professional technicians. However, registration with the Council is not compulsory (unlike the situation with other professions such as medicine or psychology, for example). This means that the number of engineering professionals registered with ECSA does not tally with the number employed according to official labour market statistics.

However, at this stage it is unclear what the future situation will be, as the controversial Built Environment Professions Bill, introduced on 30 May 2008, which proposed that a single juristic body be established – to be named the South African Council for the Built Environment (SACBE) – has since been withdrawn because of technical and legal issues.[52] ECSA will lose its status as a statutory council if the Built Environment Professions Bill goes ahead, as the proposed new body will serve as an umbrella body for all professional boards in the built environment, and registration will become compulsory.

ECSA recently announced an upsurge in registration due to the following factors: growing awareness of the benefits of registration; imminent promulgation of the Identification of Engineering Work regulations; the possible introduction of compulsory registration; compulsory registration of lifting machinery inspectors (as required by the Department of Labour); and an increase in the number of SADC and overseas engineering practitioners seeking registration and employment in South Africa.[53]

In terms of encouraging the transformation process, the National Society of Black Engineers (NSBE) in South Africa is a good example of a forum with this objective in mind. It was established in 1995 with the initial aim of focusing on the academic progress of black engineering students at universities. The Society became a fully fledged professional body, legally registered as a non-profit, non-governmental organisation, in 1998. From that time onwards, a series of developmental programmes for black engineers and students were undertaken. Monthly networking sessions were held, usually within the premises of companies employing black engineers. The intention was to give black engineers an opportunity to share ideas, and the hosting companies an opportunity to inform potential employees about the activities of the firms.

Unfortunately, the Society lost impetus around 2002 – mainly due to a lack of administrative resources and also because most of the office bearers had since assumed major responsibilities in their organisations. However, declining levels of technical skill in South Africa and insufficient growth in the number of black engineering graduates have subsequently brought about a revival of the organisation; the NSBE held its first national conference in Durban in September 2007. The conference was about the NSBE's response to a call for increased black participation and leadership in the technical fields that contribute to the economy of South Africa.

52 Built Environment Professions Bill withdrawn – Minister, *Engineering News,* 18 November 2008.

53 'Engineering Council of South Africa reaches registration milestones.' ECSA media release, 30 June 2008.

Workforce demand

Guesstimated demand?

As already mentioned, it is exceptionally difficult to come up with authoritative figures or even estimates with regard to skills shortages or demand for engineering professionals. The reasons are manifold: the quality of official statistics; double counting of especially engineering professionals in the Sector Skills Plans of SETAs in the face of infrastructure investment; absence of a comprehensive national register of qualified engineering professionals; the fact that engineering professionals are easily absorbed into industries not related to engineering; and unreliable emigration figures due to the fact that engineering professionals maintain their registration status if registered, regardless of where they are working, what type of work they are doing, or whether they are out of the country for any length of time. However, the factors discussed below can be interpreted as signals of demand.

Growth in employment

Employment is usually used as an indicator of the demand for an occupation or skills. In the absence of regular and consistent survey data based on the needs of companies that use engineering skills, LFS statistics are used here for the purpose of analysis of demand for employment. Again, it is important to note that these data can only be used as a proxy for demand.

Table 1.2 indicates an absolute employment gain of 40 605 in qualified engineering professionals (engineers, technologists and technicians) for the period 1996–2005, or an average annual growth of 6.97%. This is significant in the light of the slow 0.74% average annual growth in formal employment in the total economy over this period (Quantec 2007). However, employment for engineering occupations is expected to increase even more, in line with the massive infrastructure investment being made by government.

Vacancies

Skills shortages or the scarcity of specific skills are usually noticed in vacancies or positions for which employers cannot find suitable candidates. Table 1.6 shows vacancy data captured by the Department of Labour for the period April 2004–March 2007 (Erasmus 2007). These data were obtained from all South African vacancies published weekly in the Business Times Careers section of the *Sunday Times* over that period. Although the vacancy rates cited below are only based on the *Sunday Times* data, they do signal a demand for the skills of engineers and technologists in the South African labour market. Furthermore, if one opens any careers/employment section in any newspaper in the country, apart from domestic job advertisements one sees jobs offered to project managers and engineers in Australia, Singapore and New Zealand, which would go some way towards explaining local shortages.

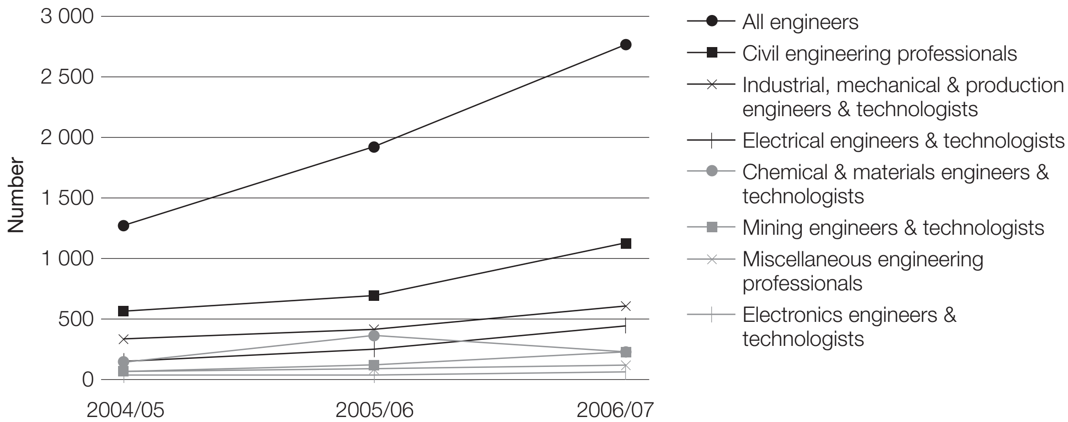
Table 1.6 Long-term vacancies reported in the Sunday Times *(April 2004–March 2007)*

	2004/05		2005/06		2006/07	
Occupation	Vacancies	Vacancies as % of total employment	Vacancies	Vacancies as % of total employment	Vacancies	Vacancies as % of total employment
Engineers and technologists	1 248	5.63	1 904	5.71	2 757	7.81

Source: Erasmus (2007)

Figure 1.11 and Table 1.7 show that the number of vacancies increased significantly for all the engineering fields between 2004/05 and 2006/07, but the greatest increase was for mining engineers and technologists (387.72%), followed by electrical engineers and technologists (355.37%).

Figure 1.11 Vacancies for engineers and technologists (April 2004–March 2007)



Source: Erasmus (2007)

Table 1.7 Number of vacancies (April 2004–March 2007)

Vacancies	2004/05	2005/06	2006/07	Increase (%)
All engineers	**1 248**	**1 904**	**2 757**	**220.91**
Civil engineering professionals	546	688	1 126	206.23
Industrial, mechanical & production engineers & technologists	326	409	594	182.21
Electrical engineers & technologists	121	243	430	355.37
Chemical & materials engineers & technologists	123	355	221	179.67
Mining engineers & technologists	57	113	221	387.72
Miscellaneous engineering professionals	42	63	112	266.67
Electronics engineers & technologists	33	33	53	160.61

Source: Erasmus (2007)

Poaching of engineering professionals
According to engineering recruitment and placement agencies, there is extensive poaching of engineering professionals by overseas companies. 'Highly skilled South Africans are being lured abroad by attractive pay cheques,' according to reporter Simpiwe Piliso.[54] The agencies indicate that if engineers go abroad, they do not come back. Like all professionals that are highly in demand, South African engineers are offered lucrative packages overseas and once they have experienced these conditions they tend not to want to give them up. According to Johan Pienaar, ECSA's registration manager, ECSA had 1 200 registered engineering professionals with overseas addresses on its database in 2007; the suggestion is that proper remuneration is required to encourage engineers to stay.[55] There is an aggressive headhunt for engineers (Interview 2007a) and recruitment agencies from abroad are opening offices in South Africa.[56]

Ratios according to international benchmarks
As noted in the section on employment ratios of engineering professionals, there is about one engineer to every 3 166 members of the population in South Africa, according to the conventional method of calculating this figure – quoting the number of professional engineers registered at a specific point in time. But in South Africa we know that very few qualified engineers register with ECSA because registration is not compulsory. This means that the engineer to population figure would look better if real employment figures or counts of engineering professionals were used. Thus, using the number of employed engineers in 2004 (22 182), according to the LFS, translates into a more favourable ratio of one engineer to every 2 113 members of the population.

Lawless (2005) emphasises that South Africa needs to develop and strengthen its infrastructure and that it is disquieting that the ratio of engineers to general population in South Africa is not significantly better than in Zimbabwe, Namibia and Tanzania and other less developed countries (as indicated in Figure 1.5).

New and replacement demand

The quality of current data on demand is not good enough to allow forecasts with regard to new and replacement demand, because the data fluctuate from one year to the next.

However, the domestic supply of young engineers and technologists is not *visible* in the local labour market, because there are very low employment figures for the age category 25–34 years (Figure 1.10). This issue has already been addressed in the section on the age profile of engineering professionals. If, as Althea Povey (former SAACE president) has stated, it is correct that many graduates leave the country to seek opportunities elsewhere in order to gain experience, then an urgent strategy should be implemented to assist young graduates to enter the South African labour market, and incentive schemes should be put in place to retain them.

Reasons for shortages

An array of reasons can be put forward to explain shortages in engineering skills, ranging from socio-economic factors such as economic growth and emigration,

54 Piliso S, Exodus – movement of the people, *Sunday Times*, 25 February 2007.
55 SA's wide engineering gap, *Fin24.com*, 21 October 2007.
56 Wêreld ontgin SA kundigheid [The world is mining SA expertise], *Finweek (Fin & Tegniek)*, 16 November 2005.

through educational factors such as poor mathematics education at school level, and low throughput of engineering students at higher education institutions, to labour market intervention factors such as transformation policies. Dave Mars (Cape editor at *Business Day*) summarised the reasons for shortages of engineering skills as follows: 'Failure to market engineering as a career to attract the best students, an investment "strike" on the part of the state during the fiscally austere early 1990s, which caused many engineers to emigrate or change careers, and the overzealous application of affirmative action policies.'[57]

Economic reasons

According to Steyn and Daniels (2003), employment trends and demand for engineering professionals were determined to a large extent by the following two significant economic drivers in South Africa during the past three decades: the reduction in agriculture and mining's share of the GDP; and the relative changes within sectors with regard to labour productivity and capital intensity – such as the recessionary period in the construction industry in the 1980s and 1990s. This opinion is also shared by Cees Bruggemans, chief economist at FNB;[58] Pieter Louw of PA Louw and Associates;[59] and Dave Mars.[60] This led to an outflow of engineering professionals and artisans to other non-related industries in South Africa as well as to global markets. The current situation is different. Sustained high economic growth since 2000 in South Africa, fuelled by the unprecedented boom in global commodity prices since 2000 and the government's commitment to increased infrastructure spending over the next few years, are among the primary causes of South Africa's skills shortage predicament. However, with the credit crisis in 2008, South Africans with the right skills may return to South Africa, although South Africa still needs to compete for scarce skills with countries such as Canada, Australia and China (Isaacson, 2009).

In their bid to achieve accelerated growth, state-owned enterprises such as ESKOM, Transnet and Spoornet have increased their investments, adding new capacity to electricity, port and rail infrastructure, while projects such as the De Hoop Dam, the King Shaka Airport and the Gautrain, as well as the R20 billion-plus outlays for the 2010 World Cup, further add to the demand for engineering skills, as indicated by then Deputy President Phumzile Mlambo-Ngcuka[61] and Dirk Hermann, Solidarity's general secretary.[62] Furthermore, SAICE found most of South Africa's infrastructure to be in desperate need of repair and maintenance.[63]

The South African government has decided to take the route of a developmental state – meaning that the state is an active promoter of economic growth – by investing heavily in infrastructure in order to enhance economic activity for all. The delivery of services is important to allow previously excluded people access to the labour market. A strategy like this requires technical skills to work on infrastructure projects and experienced technical managers who can run with and complete projects. This is especially the case for engineering professionals.

57 Mars D, Engineering a response to SA's infrastructure woes, *Business Day*, 5 March 2007.
58 How new infrastructure could lift growth floor, *Sunday Times*, 27 May 2007.
59 With bridge-building prospects improving, SA mulls skills-dearth challenge, *Engineering News*, 7 July 2006.
60 Mars D, Engineering a response to SA's infrastructure woes, *Business Day*, 5 March 2007.
61 ASGISA investment leaps forward, *Business Report*, 23 March 2007.
62 Better pay, incentives may save SA from skills shortage, *Business Day*, 6 July 2007.
63 Call for engineers to help municipalities, *Business Day*, 22 February 2008.

Emigration, mobility and the global economy

By all standards, levels of emigration of highly skilled people – and particularly engineering professionals – from South Africa are high. Quantifying this trend is not an easy task due to unreliable data and record-keeping in this regard. Worth noting is that emigration is usually higher than what is recorded through official South African data (Bhorat, Meyer & Mlatsheni 2002). Bhorat et al. argue that a degree of mobility is necessary if developing countries want to be part of the global economy, but that a significant outflow of skilled people can impact on growth and development. This is especially valid with regard to engineering professionals in South Africa, given government's current massive investment in infrastructure.

There is a very lively global market for skills, especially for engineering professionals, and it extends further than simply developed countries. Some examples are the Middle East and the oil states, which are magnets for specifically engineering professionals. The South African navy is losing engineers to the lucrative oil industries of Angola and Nigeria, as indicated by Johannes Mudimu, South Africa's navy chief.[64] In Europe, demographic changes are driving demand for skills – populations are ageing and contracting. The skills market is fluid, engineering professionals can move between industries and they have access to global opportunities. The global industry also offers much higher salaries.

South African-based employment agencies react to this demand by supplying the desired skills. According to the joint chief executive of the Capital Outsourcing Group, 'South Africans are in such great demand abroad because: they speak English; are hard working; experienced; multi-skilled and familiar with tough working environments'; in addition, South Africa's longitudinal position makes it easy in terms of time and money for workers to get to their destinations; and it is easy for locals to get visas for African countries.[65]

According to SAICE, South Africa has lost an estimated 6 000 civil engineers over the past 25 years.[66] The South African Federation of Civil Engineering Contractors confirmed this trend by showing that about a third of South Africa's engineering graduates over the past 40 years worked abroad.[67]

Lower remuneration than in other professions

As already indicated, engineering professionals earn less compared to those in other professions, such as medical doctors and chartered accountants. Lower remuneration as well as an apparent lack of glamour associated with engineering are therefore among the major factors causing skills shortages in the engineering field. Stakeholders and analysts such as Ravi Nayagar, CEO of ECSA;[68] Murray and Roberts Cementation;[69] Professor Frank Horwitz, director of the UCT Graduate School of Business;[70] Martin Westcott, managing director of P-E Corporate Services;[71] and Webster Ndodana, first black president of SAACE,[72] are convinced that extensive

64 Navy losing engineers to African oilfields, but training more, *Cape Times*, 23 February 2007.
65 South African TES company operating globally, *The Star*, 30 January 2007.
66 'Gebruik die kundige ingenieurs' ['Use the expert engineers'], *Rapport*, 22 January 2006.
67 Skills shortage 'drives up salaries', *Business Day*, 1 June 2007.
68 SA's wide engineering gap, *Fin24.com*, 21 January 2007.
69 Better pay, incentives may save SA from skills shortage, *Business Day*, 6 July 2007.
70 Need for skills shortage solution, *The Herald* (*EP Herald*), 30 November 2006.
71 Skills shortage 'drives up salaries', *Business Day*, 1 June 2007.
72 Ingenieurs moet na SA terugkom [Engineers need to return to SA], *Beeld*, 19 January 2006.

salary increases would serve as an incentive to save South Africa from engineering skills shortages.

The managing director of Engineering Work Solutions (a recruitment and placement agency in the construction sector) indicated that salary offers for engineering professionals in this sector had increased by more than 25% in the course of the previous year (Interview 2007a). An increase in wages can be an indicator of the demand for certain skills. As already indicated in the section on remuneration of engineering professionals, industry stakeholders are generally reluctant to provide salary data, and quantitative surveys on the matter are, as a rule, confidential and only available to participants. LFS data for the period 1997–2005 were therefore used to obtain an estimate of remuneration trends for engineering professionals. The data show an average annual increase in engineering technicians' salaries of 8.89% and for engineers and technologists of 12.88% over the period. P-E Corporate Services also reported that the shortage of technical, engineering and manufacturing staff pushed up the salaries of this group compared to other employees. Further evidence in this regard was provided by engineering recruitment and placement agencies as well as by related professional organisations (Interview 2006b; Interview 2006d).

Secondary school education

Chapter 2 discusses in more detail the challenge that South Africa faces in terms of secondary education that contributes to the shortage of engineering skills, and refers to the strategies applied in attempts to address the problem. Nonetheless, the two most important matters to mention are the low numbers of school leavers (hitherto known as 'matriculants')[73] passing Grade 12 with higher grade mathematics and physical science (minimum D symbol) and thus qualifying for engineering studies, and the quality of mathematics and science knowledge that these engineering students bring with them. In addition to this predicament, it is well known that the engineering field has to compete with other professions such as medicine and commerce to attract potential students from the limited mathematics and/or science pool of Grade 12 school leavers.

In terms of shortages of engineering professionals and artisans, the irony is that the DoE invested close on R1 billion in 2006/07 for infrastructure development in schools, for example, but KwaZulu-Natal's MEC for Education, Ina Cronjé, at the time warned that there were not skilled people available to put in the plumbing, build the foundations and lay the cables![74]

Low throughput at higher education institutions

Throughput trends at universities and universities of technology are discussed in detail in Chaper 2. The most important factor to consider in this section on the reasons for shortages of engineering skills is that the throughput rates, delivering the current average of 2 000 graduates at universities and 3 000 graduates at universities of technology, are far from optimal. This is one of the factors explaining our low engineer to population ratios as compared to other developing countries.

73 Previously, this final, school-leaving exam was widely referred to as 'matric', with those who passed being termed 'matriculants'. However, with the introduction of a new curriculum and qualification, the National Senior Certificate, for Grade 12 school leavers in 2008, both 'matric' and the system of differentiating between subjects taken on the higher or standard grade fell away.

74 Growing SA's skills, *The Witness*, 25 May 2007.

Failure to market engineering as an attractive career

Chapter 2 recounts some of the reasons why potential students do not pursue studies to follow a career in engineering. A European Commission (2006) report argues that lack of information is a major factor influencing, for example, women's decision to consider a career in engineering. None of the students interviewed in their WomEng project had any precise information about the job and actual activities of an engineer. This means that none of them had a good idea of their future career paths as engineers when they started their training. There are many stakeholders who have embarked on exceptional initiatives to persuade more school learners to pursue engineering as a career. However, it would seem that much more has to be done to provide information on engineering in order to market it to the best students as an attractive career.

Lack of experiential training opportunities

As discussed in the section on employment of engineering professionals, the lack of experiential workplace opportunities for engineering technicians is a big concern and contributes to the existence of skills shortages. Lawless (2005) found in her civil engineering study that about 60% of final-year National Diploma students who responded to her survey in October and November 2004 had not yet had experiential training and therefore could not graduate. Pierre Blaauw of the South African Federation of Civil Engineering Contractors stated that, at the artisan and technician level in the building sector, about 50% of the labour market of about 500 000 do not have access to sufficient training because of subcontracting practices and the use of temporary staff in the industry.[75]

Transformation policies

Migration of white engineering professionals out of the state and parastatal sectors due to transformation policies[76] is frequently put forward as a reason for the engineering skills shortages, for example by Marius Fransman, transport and public works MEC;[77] Webster Ndodana, the first black president of SAACE;[78] Gareth van Onselen, the Democratic Alliance's director of special issues;[79] and Phumzile Mlambo-Ngcuka, South Africa's deputy president at the time.[80] In general, it has been argued that affirmative action has been pursued too aggressively;[81] that it is too costly, according to Ann Bernstein, executive director of the Centre for Development and Enterprise;[82] that it undermines institutions, according to Gareth van Onselen;[83] that we should be basing appointments on competence and not race, according to Eddie Durant, managing director at Grinaker-LTA;[84] and that we need to debate the impact of employment equity in a mature manner, according to Dr Mamphela Ramphele, former vice-chancellor of UCT and a former managing director of the World Bank (Ramphele 2008). Danai Magugumela, CEO of BKS Consulting Engineers, adds that, 'We need to manage transformation responsibly by recognising

75 Boubedryf kan nie in opbloeitydperk in behoeftes voorsien [During an upswing, the construction industry cannot address needs], *Beeld*, 19 February 2007.
76 It's not about the money, *Mail & Guardian*, 11–17 April 2007.
77 Engineering a response to SA's infrastructure woes, *Business Day,* 5 March 2007.
78 'Gebruik die kundige ingenieurs' ['Use the expert engineers'], *Rapport,* 22 January 2006.
79 The public service and affirmative action, *SA Government,* 12 May 2008.
80 Who will build the future when the skills dry up? *Financial Mail,* 16 December 2005.
81 'Get SA out of BEE trouble', *Fin24.com,* 7 May 2008.
82 Our obsession with job equity could be costing our economy, *Daily Dispatch,* 18 June 2007.
83 The public service and affirmative action, *SA Government,*12 May 2008.
84 Skills shortage is genuine threat to growth, say bosses, *Business Report,* 24 May 2007.

and retaining exceptional engineering talent, irrespective of race or gender identity.'[85] In 2007, the SAIRR found that almost a fifth (one million) of the white population had left the country in the last 10 years, listing crime and affirmative action as the biggest reasons for the exodus.[86]

In engineering specifically, ECSA has pointed to the dangers of pursuing transformation at all costs. In a press release, the Council said that it had obtained an interdict against Tshwane metropolitan municipality to stop all disciplinary action against an engineer who had reported to ECSA that the municipality was appointing inexperienced candidates in a bid to accelerate transformation. The candidates were appointed as systems operators at the Tshwane Power Control System, despite testing poorly prior to their appointment. The engineer in question believed that this posed a danger to public safety as well as to the lives of the systems operators themselves, but faced disciplinary action at the municipality after reporting the matter in writing to ECSA. According to ECSA, the court ruled that it was the duty of a professional engineer to pay due regard to public safety considerations, and disapproved of 'acceleration of transformation at all costs while disregarding safety considerations', and the court required 'a sensible balance between transformation and safety'.[87]

Viv Crone, president of the South African Institute of Electrical Engineers, argues that the employment scorecard works against skills development goals.[88] He argues that the scorecard awards companies more points for board and management representivity than for recruitment and training of junior personnel; that is, the emphasis is on senior people and not junior appointments. He suggests that flexibility and creativity be applied to the current system to maximise the resources available. Engineering professional Robert de Neef suggests that it is not the pull of the private sector that makes engineers leave government, but the push of transformation policies and restructuring.[89]

Whatever the reasons, there has clearly been a large drop in employment of white people in the engineering professions, as indicated by the SAIRR.[90] Our own research shows that white engineering professionals, as a proportion of total engineering professionals employed, dropped from 76.9% over the 1996–1999 period to 63.2% over the 2000–2005 period (Figures 1.6 and 1.7).

Lawless (2005) suggests that employment equity policies need to be reviewed, particularly in departments that are critically short of engineering staff, and that senior staff should be retained post-retirement age to initiate and manage projects and train young graduates.

In 2007 an ANC provincial executive member and MEC for Transport and Public Works, Marius Fransman, appealed for a mature and thorough debate on a moratorium on affirmative action, in the light of the shortage of engineers. He said:

85 Engineering transformation: 'Retain talent irrespective of race or gender', *Engineering News,* 23–29 June 2006.
86 Beat the skills trap by employing mentors and mentees, *The Star*, 1 February 2007.
87 'Engineering Council of South Africa obtains interdict against Tshwane metropolitan municipality'. ECSA media release, 1 February 2008.
88 BEE 'hampers training goals', *The Weekender*, 25 March 2007.
89 It's not about the money, *Mail & Guardian*, 11–17 April 2007.
90 White exodus, *Citizen*, 3 October 2006.

> One of the unintended consequences of employment equity is the 'leakage' from the economy of white graduates with scarce skills. While employment equity is a strategy to redress historical imbalances, our country cannot afford to lose too many engineers. The question of a possible moratorium on employment equity needs to be thoroughly and maturely debated, based on research into the loss of scarce skills professionals within the context of 'binding constraints' on economic growth and the consequent lack of delivery to the poor. The existence of a 'second economy trap' is arguably the most important historical imbalance that needs to be redressed in South Africa currently. (Fransman 2007)

Not surprisingly, Fransman's remarks were taken up by opposition parties, who subsequently called for a complete moratorium on affirmative action.[91] However, various government ministers at the time, including the minister of finance, Trevor Manuel, the deputy president, Phumzile Mlambo-Ngcuka, and the minister of labour, Membathisi Mdladlana, denied the possibility of this happening.

Fransman's appeal was supported, however, by Dr Mamphela Ramphele (Ramphele 2008). Speaking at an awards ceremony at Masakh' iSizwe Centre of Excellence, which awards bursaries to students in the engineering and built-environment fields and also has an engineering skills development programme aimed at producing 'engineers with a social conscience', Ramphele referred to Fransman's suggestion and said that the reaction from some ministers was to 'shut down the debate' (Ramphele 2008: 9). She said that she was concerned that employment equity was being treated as a 'holy cow'.

> Given the many concerns expressed across the board, and the tough global skills market it is surprising we are not examining the impact of employment equity on our performance as a nation. Are we as much in denial about this as we were about AIDS and Zimbabwe? Why are we not debating this issue in a mature and considered manner? (Ramphele 2008: 9)

Impact of skills shortages in engineering

As discussed, at the macro level engineers are at the core of two key areas of the development enterprise in a country: building and maintaining infrastructure in the public sector and contributing to economic growth in the private sector. In the public domain, engineers in the employ of the parastatals have always been involved in the provision of transport, communication and electrification. Those specifically in the civil engineering field are involved in general urban development and upgrading of infrastructure and are by and large employed by local or provincial government. In the private sector engineers work in a wide range of commercial enterprises, including small consulting firms, medium-sized businesses and large multinational companies. There are also sizeable contingents of engineers who are not working in the traditional engineering sector but are contributing to sound planning and management in general business. It is therefore very clear that in South Africa a shortage of engineering skills impacts on economic growth in general, and on government's ASGISA, which depends on investment in public infrastructure, in particular.

91 Parties call for cap on AA, *SAPA*, 1 March 2007.

Following are examples of the impact of skills shortages in engineering:

- Testimonies regarding shortages in civil engineering, of which the seminal report by Lawless (2005) is the most comprehensive and contemporary, indicate that a surge in the supply of engineering professionals in this field is a high priority, otherwise the infrastructure investment of government will not be realised and the 2010 World Cup could be at risk.
- Vacant positions at metropole and municipal levels are numerous. In the metropoles there is a ratio of one civil expert (engineer or technologist or technician) to every 21 311 members of the population and only one civil engineer to every 60 000 members of the population, while the worst-hit metropole is Cape Town, with only one civil engineer to every 71 400 members of the population.[92] Lawless (2005) reports that a census of all local and district municipalities and metros showed that of the 231 local municipalities surveyed, 79 (over a third) had no civil engineers, technologists or technicians. Lawless further indicates that South Africa is disadvantaged in comparison to other developing nations with regard to the number of people per engineer. Malaysia has 543 people per engineer, Brazil 227 people per engineer, India 157 people per engineer and South Africa as many as 3 166 people per engineer.
- In 2007, the then provincial and local government minister, Sydney Mufamadi, emphasised that the lack of civil engineering professionals at municipal level was having a negative effect on service delivery aimed at alleviating poverty in South Africa.[93]
- Gains in service delivery brought about through Project Consolidate may be lost unless more engineers are attracted to municipalities, according to a report by engineers seconded to struggling municipalities as part of the project launched by the Department of Provincial and Local Government. With many of the posts vacant, the engineers seconded to struggling municipalities found that there were no full-time staff to mentor and they were forced to do projects themselves instead of transferring skills.[94]
- According to Neil Macleod, quoted in his capacity as president of SAICE, 'The South African economy needs municipalities to play their part in ensuring well-constructed and maintained engineering infrastructure if our economy is to achieve the ultimate gross domestic product (GDP) growth target of over 6% a year.'[95]
- Shortages in engineering skills lead to project delays, poor quality of work, lack of monitoring and an inferior product/service being delivered, according to engineers seconded to struggling municipalities.[96] Delays in the implementation of projects further affect the expenditure of the budgets on service delivery, according to Ali Said, infrastructure and engineering business unit manager at the Nelson Mandela Bay municipality.[97] This is already obvious in the fact that at municipal level budgets are not being spent.
- Because of bad planning in terms of the demand for skills and the ambitious R95 billion programme to upgrade electricity capacity, power cuts by ESKOM occur. Despite an ongoing recruitment drive, ESKOM is still short-staffed, including engineers.[98] Professor Christo Viljoen, former member of the old

92 Serious skills shortage in engineering field undermines service delivery, *Cape Times*, 29 January 2007.
93 Call for engineers to help municipalities, *Business Day*, 22 February 2007.
94 Engineers warn of dire straits in local councils, *Business Day*, 2 March 2007.
95 Call for engineers to help municipalities, *Business Day*, 22 February 2007.
96 Engineers warn of dire straits in local councils, *Business Day*, 2 March 2007.
97 Bursaries address shortage of skills, *The Herald*, 19 April 2007.
98 Power cuts blamed on skills blackout, *The Star*, 22 January 2007.

Electricity Board, has warned that a thousand additional engineers, technicians and operators need to be employed each year at ESKOM until 2010 but that they are simply not available.[99]

- Michael McDonald, economic and commercial manager of the Steel and Engineering Industries Federation of South Africa, argues that engineering skills shortages will definitely hinder the potential to double exports.[100]
- According to Productivity SA and the 2007 International Institute for Management Development *World Competitiveness Yearbook*, South Africa has the world's highest brain drain and the worst skills shortages of 55 country studies, its productivity is plummeting and the country ranked last on the availability of engineers.[101]

Conclusion

The capacity problem in engineering is a worldwide phenomenon, but issues such as migration, equity, lack of experiential training opportunities, shortage of mentors, and the expansion of infrastructure spending further complicate matters in South Africa.

Over the 1996–2005 period there was growth in employment of engineering professionals combined (6.97% average annual growth), but the number of engineers and technologists showed an average annual growth rate of only 5.91%, while the number of technicians showed an average annual growth rate of 7.65%. Over this period the majority of engineers and technologists worked in the manufacturing and financial and business services sectors. The construction sector is very dependent on the domestic market, in which the public sector is dominant. The construction industry went through a slack period, but has picked up over the last few years, and since 2004 an increase in employment has been reported in this sector. ASGISA will surely stimulate and ensure further growth of this sector over the next few years and will lead to a demand for employment in the public sector in particular. With the current rate of reported skills shortages in the engineering field it will not be easy to fill current and future vacancies in the public sector.

Progress in racial transformation is visible in employment figures. However, the proportion of female to male engineers, technologists and technicians decreased during the 1996–2005 period and the under-representation of women in the engineering labour market remains an issue. A major shortage of older and experienced professionals is evident; this has a significant impact on the transfer of skills to the younger generation of engineering professionals.

Analysis of data and the investigation of contextual factors show that there is a demand for engineering professionals in the South African labour market. An array of reasons is put forward to attempt to explain the shortages of engineering skills. These reasons range from socio-economic factors such as economic growth and emigration, and educational factors such as poor mathematics education at school and low throughput of engineering students at higher educational institutions, to labour market intervention factors such as transformation policies.

99 Waar gaan ESKOM nog 1 000 kundiges per jaar kry? [Where is ESKOM going to find another 1 000 experts per annum?], *Rapport*, 26 January 2006.
100 Engineering sector faces hitches, *The Star*, 19 February 2007.
101 'Get SA out of BEE trouble', *Fin24.com*, 7 May 2008.

CHAPTER 2

The educational context for engineering professionals

Against the background of the demand for engineering professionals in South Africa the focus turns to the supply of engineering professionals and the educational context for engineering. The vice-president of ECSA (Interview 2006a) emphasised that it takes about 10 to 11 years to educate and train an engineer, starting in Grade 9 with good mathematics and physical science education at secondary school level and ending when the three years' workplace experience is completed. The same principle is valid for engineering technologists and technicians.

It is apparent that engineering graduates enter a profession characterised by both global competition and global collaboration; we are in an era when engineering can no longer be considered anything but a global profession. Higher education institutions are today committed to preparing students to become engineering professionals in the global market. Internationally, the research done by the Carnegie Foundation for the Advancement of Teaching on the education of engineers is an example of such an exercise (Sheppard & Silva 2001). Domestically, the Centre for Research in Engineering Education at UCT is the key player in the promotion of engineering education, research and development across the whole country.

This chapter identifies some of the drivers of change in the education of engineering professionals. It explores the sufficiency of the skills pipeline for engineering by looking into secondary school education; reasons for studying engineering; the supply of engineering professionals by higher education institutions, including discussion of trends in engineering enrolment and graduation at universities and universities of technology; the engineering programmes and the accreditation process; challenges for institutions offering these programmes; and issues of student access and mobility. It also briefly mentions engineering training by FET colleges and through learnerships.

Drivers of change in engineering education

There are at least three major drivers of change that have an effect on the education of engineers (Interview 2007b): professional and quality requirements, the DoE, and international accords. A new driver in terms of scarce and critical skills, now and in the next few years, is ASGISA and its associated Joint Initiative on Priority Skills Acquisition (JIPSA).

Engineering education is the domain of the profession as well as the higher education institutions and is therefore highly regulated by ECSA; all of the engineering education programmes are accredited by ECSA. The Engineering Standards Generating Body (ESGB) plays an important role in setting up qualifications, and ECSA (by law) accredits all programmes. The engineering programmes and the process of accreditation are discussed in more detail later in this chapter.

The DoE is the second driver in terms of the national imperative of access, throughput and articulation. Selection for access to engineering programmes at higher education institutions is almost exclusively based on potential students' results in mathematics and physical science in the final Grade 12 school-leaving exam. The quality of teaching in mathematics and science as well as the small number of learners passing these exams with the required results pose major challenges for the education of engineering professionals. In 2005 only 39.94% of matriculants who passed higher grade mathematics passed with a C symbol or higher and only 23.14% of matriculants who passed physical science at higher grade passed with a C symbol or higher (DoE 2005). Under the previous curriculum, higher grade C was regarded as the minimum standard in mathematics in order to follow an engineering programme at all but two of the universities (the other two required higher grade D). The new mathematics curriculum and the question of whether it will provide an adequate foundation for engineering programmes adds to this challenge. The articulation between programmes is also a topic of concern. Access and the mobility of engineering students are discussed in more detail later in this chapter, as are throughput trends. In terms of throughput rates, the low output of engineering graduates forces the engineering education institutions to grapple with this challenge.

International accords are another driver of change. The Washington Accord is a system of mutual recognition of graduate engineering qualifications across a group of countries including Australia, Canada, Hong Kong, Ireland, New Zealand, the UK and the USA. This agreement recognises the substantial equivalence of programmes accredited by these countries, and recommends that graduates of accredited programmes in any of the signatory countries be recognised by the other countries as having met the academic requirements for entry to the practice of engineering. The Washington Accord was signed in 1989. This was followed by the Sydney Accord in 2001, which applies to technologists, and the Dublin Accord (signed in 2002) for technicians.

There is also a Deans' Forum that was formed by the International Council for Research and Innovation in Building and Construction (CIB). In this forum, deans leading faculties of various departments that undertake teaching, learning and research and that encompass architecture, civil engineering, planning and construction fields of study, can work together on two aspects of international accreditation: integrating accreditation across fields of study within countries; and integrating and coordinating multiple accrediting bodies operating internationally across countries.[102] The goals of improving consistency of standards and approach and improving effectiveness of resourcing for universities and professional institutions were seen as drivers for the Deans' Forum. The ambition of the Deans' Forum is to move, over time, towards the principles of the Washington Accord in engineering accreditation.[103]

As mentioned, a new driver in terms of scarce and critical skills, now and in the next few years, is ASGISA and its associated programme, JIPSA. It is a worldwide trend that lack of engineering capacity is hampering development. South Africa's shortage of engineering skills is seen as one of the worst capacity and scarce-skills crises in years. The country is currently in a period of extensive expansion of state expenditure, particularly on infrastructure. JIPSA has requested higher education institutions to increase their delivery of graduated engineering professionals. To date there are no formal arrangements between JIPSA and higher education institutions, except for the R20 million monetary contribution to some of the institutions in an attempt to increase the number of engineering graduates. However, this would seem

102 Launch CIB Deans' Forum, *CIB News*, 14 June 2007.
103 Launch CIB Deans' Forum, *CIB News*, 14 June 2007.

difficult against the background of the low number of Grade 12 school leavers with suitable results in mathematics and physical science from which the engineering faculties can source potential students, and the low throughput rates of graduates in engineering programmes at universities and universities of technology.

Secondary school education

A universal problem for the engineering profession across the world is the quality of school mathematics and physical science. In South Africa there are two important considerations, interrelated but distinct: the numbers of Grade 12 school leavers who qualify for engineering, and the quality of mathematics and physical science knowledge that these students bring with them (Case 2006). To prepare school learners for their final exam, a good education system with sufficient, properly qualified teachers from Grade 1 to Grade 12 level is required. High quality engineering students come from good schools with good quality mathematics and physical science teachers (Interview 2006g).

Up to now, to study engineering at university, a higher grade mathematics symbol of A, B or C was required; and for most universities of technology a minimum of a C symbol for standard grade mathematics was required. These criteria present a challenge. Of the 169 026 matriculants who passed mathematics in 2005, 32 112 (19.00%) passed at higher grade. Among those who passed mathematics at higher grade in 2005, only 4 210 (13.11%) passed with an A symbol, 3 302 (10.34%) with a B symbol, 5 296 (16.49%) with a C symbol, and 6 342 (19.75%) with a D symbol (DoE 2005). The DoE aimed to increase the number of schools that teach mathematics, in a bid to deliver 50 000 Grade 12 learners with mathematics in 2008.[104] Considerably fewer Grade 12 school leavers write physical science. In 2005 only 45 652 (35.29%) passed physical science at higher grade. Of those who passed physical science at higher grade in 2005, only 3 051 (6.68%) passed with an A symbol, 2 811 (6.16%) with a B symbol, 4 703 (10.30%) with a C symbol, and 7 536 (16.51%) with a D symbol (DoE 2005).

It is well known that the engineering field has to compete with other professions, such as medicine and commerce, to attract potential students from the limited mathematics and/or science pool of school leavers. Jawitz, Case and Tshabalala (2000) found in interviews with the pool of suitably qualified female students at UCT that their preference was for medicine as an initial choice, and that students also expressed a strong attraction to commerce. Only female students who had already decided to pursue BSc degrees thought that they might also consider engineering as a possible study field.

Furthermore, as already mentioned, to prepare suitably qualified school leavers, a good education system with enough properly qualified teachers from Grade 1 up to Grade 12 level is required. The Third International Mathematics and Science Study, which was carried out in 1995 and 1998, suggested that levels of mathematics and science literacy are particularly low in South African schools (Howie 2005). It was widely reported that South Africa came last in the group of international participants in this study. Howie (2005) found that language seems to be a critical influencing

104 Pushing science, maths at schools, *BuaNews*, 17 August 2005.

factor, and also highlights the importance of other classroom and socio-economic variables. Studies like this show that quality problems in terms of mathematics achievement are systemic.

Case (2006) warns that, in the light of this existing scenario, early reports on the implementation of the new FET curriculum are alarming. It is reported that teachers only received a total of five days of orientation during 2005 to prepare for the new curriculum to be implemented in 2006. This involves a new mathematics curriculum, which seems similar to the former higher grade mathematics curriculum, and a completely new subject, mathematical literacy.

Another relevant curriculum development for engineering at secondary school level is that the subject of technology, which was recently introduced at junior secondary level, has since been removed from the school curriculum (Case 2006). Some of the higher education institutions highlighted the contribution of the subject to improving technological literacy among the population, thus acting as a useful foundation to studies in engineering (Reed, Case, Linder & Ingerman 2005).

From the late 1980s onwards students from disadvantaged schooling backgrounds started to have access to privately funded extra-curricular initiatives in mathematics and science. These include initiatives of institutions such as the Science and Industrial Learnership Initiative (SAILI), and the Programme for Technological Careers (PROTEC), a national independent non-profit educational service provider in South Africa that specialises in mathematics, science and technology education and provides educator-based training and learner-based education.

A host of other Saturday schools, afternoon tutorials and vacation projects are also attempting to improve the mathematics and science pool of learners. While it would seem that there is no systematic investigation into the collective impact of these projects, it has been anecdotally reported that most of the engineering students from former Department of Education and Training schools have been involved in at least one of these initiatives (Case 2006). Case argues that the engineering profession needs to get more involved in schools, to make any relevant contributions it can towards improving mathematics and science teaching, and also to encourage learners to take up careers in engineering.

A World Bank (2007) report describes potential initiatives being implemented in developing Asian countries, where high-school children were, for example, given monetary incentives to study mathematics and science in Grade 12.

South Africa's National Research and Development Strategy (Department of Science and Technology 2002) recognises that human resources in science and technology are not being adequately developed and renewed. The strategy proposes a highly targeted approach to increasing excellence in mathematics and the sciences among black school leavers and young women. New centres of excellence are being established to attract young people to sustainable careers in scientific research. Special programmes for the promotion of women in science have also been proposed.

Reasons for studying engineering

Encouraging more students to take up careers in engineering is not an easy task. The underlying reasons for career choices are complex. Engineering is not always the exclusive choice of an individual and in many instances it is found that students' families have influenced them. The European Commission (2006) report reveals that the level of education of the two parents of female engineers has an important influence on their choice of engineering as a study field and career, and even more so if they have engineers in their family or close environment. A number of other studies also emphasise the positive effect of a role model on choosing engineering (Carter & Kirkup 1990; Coles 1994; Smith & Erb 1986).

Jawitz and Case (1998) investigated the reasons given for studying engineering by a first-year cohort across the Western Cape province of South Africa. The results were disaggregated according to race and gender. The study showed that financial incentives were mentioned across all groups with no significant differences between them. White male students made strong mention of practical engineering activities and problem-solving. White female students appeared to be strongly motivated by school experiences and by supportive family environments, while black male and female students seemed to be motivated by opportunities to serve their communities and to prove themselves in careers historically dominated by white men. This latter finding was further supported by a later series of studies among mechanical engineering students at UCT (Reed & Case 2003).

The European Commission (2006) report argues that lack of information is one of the major factors influencing women's decision to consider (or not, as is more usually the case) a career in engineering. None of the students interviewed in their WomEng project had any precise information about the job and the actual activities of an engineer. This means that when they started their training none of these female students had a good idea of their future career paths as engineers. Usually training institutions that offer engineering studies have information policies and events to inform potential students about the course. The report mentions that getting information through personal contact seems to be a decisive factor (2006).

With regard to encouraging more students to take up careers in engineering, again there are no simple solutions. The experience of the civil engineering profession is instructive in this regard. Following periods with low student numbers, they have embarked on unprecedented initiatives to draw in more school learners. There have since been some increases in the numbers of civil engineering students but it is not clear whether this can be attributed directly to these initiatives or whether it is possibly more as a result of coinciding with a general economic upturn.[105]

Higher education: the supply of engineering professionals

In 2005 the enrolment ratios between humanities (including education); business and commerce; and science, engineering and technology were 49%:26%:25% (Bot 2007). The *National Plan for Higher Education* (Ministry of Education 2001) proposes a shift in enrolment over the next five to ten years towards the science, engineering and

105 Le Roux H, SA engineers at the ready to deliver vital infrastructure, *Engineering News*, 24 March 2006.

technology (SET) fields. The goal sets ratios of 40%:30%:30% respectively. Following the initiation of ASGISA, there is anecdotal evidence of universities being asked by the government to dramatically increase the size of their engineering faculties. However, what needs to be taken into account is that the pool of potential candidates for higher education institutions has not increased sufficiently, especially in terms of those with suitable passes in mathematics and physical science.

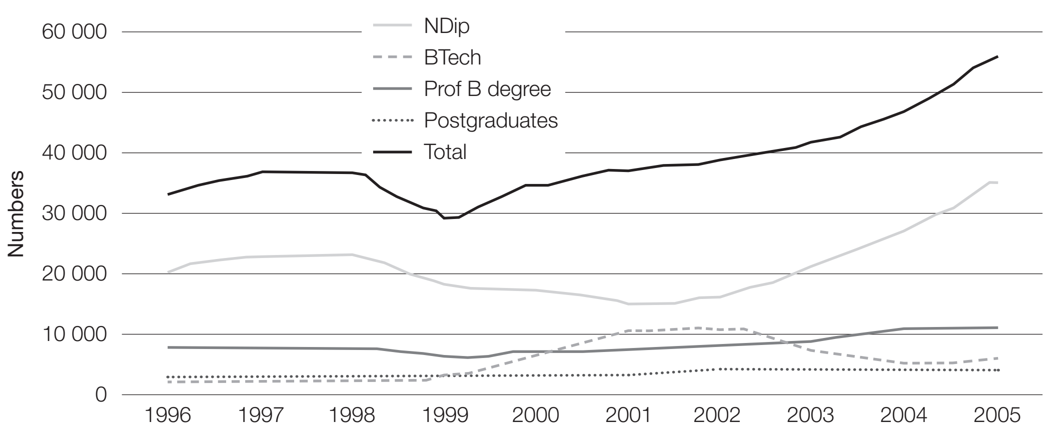
In discussing the supply of engineering professionals, it is necessary to consider enrolment, graduation and throughput at universities and universities of technology. In order to gain an understanding of transformation in the supply of engineering professionals, we also distinguish between race and between gender when considering enrolment and graduation trends.

Enrolment trends at higher education institutions

With regard to career choice, there has been an insignificant change in the number of students taking up engineering studies at universities compared to the dramatic increase in those studying towards an engineering qualification at universities of technology, specifically at the BTech level (13.85% average annual growth over the 1996–2005 period), as the universities of technology started off from a low base (a mere 1 840 enrolments in 1996). Enrolment for the National Diploma is, however, still the highest (34 874 in 2005) and postgraduate enrolment the lowest (4 276 in 2005) (Figure 2.1). Enrolment for the Professional Bachelor's (Prof B) degree increased by only 3.92% over the 1996–2005 period (Table 2.1).

The decrease in enrolment between 1998 and 2002, specifically for students at the technician level, was mainly the result of the fact that the public sector did not offer bursaries over that period in areas such as electrical engineering (Interview 2006b; Interview 2007b).

Figure 2.1 Engineering enrolment (1996–2005)



Source: DoE (1996–2005)

Enrolment data obtained from the DoE and ECSA differ to some extent, as shown in Tables 2.1 and 2.2, because the DoE includes under engineering some fields of study that are excluded by ECSA. For example, the DoE data also include engineering fields of study such as graphics and drafting, engineering mechanics, and engineering science. ECSA includes only nine main fields of study: aeronautical, agricultural, chemical, civil, electrical, industrial, mechanical, metallurgical, and mining engineering. The DoE, in addition to these nine main fields of study, also gives a breakdown according to: automotive engineering, bio-engineering, computer engineering, environmental engineering, geological engineering, instrumentation, manufacturing engineering, marine engineering, materials engineering, and surveying and mapping, which are subfields of study under ECSA's nine main fields of study.

Table 2.1 Average annual growth rate: undergraduate engineering enrolment (1996–2005)

Undergraduate engineering enrolment	Source	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Engineer enrolment	HEMIS	7 895	7 850	7 967	6 050	7 188	7 656	8 135	8 901	10 886	11 159	3.92
	ECSA			8 014	5 548	6 524	6 845	7 166	7 861	8 613		
University of technology enrolment	HEMIS	22 265	25 691	25 564	20 831	23 904	25 908	26 760	28 538	31 772	40 784	6.96
	ECSA			21 984	13 944	16 774	19 586	18 090	20 814	28 690		
Technician enrolment	HEMIS	20 426	23 188	22 965	17 993	17 270	15 231	16 157	20 926	27 033	34 874	6.12
Technologist enrolment	HEMIS	1 840	2 503	2 599	2 838	6 635	10 676	10 603	7 612	4 739	5 910	13.85
Total	**HEMIS**	**30 160**	**33 541**	**33 531**	**26 881**	**31 092**	**33 563**	**34 895**	**37 439**	**42 657**	**51 944**	**6.23**
	ECSA			**29 998**	**19 492**	**23 298**	**26 431**	**25 256**	**28 675**	**37 303**		

Sources: DoE (1996–2005); ECSA (2005)

Note:
DoE data include engineering fields of study that are excluded by ECSA, such as graphics and drafting; engineering mechanics; and engineering science.
Totals do not in all instances add up because of rounding.

Graduation trends at higher education institutions

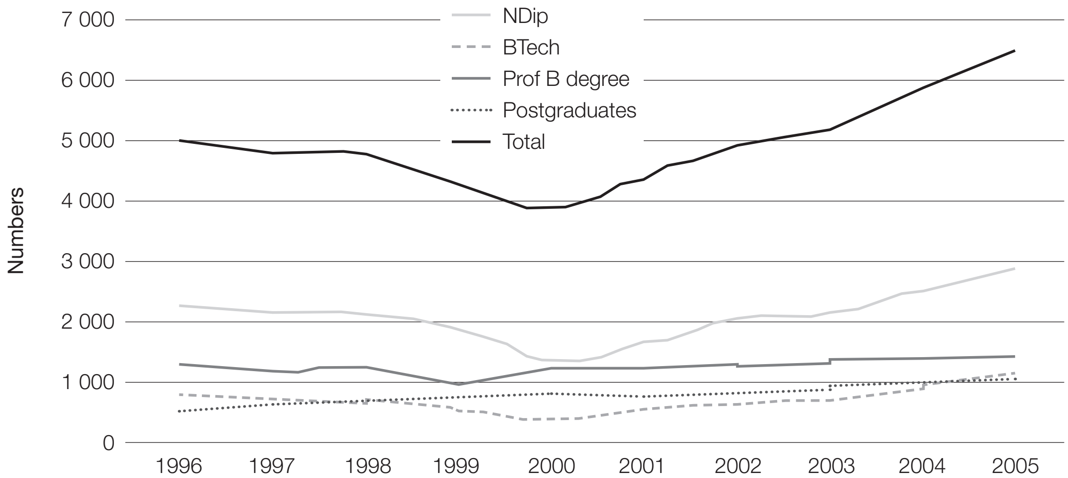
There was only a marginal increase in the absolute number of engineers graduating from universities, and technologists and technicians graduating from universities of technology, between 1996 and 2005 (Figure 2.2 and Table 2.2).

In 2005 there was a total of 6 568 graduates (both undergraduates and postgraduates) in engineering, of which only 16.18% (1 063) were postgraduates. Among the 5 506 undergraduates in 2005, 52.85% (2 910) were NDip graduates, 26.63% (1 130) BTech graduates, and 20.52% (1 466) Prof B degree graduates.

The average annual growth rates for undergraduate engineers, technologists and technicians, were only 1.00%, 3.73% and 2.50% respectively over the 1996–2005 period (Table 2.2). The annual output of engineering professionals remained almost static, despite the increasing demand for both engineering services and the replacement of engineering professionals retiring from the workforce.

As already noted, graduation data from the DoE and ECSA differ, given that ECSA uses only nine main study fields, while the DoE additionally makes use of what ECSA consider to be ten subfields of study.

Figure 2.2 Engineering graduation (1996–2005)



Source: DoE (1996–2005)

Further, as discussed, the sharp drop in the number of technician graduations between 1998 and 2002 can be related to the difficulty that students at the time experienced in getting access to bursaries and finding industrial placements for their experiential training year (Interview 2006b; Interview 2007b). Employment agencies contribute to this situation by placing technicians and technologists for short periods at different employers. This would suggest that such students fail to get the opportunity to work at one employer for the required period of time in order to complete their experiential training and obtain their qualifications (Interview 2006b; Interview 2006d). The civil engineering study by Lawless (2005) reports that about 60% of final-year National Diploma students who responded to her survey conducted in October and November 2004 had not yet had experiential training and therefore could not graduate. Some of the reasons put forward to explain this trend are: employers' concerns regarding the quality of the higher education training of students; the location of some of the universities of technology, which poses a problem in terms of access to employers because many students do not have the financial means to travel to urban centres to look for work; limited assistance by universities of technology to find job opportunities for students; resistance of businesses to employing inexperienced students and a requirement that candidates have at least five years' work experience; and the revision of labour laws, adding to the resistance of businesses to take on employees who are not able to add immediate value to their organisations. Lawless argues for the necessity of converting the National Diploma in civil engineering to a learnership, in a bid to ensure that industry is compensated for its involvement in training.

Table 2.2 Average annual growth rate: undergraduate engineering graduation (1996–2005)

Undergraduate engineering graduation	Source	1996 N	1997 N	1998 N	1999 N	2000 N	2001 N	2002 N	2003 N	2004 N	2005 N	Average annual growth (%)
NDip graduation	HEMIS	2 330	2 189	2 140	1 947	1 385	1 710	2 104	2 196	2 564	2 910	2.50
BTech graduation	HEMIS	812	756	691	564	433	641	687	772	952	1 130	3.73
Total: University of technology graduation	HEMIS	3 143	2 945	2 831	2 511	1 817	2 350	2 791	2 968	3 517	4 039	
	ECSA			2 341	1 404	1 292	1 814	1 956	2 284	3 160		
Prof B Degree graduation	HEMIS	1 341	1 243	1 277	1 051	1 292	1 286	1 306	1 354	1 424	1 466	1.00
	ECSA			1 226	995	1 235	1 274	1 691	1 305	1 177		
Total	**HEMIS**	**4 483**	**4 188**	**4 108**	**3 562**	**3 109**	**3 636**	**4 097**	**4 323**	**4 941**	**5 506**	**2.31**
	ECSA			**3 567**	**2 399**	**2 527**	**3 088**	**3 647**	**3 589**	**4 337**		

Sources: DoE (1996–2005); ECSA (2005)

Notes:
DoE data include engineering fields of study that are excluded by ECSA, such as graphics and drafting; engineering mechanics; and engineering science.
Totals do not in all instances add up because of rounding.

Throughput trends at higher education institutions

The throughput rates in order to supply the 1 466 engineering graduates at universities and the 4 039 engineering graduates at universities of technology are very poor. If one considers that the BSc (Eng) is designed to take four academic years, the National Diploma three years, and the BTech one additional year after the National Diploma, it is clear that throughput rates are far from optimal. In order to determine throughput, the number of enrolments is compared to the number of graduations three and four years later. Although this method is useful from a comparative point of view, it is not a precise measurement as first-year enrolment will include those who are repeating, and final-year graduation will include those who are graduating after five or more years of study. Figure 2.3 shows the throughput trend for first-time entering engineers, Figure 2.4 for first-time entering technologists, and Figure 2.5 for first-time entering technicians for the period 1996–2005.

The throughput rate of first-time entering engineers qualifying at universities stayed static at about 60% between 1999 and 2005. The average throughput rate over the same period for first-time entering technicians was only 40% and for first-time entering technologists about 55%. According to Lawless (2005), there are a few possible factors contributing to the low throughput rates. These factors include the following: previously disadvantaged learners were encouraged to enter higher education without the institutions applying and enforcing entry criteria; learners who entered had poor grounding in mathematics and physical science and lacked proficiency in the language of instruction; not all institutions were ready to offer supplementary or bridging programmes to prepare these learners for higher education; the increase in enrolment levels caused problems in terms of the size of classes, and extra staff with inadequate qualifications were taken on; black students struggle to afford higher education unless they obtain loans or bursaries, and when they attempt to fund themselves problems occur; and the biggest drop out takes place at the universities of technology, where students are required to do workplace training before qualifying – yet sufficient opportunities are not always available. Students at the universities of technology reported that they find it difficult to find industrial placements for their experiential training year. Students are awarded the National Diploma only after completion of this training as well as four semesters of academic work, and it would appear that many students are unable to complete the diploma for lack of this work experience. With the economic pressures on companies, together with a shortage of experienced professionals, companies seem to be less willing to take on personnel who require training – such as in-service trainees from the universities of technology.

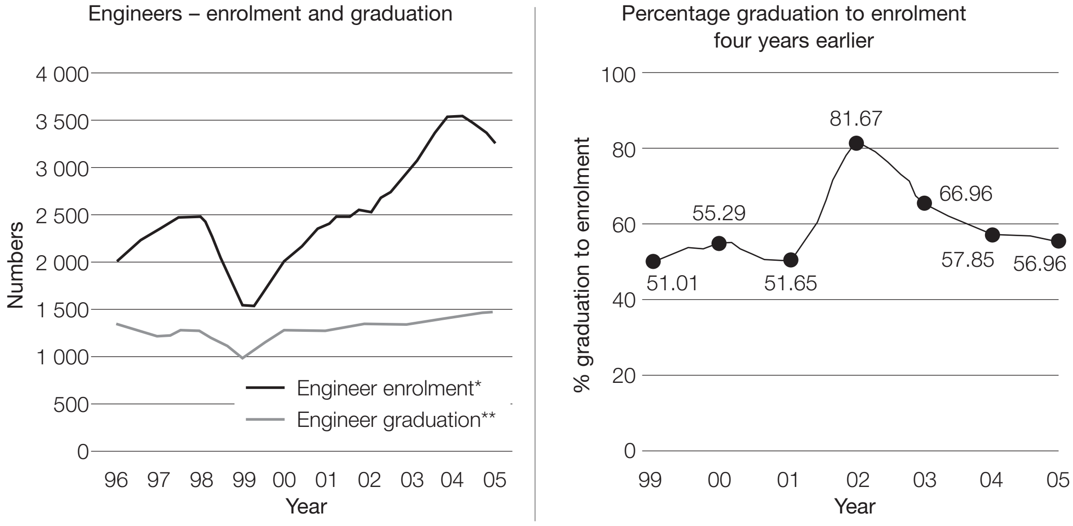
Higher education institutions are trying to address the poor throughput rate by applying the following strategies (Interview 2006g; Interview 2006h; Interview 2007b; Lawless 2005):

- Rigorous entry criteria – some of the universities that achieve the highest throughput rates are known to apply the most stringent entry criteria and procedures.
- Dedicated foundation and extended degree programmes – institutions have established foundation programmes to help students deal with the challenges of higher education. Some universities decided to extend the engineering programme by converting the four-year degree into a five-year one.
- Funding – many students do not have the financial means to afford training at a higher education institution. In such instances the institutions strive to assist students to obtain loans and bursaries.
- Monitoring and support – support is given by means of supplementary lessons, assigning a senior student as a mentor, and providing students with life-skills training.
- Introducing students to young graduates as role models – students are encouraged to communicate with young graduates and to join professional associations in order to obtain access to people who can provide them with advice.
- Appointing more lecturers – in some institutions the staff to student ratios were too low as a result of an increase in enrolment levels. In such cases additional staff are appointed.
- Upgrading the qualifications of lecturers, especially at universities of technology.

Maree, Pretorius and Eiselen (2003) note that engineering students who perceive their environment to be supportive, who know where to find help, and who do not struggle with the language of mathematics, are more likely to be successful in their studies. Pitt (2002) declares that students in higher education need an assortment of strengths, including motivation, to achieve success.

The JIPSA (2006) business plan suggests that the supply of engineering professionals could be increased by an additional 1 000 per annum. JIPSA came to this conclusion after a process of consultation with deans of the faculties of engineering and the built environment at universities. JIPSA is expecting that the output in the form of registered professionals will increase by 1 000 over and above current output without a significant increase in the inputs; the target of 1 000 could include construction-related professions such as construction and project management, quantity surveying and architecture.

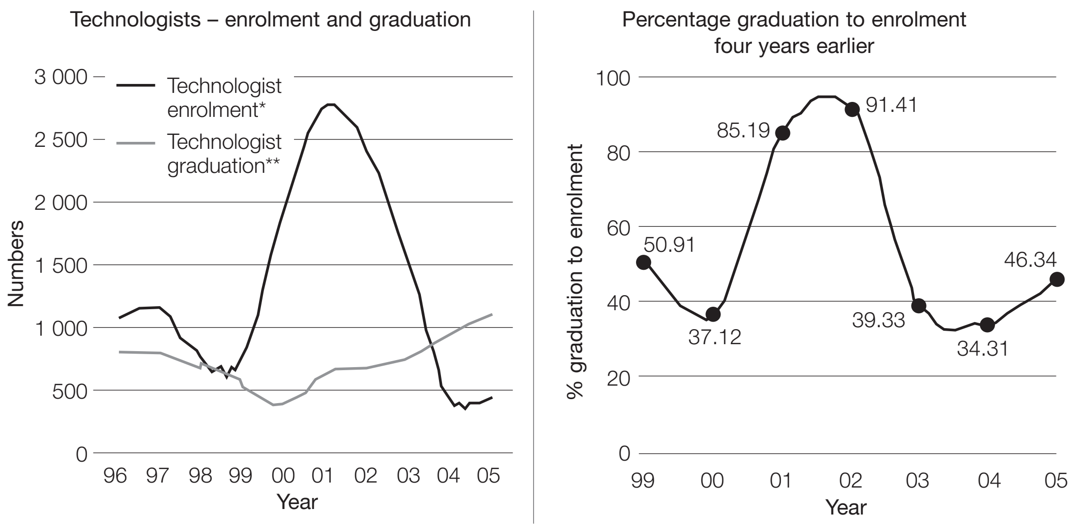
Figure 2.3 Throughput trends for first-time entering engineers (1996–2005)



Source: DoE (1996–2005)

Notes:
** First-year enrolled*
*** Graduation four years later*

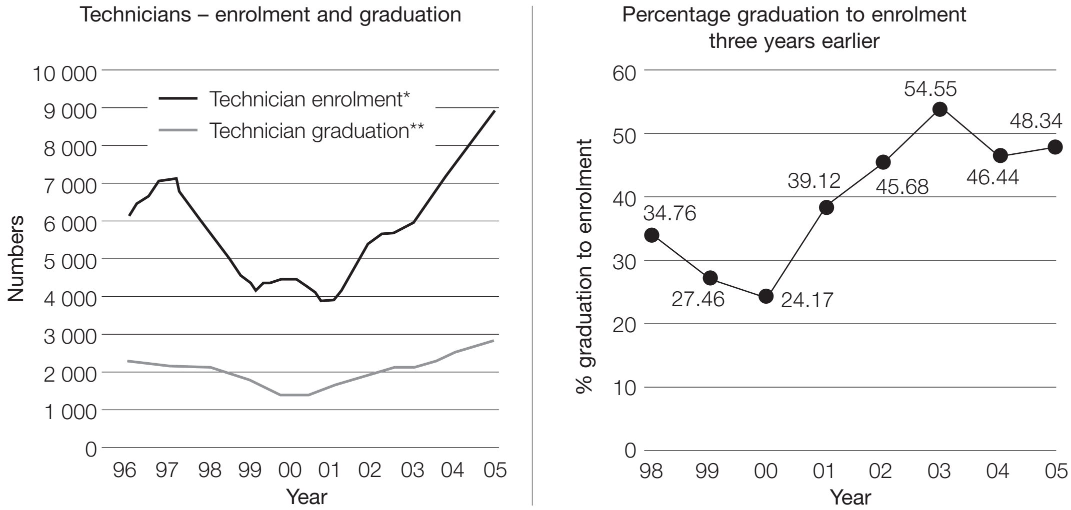
Figure 2.4 Throughput trends for first-time entering technologists (1996–2005)



Source: DoE (1996–2005)

Notes:
** First-year enrolled*
*** Graduation four years later*

Figure 2.5 Throughput trends for first-time entering technicians (1996–2005)



Source: DoE (1996–2005)

Notes:
** First-year enrolled*
*** Graduation three years later*

Graduation trends in different engineering fields of study

Table 2.3 reports the undergraduate graduation trends for engineering fields of study at universities and universities of technology over the 1996–2005 period. Table A.1 (see Appendix) disaggregates engineering fields of study data for engineers, technologists and technicians by both undergraduate and postgraduate. There was an improvement in engineering graduation in a few fields of study between 1996 and 2005. One of the factors contributing to low levels of graduation in certain scarce fields of study is the fact that higher education institutions are struggling to retain quality teaching and research staff in fields of study that compete with demand in the private sector (Interview 2006h).

Although small (3.30% average annual growth), the growth in electrical engineering graduation levels over the 1996–2005 period is encouraging seen against the expansion plans of ESKOM in building new power stations and the reported shortages in municipalities.

Graduation levels in civil engineering showed an average annual growth of only 2.40% over the 1996–2005 period. This low growth may not be sufficient, given government's huge capital investment in infrastructure. A major beneficiary of this investment is construction in general, and civil engineering in particular. However, it will take some years for the South African construction industry to overcome the current skills shortages in this sector. The specialised skills pool of bridge-building in South Africa has, for example, been severely depleted, as several experienced bridge engineers have been lost to emigration and retirement, according to Pieter Louw of PA Louw and Associates.[106]

106 With bridge-building prospects improving, SA mulls skills-dearth challenge, *Engineering News*, 7 July 2006.

Table 2.3 Undergraduate graduation trends in engineering fields of study (1996–2005)

Field of study	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Electrical	1 412	1 317	1 349	1 157	971	1 164	1 348	1 517	1 666	1 890	3.30
Civil	725	648	683	694	639	674	731	720	875	898	2.40
Mechanical	803	754	702	524	453	603	587	610	616	743	–0.86
Chemical	496	422	459	305	437	516	498	541	664	640	2.87
Industrial	347	397	264	197	154	201	208	233	309	372	0.77
Mining	125	142	172	99	42	39	47	53	65	156	2.49
Metallurgical	137	95	102	78	85	108	77	100	111	196	4.03
Materials	71	78	98	66	38	50	68	65	83	79	1.21
Surveying	116	110	81	108	83	68	67	75	69	83	–3.60
Computer	44	45	97	0	4	3	45	88	139	112	10.88
Engineering mechanics	0	0	0	60	67	14	131	63	101	85	* 5.82
Environmental	0	0	0	24	26	32	27	34	29	11	* –12.38
Agriculture	29	31	15	17	16	17	21	21	16	19	-4.82
Marine	13	7	26	16	13	25	36	49	51	50	16.15
Bio-engineering	0	0	0	0	0	52	69	64	10	9	** –36.42
Graphics	0	0	0	75	10	1	21	29	29	60	* –3.77
Aerospace/ aeronautical	83	54	13	5	4	4	7	11	16	9	–21.87
Manufacturing	0	0	0	16	17	8	18	4	0	16	* 0.53
Engineering science	0	0	0	3	0	0	27	3	3	0	0.00
Automotive	0	0	0	3	0	0	0	0	1	2	–8.91
Instrumentation	0	0	0	6	0	0	1	1	0	0	0.00
Geological	0	0	0	1	0	0	0	0	0	0	0.00
Other engineering & engineering technology	83	88	47	109	51	59	64	44	90	79	–0.57
Total undergraduates	4 483	4 188	4 108	3 562	3 109	3 636	4 097	4 323	4 941	5 506	2.31
Total postgraduates	576	682	673	728	842	826	892	932	998	1 063	7.05
Total	**5 059**	**4 870**	**4 781**	**4 289**	**3 951**	**4 463**	**4 989**	**5 255**	**5 939**	**6 568**	**2.94**

Source: DoE (1996–2005)

Notes:
** 1999–2005; ** 2001–2005*
Totals do not in all instances add up because of rounding.

The automotive industry is the third-largest and most expanding sector in the South African economy,[107] but there was negative growth in automotive and mechanical engineering graduation levels over the 1996–2005 period. Mechanical engineers are required in most sectors of the economy and especially in the automotive industry (Interview 2006g; Interview 2006h). The very low levels of graduation of automotive technologists and technicians is very discouraging, and this fact needs to be addressed if the South African automotive industry wants to continue focusing on further improvements in competitiveness in terms of production and quality, according to Nico Vermeulen, director of the National Association of Automobile Manufacturers of South Africa (NAAMSA). 'Component manufacturers ideally require high local content and high-volume domestic production to grow the automotive industry,' according to Dr Justin Barnes, speaking in his capacity as managing director of consultancy Benchmarking and Manufacturing Analysts.[108] It is fortunate that NAAMSA is planning programmes to increase technical/autotronics and commercial skills development in the automotive industry;[109] the Nelson Mandela Metropolitan University has also commenced a new BEng degree in mechatronics (a combination of electronic and mechanical engineering).

The positive growth in levels of chemical engineering graduation over the 2000–2005 period, after a decline over the 1996–1999 period, is encouraging, given that chemical engineering is very versatile and chemical engineers can be employed as petroleum engineers, metallurgical engineers or in the minerals and mining industries. Petronet aims to be the foremost operator and maintenance partner for all future liquid fuel and gas pipelines and related facilities in southern Africa (Department of Public Enterprises 2006). Furthermore, an upturn of activity in the southern African offshore oil and gas industry has increased demand for specialised offshore services that are essential to overall safety and integrity.[110] With forthcoming environmental legislation and new emphasis being placed on environmental protection in South Africa, increased levels of graduation in environmental engineering will be necessary.[111]

The increase in levels of mining and metallurgical engineering graduation could be attributed to the growing availability of bursaries in this field, especially for black students (Interview 2006h). Historically, the gold mining industry has been a significant employer of engineers, but employment levels have decreased substantially in recent years.

The number of computer engineering graduations grew from 44 in 1996 to 112 in 2005, but it is still difficult to find computer engineers with the right skills, especially with security, internet protocol, telephony and wireless networking skills.[112] According to ASGISA, electronic communications will receive priority attention in growing South Africa's broadband network, in completing a submarine cable project to provide international access, and in establishing telecommunications, especially in the rural areas of the country (South African Government Information 2006). According to research findings by the Industrial Development Corporation, the demand for networking skills far outstrips the supply.[113]

107 Auto industry prospects for 2006, *Engineering News*, 10 March 2006.
108 When MIDP ends, will South Africa still have an auto industry? *Engineering News*, 17 March 2006.
109 Auto industry prospects for 2006, *Engineering News*, 10 March 2006.
110 Specialised services are in great demand, *Engineering News*, 10 June 2005.
111 Engineered technology division well positioned for new business, *Engineering News*, 26 November 2004.
112 SA needs 70 000 techies, *Citizen*, 7 July 2006.
113 SA needs 70 000 techies, *Citizen*, 7 July 2006.

The negative growth in agricultural engineering graduation is cause for concern in a country like South Africa where agricultural engineering can contribute to increased productivity to address food shortages and job creation (Berry 2006).

The positive growth (9.05% average annual growth over the 1997–2005 period) in levels of aerospace/aeronautical engineering graduation from universities (engineers) is encouraging (Table A.1 in the Appendix) in the light of the expected doubling in the number of air passengers in the next 10 years and its trebling within 15 years.[114] South Africa's minister of public enterprises at the time of this study commented on the government's keenness to make South Africa a centre for aerospace manufacturing.[115] However, the same positive trend is not noted for aerospace/aeronautical technologists and technicians. There is a shortage of aeronautical technicians in the air force, and unqualified technicians have to stand in and do the work of qualified aeronautical technicians.[116] The decrease in levels of graduation from aeronautical technical courses is thus disappointing.

According to Professor Ricardo Hausmann, a Harvard University economist,[117] South Africa needs to generate jobs in the export-oriented manufacturing sector to make growth sustainable, as declines in most developing countries' growth coincide with collapses in exports. He argues that economic growth based on growth in the construction sector is an unsustainable strategy. The overall decline in manufacturing engineering graduation and the very low levels of undergraduate manufacturing graduation are thus also disappointing.

Transformation

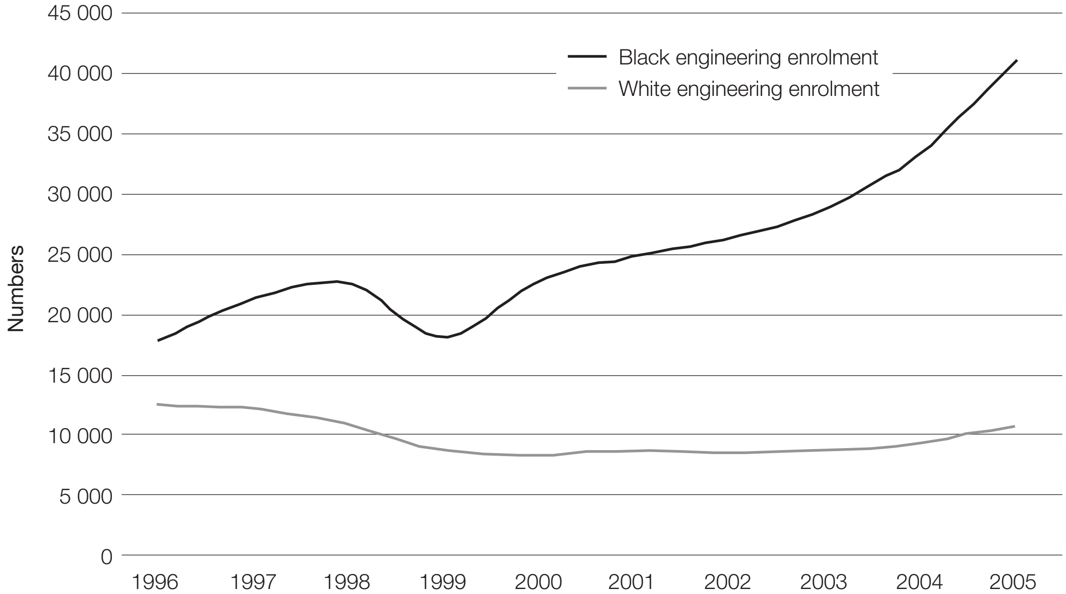
Enrolment

The democratisation of South Africa introduced a dramatic transformation in the student intake at historically white higher education institutions. The increase in enrolment (for the National Diploma, the BTech, and the Prof B Degree) of black engineering students – comprising African, coloured and Indian students – as a proportion of the whole is proof of this, as shown in Figures 2.6 and 2.7, and Table 2.4. A breakdown by race for postgraduate engineering enrolment is not given, because the numbers are too small.

Enrolment of undergraduate black engineering students more than doubled over the 1996–2005 period (from 17 666 to 41 076 students), indicating an average annual growth rate of 9.83% over this period. In comparison, enrolment of white engineering students decreased by an average annual rate of 1.57% – there were 12 494 white students enrolled in 1996 and only 10 840 nine years later (2005). Disaggregating the black engineering student group shows that the average annual growth rate of enrolment for Africans was the highest – 11.43% for African engineering students compared to 4.20% for coloured and 3.20 for Indian engineering students.

114 SA's airbus designer tells how he started with just a matric, *Daily Dispatch*, 24 March 2006.
115 Investment in technology key to competitiveness, *Engineering News*, 2 June 2006.
116 Lugmag: Tegnici 'nie opgelei', herstelwerk maak vliegtuie 'tydbomme' [Airforce: Technicians are 'not trained', repair work makes aeroplanes 'time bombs'], *Die Burger*, 17 March 2006.
117 Export-oriented manufacturing key to meeting SA growth target – Harvard economists, *Engineering News*, 11 August 2006.

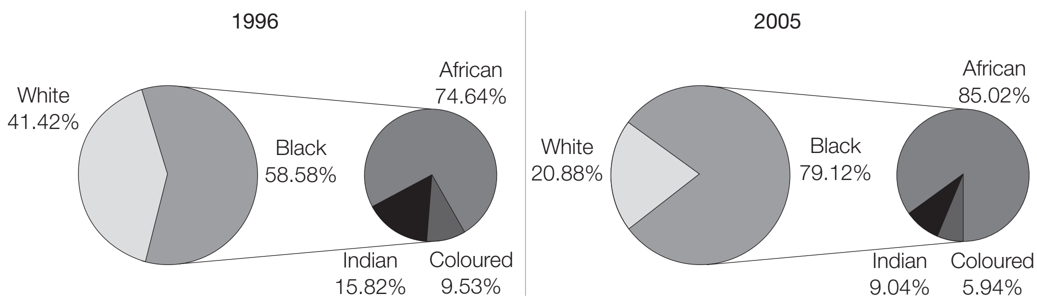
Figure 2.6 Undergraduate engineering student enrolment, by race (1996–2005)



Source: DoE (1996–2005)

Proportionally, enrolment of black engineering students constituted just over half (58.58%) of the number of total engineering enrolments in 1996 compared to more than three-quarters (79.12%) in 2005. Figure 2.7 shows the proportions of the disaggregated black student group. In 1996 African engineering students comprised 74.64% of the group and this figure increased to 85.02% by 2005.

Figure 2.7 Enrolment proportions of undergraduate engineering students, by race (1996 and 2005)

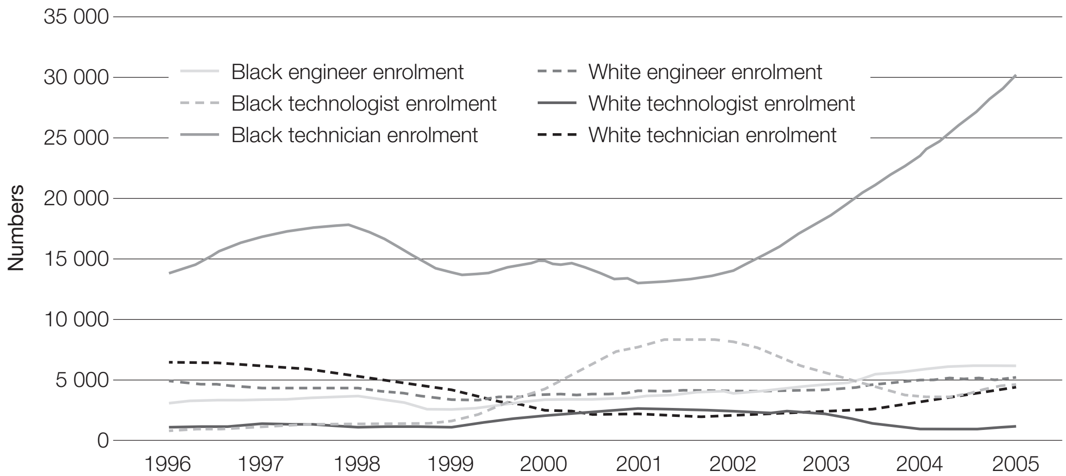


Source: DoE (1996–2005)

Figure 2.8 shows the undergraduate enrolment trends separately for engineer, technologist and technician students, and Figure 2.9 the enrolment proportions. Enrolment of black engineer students almost doubled from 1996–2005 (from 3 077 to 6 081), indicating an average annual growth rate of 7.86% over this period. There was practically no growth (average annual growth of 0.55%) in white engineer student enrolment over this period. In 1996 enrolment of black engineer students constituted more than a third (38.98%) of all engineer students compared to more than half (54.57%) in 2005. Disaggregating the black engineer student group shows that in

1996, 59.40% of this group was African, while by 2005 this figure had increased to over two-thirds (64.98%) – 1 825 African students in 1996 compared to 3 951 in 2005.

Figure 2.8 Undergraduate enrolment of engineer, technologist and technician students, by race (1996–2005)



Source: DoE (1996–2005)

Enrolment of black technologist students increased from 692 in 1996 to 4 667 in 2005, averaging an annual growth rate of 23.62%, while enrolment of black technician students increased from 13 897 to 30 328, averaging an annual growth rate of 9.06% (Table 2.4). Black technologist enrolment compared to white technologist enrolment as a proportion of the whole increased dramatically from 1996–2005. In 1996 black technologist enrolment constituted more than a third (37.62%) of all technologist enrolment but by 2005 this proportion had increased to more than three-quarters (78.99%). Disaggregating the black technologist student group shows that in 1996, 53.86% were African, while by 2005 this figure had increased to 83.60%.

Table 2.4 Average annual growth rate: undergraduate engineering professional enrolment, by race (1996–2005)

Undergraduate engineering enrolment	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Black engineer enrolment	3 077	3 371	3 571	2 595	3 371	3 672	3 997	4 630	5 954	6 081	7.86
African	1 828	2 046	2 212	1 884	2 043	2 257	2 485	2 903	3 761	3 951	8.94
Coloured	279	258	273	225	229	248	271	299	357	381	3.53
Indian	970	1 067	1 086	486	1 099	1 168	1 241	1 428	1 836	1 748	6.76
White engineer enrolment	4 818	4 479	4 396	3 455	3 816	3 983	4 137	4 268	4 928	5 062	0.55
Total engineer enrolment	**7 895**	**7 850**	**7 967**	**6 049**	**7 187**	**7 655**	**8 134**	**8 897**	**10 883**	**11 143**	**3.90**

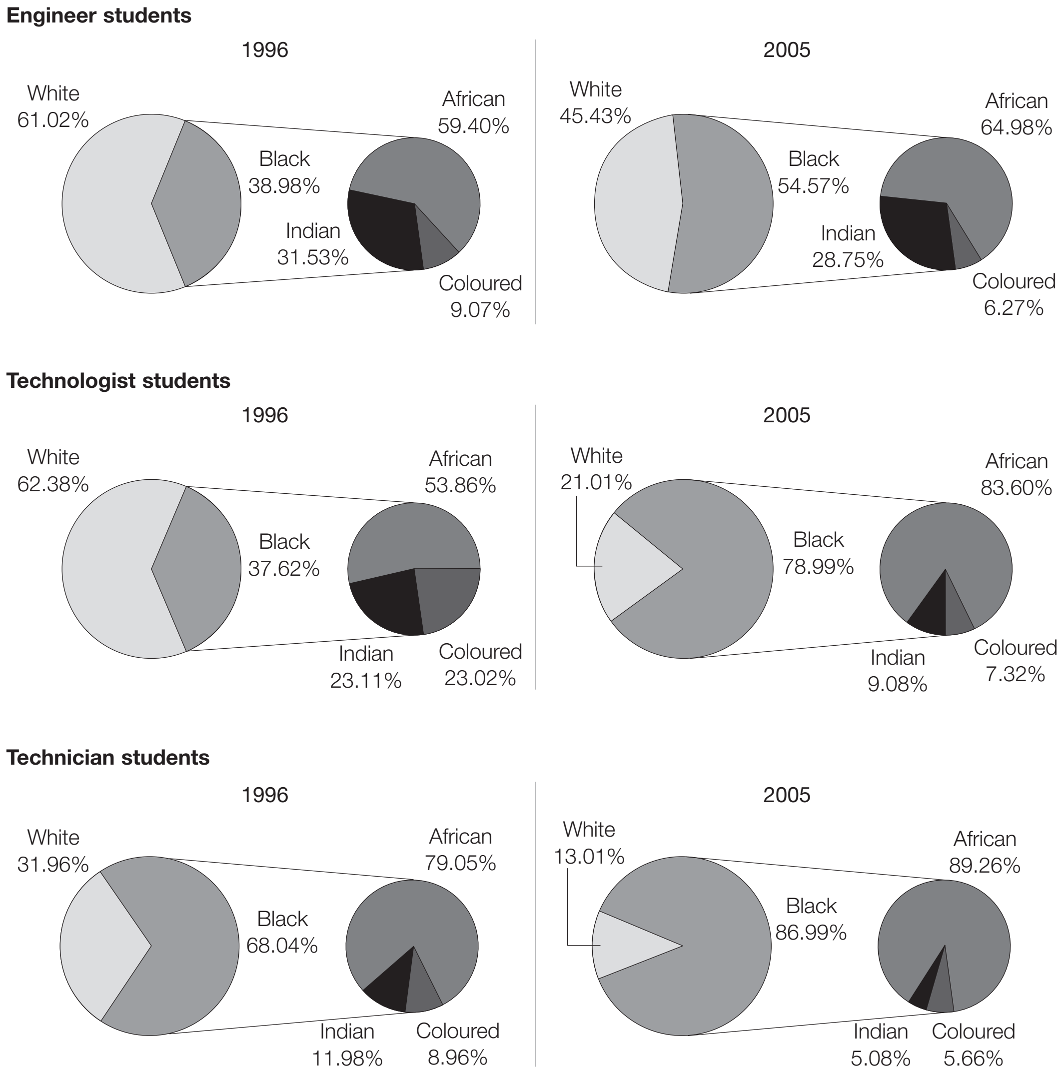
Undergraduate engineering enrolment	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Black technologist enrolment	692	1 122	1 353	1 621	4 486	8 006	8 142	5 528	3 694	4 667	23.62
African	373	658	905	1 125	3 712	7 214	7 267	4 797	3 019	3 902	29.81
Coloured	159	192	185	177	273	316	375	340	290	342	8.84
Indian	160	273	263	319	502	477	500	391	385	424	11.42
White technologist enrolment	1 148	1 381	1 246	1 201	2 148	2 670	2 461	2 084	1 044	1 242	0.88
Total technologist enrolment	**1 840**	**2 503**	**2 599**	**2 822**	**6 635**	**10 676**	**10 603**	**7 612**	**4 738**	**5 908**	**13.84**
Black technician enrolment	13 897	16 902	17 631	13 848	14 829	13 165	14 172	18 574	23 766	30 328	9.06
African	10 986	13 533	15 024	11 552	12 787	10 857	11 699	16 178	21 083	27 072	10.54
Coloured	1 246	1 285	1 521	1 167	962	1 213	1 347	1 402	1 519	1 717	3.63
Indian	1 665	2 084	1 086	1 129	1 080	1 095	1 126	994	1 164	1 540	–0.86
White technician enrolment	6 529	6 286	5 334	4 077	2 429	2 057	1 984	2 352	3 257	4 536	–3.96
Total technician enrolment	**20 426**	**23 188**	**22 965**	**17 927**	**17 260**	**15 223**	**16 156**	**20 926**	**27 023**	**34 865**	**6.12**
Total black enrolment	**17 666**	**21 395**	**22 554**	**18 065**	**22 687**	**24 844**	**26 311**	**28 731**	**33 414**	**41 076**	**9.83**
African	13 187	16 238	18 141	14 563	18 542	20 329	21 451	23 878	27 863	34 925	11.43
Coloured	1 684	1 734	1 978	1 569	1 464	1 776	1 993	2 040	2 166	2 440	4.20
Indian	2 795	3 424	2 435	1 933	2 681	2 740	2 867	2 813	3 385	3 712	3.20
Total white enrolment	**12 494**	**12 146**	**10 976**	**8 732**	**8 394**	**8 710**	**8 583**	**8 704**	**9 230**	**10 840**	**-1.57**
Total engineering enrolment	**30 160**	**33 541**	**33 531**	**26 798**	**31 081**	**33 554**	**34 893**	**37 435**	**42 643**	**51 916**	**6.22**

Source: DoE (1996–2005)

Note:
Totals do not add up in all instances because of rounding.

Black technician enrolment comprised more than two-thirds (68.04%) of total technician enrolment in 1996, and this figure further increased to 86.99% by 2005, while the number of white technician graduates decreased considerably. Disaggregating the black technician student group shows that enrolment of coloured and Indian technician students decreased from 1996–2005, while enrolment of African technician students increased from 79.05% to 89.26%.

Figure 2.9 Undergraduate enrolment proportions of engineer, technologist and technician students, by race (1996 and 2005)



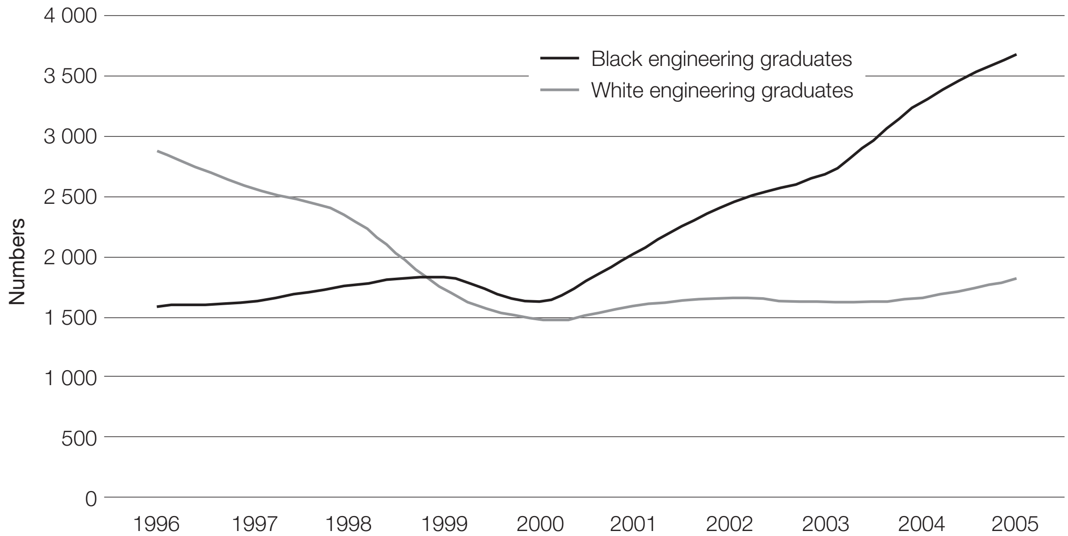
Source: DoE (1996–2005)

Graduation

Figure 2.10 displays the graduation trends for all engineering qualifications according to race (see also Table 2.5). The number of black engineering graduates more than doubled over the 1996–2005 period (from 1 598 to 3 685), indicating an average annual growth rate of 9.73% over this period. In comparison, the number of white engineering graduates decreased by an average annual rate of 4.99% – there were 2 886 white engineering graduates in 1996 and only 1 820 by 2005.

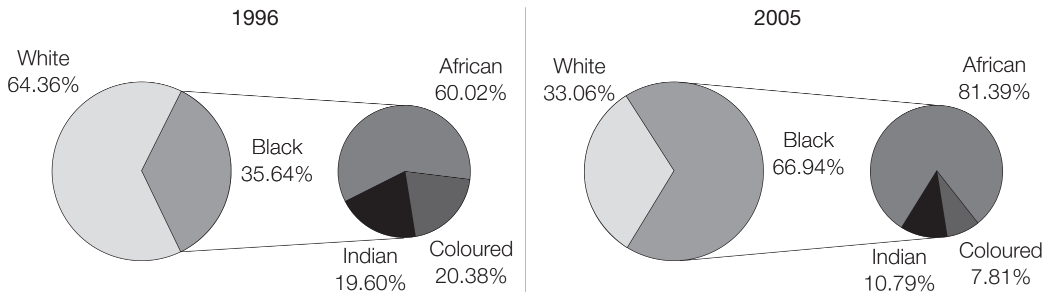
Proportionally, black engineering graduates comprised over a third (35.64%) of all engineering graduates in 1996 compared to more than two-thirds (66.94%) in 2005 (Figure 2.11). Disaggregating the black engineering student group shows that the average annual growth rate of graduation for Africans was the highest, 13.51%, compared to –1.35% for coloured students and 2.69% for Indian students – 959 African engineering students graduated in 1996 compared to 3 000 in 2005.

Figure 2.10 Undergraduate engineering student total graduation, by race (1996–2005)



Source: DoE (1996–2005)

Figure 2.11 Graduation proportions of all engineering students, by race (1996 and 2005)

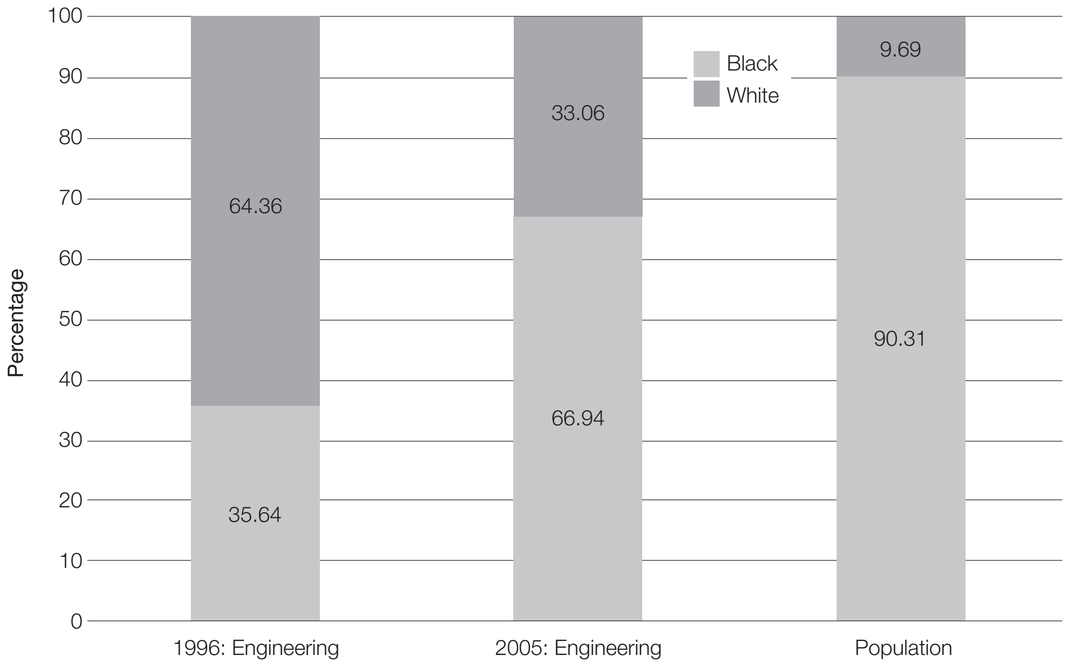


Source: DoE (1996–2005)

Gradually the proportion of black engineering graduates to the black population is increasing, with the proportion of white engineering graduates decreasing, as shown in Table 2.5. Figure 2.12 shows that in 1996 black engineering graduates constituted just over a third (35.64%) and white engineering graduates almost two-thirds (64.36%) of total engineering graduation (engineers, technologists and technicians); conversely, in 2005 black engineering graduates constituted just over two-thirds (66.94%) and white engineering graduates a third (33.06%) of engineering graduation. According to the 2001 population census, 90.31% of the population was black and 9.61% white (Quantec 2007).

Figure 2.13 (see also Table 2.5) shows the graduation trends separately for black engineer, technologist and technician students, and Figure 2.14 the graduation proportions in terms of race. The number of black engineer graduates almost doubled from 1996–2005 (from 306 to 580), indicating an average annual growth rate of 7.34% over this period. Proportionally, black engineer graduates comprised less than a quarter (22.84%) of all engineer graduates in 1996 compared to over a third (39.53%) in 2005. Disaggregating the black engineer student group shows that in 1996 less than half (41.04%) of this group was African, while by 2005 this figure had increased to almost two-thirds (62.62%) – 126 African engineer students graduated in 1996 compared to 363 in 2005.

Figure 2.12 Engineering graduation levels as a proportion of the population, by race (1996 and 2005)



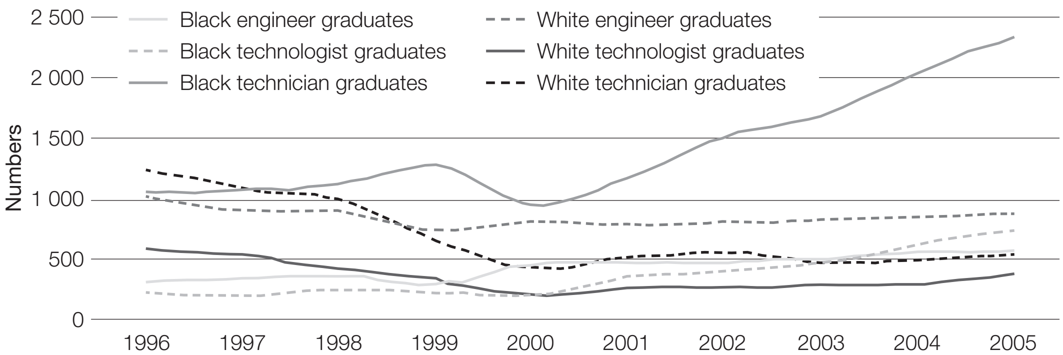
Sources: DoE (1996–2005); Quantec (2007)

The average number of black technologist graduates increased from 222 in 1996 to 747 in 2005, showing an average annual growth rate of 14.45%, while the average number of black technician graduates increased from 1 070 to 2 359, showing an average annual growth rate of 9.18%. The number of black technologist graduates as a proportion of the whole increased dramatically from 1996–2005: in 1996 black technologist graduates constituted just over a quarter (27.29%) of technologist graduates but by 2005 this proportion had increased to two-thirds (66.13%). Disaggregating the black technologist student group shows that in 1996 just over half (56.92%) of this group was African, while by 2005 this figure had increased to 80.88% – 126 African technologist students graduated in 1996 compared to 604 in 2005.

Black technician graduates comprised almost half (45.91%) of all technician graduates in 1996, but this figure increased to 81.06% by 2005; the number of white technician graduates decreased considerably in this period. Disaggregating the black technician student group shows that in 1996 two-thirds (66.10%) of this group was African, while by 2005 this figure had increased to 86.17% – 707 African technician students graduated in 1996 compared to 2 033 in 2005.

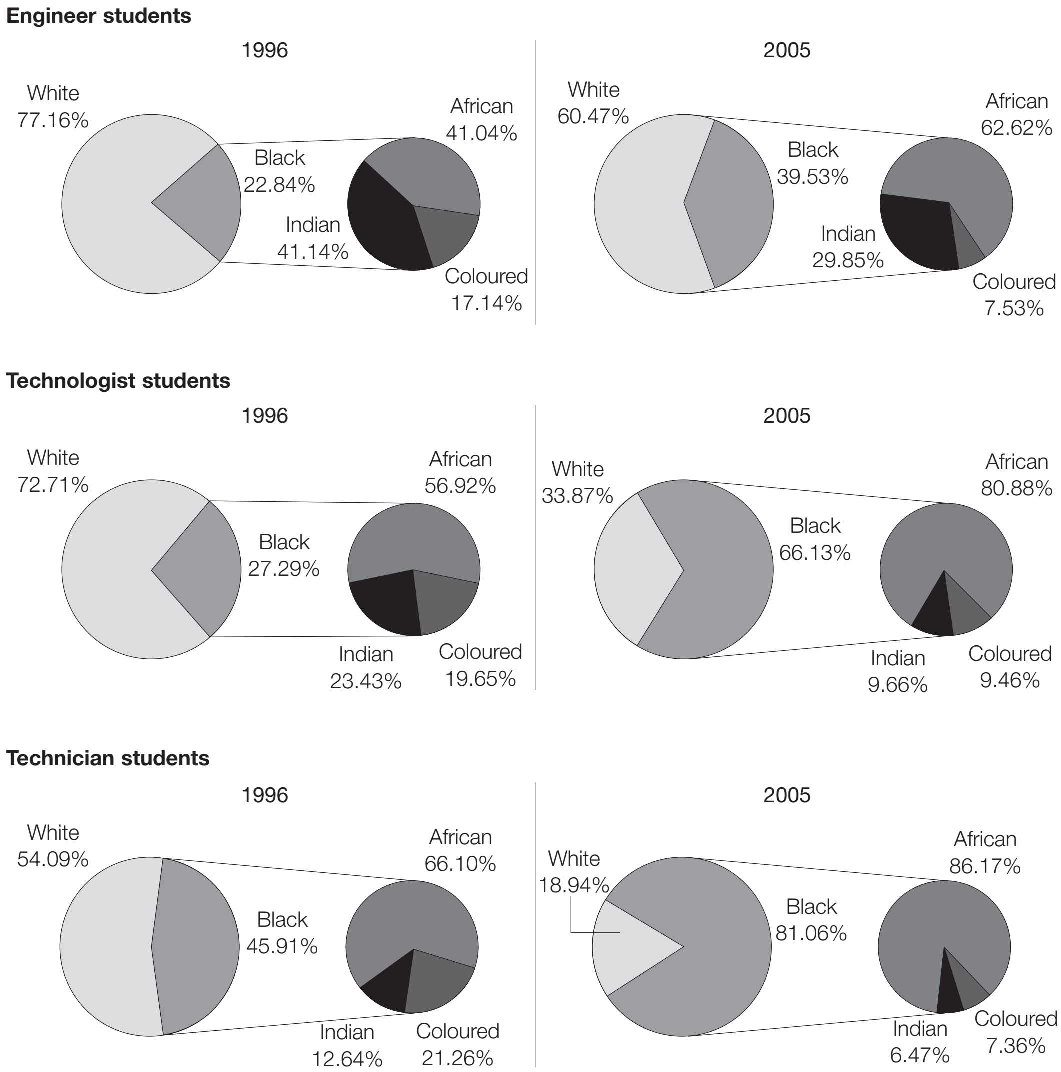
While the increase in the number of African graduations is encouraging, it is worth noting that it has coincided with an extreme decline in the number of graduations of coloured and Indian engineering professionals (Figure 2.11).

Figure 2.13 Graduation of engineer, technologist and technician students, by race (1996–2005)



Source: DoE (1996–2005)

Figure 2.14 Graduation proportions of engineer, technologist and technician students, by race (1996 and 2005)



Source: DoE (1996–2005)

Table 2.5 Average annual growth rate: undergraduate engineering professional graduation, by race (1996–2005)

Undergraduate engineering graduation	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Black engineer graduation	306	336	369	309	462	484	488	513	567	580	7.34
African	126	151	201	210	252	272	277	307	329	363	12.50
Coloured	55	40	39	37	40	47	46	36	36	44	–2.45
Indian	126	145	129	61	170	165	165	170	202	173	3.59
White engineer graduation	1 035	907	908	742	830	803	818	841	858	887	–1.70
Total engineer graduation	**1 341**	**1 243**	**1 277**	**1 051**	**1 292**	**1 287**	**1 306**	**1 354**	**1 425**	**1 467**	**1.00**
Black technologist graduation	222	208	259	235	216	367	420	479	647	747	14.45
African	126	126	157	137	127	262	275	337	498	604	19.01
Coloured	44	39	53	33	37	40	63	59	65	71	5.53
Indian	52	42	49	65	52	65	82	83	85	72	3.72
White technologist graduation	591	548	432	329	217	273	267	294	305	383	–4.71
Total technologist graduation	**813**	**756**	**691**	**564**	**433**	**640**	**687**	**773**	**952**	**1 130**	**3.73**
Black technician graduation	1 070	1 087	1 134	1 289	957	1 184	1 528	1 710	2 064	2 359	9.18
African	707	764	923	1 019	754	953	1 259	1 460	1 739	2 033	12.45
Coloured	227	135	135	173	110	155	195	201	199	174	–2.95
Indian	135	188	75	97	94	76	74	49	126	153	1.34
White technician graduation	1 260	1 102	1 006	658	428	526	576	486	501	551	–8.78
Total technician graduation	**2 330**	**2 189**	**2 140**	**1 947**	**1 385**	**1 710**	**2 104**	**2 196**	**2 565**	**2 910**	**2.50**
Total black graduation	**1 598**	**1 631**	**1 761**	**1 832**	**1 634**	**2 035**	**2 436**	**2 702**	**3 277**	**3 685**	**9.73**
African	**959**	**1 041**	**1 281**	**1 366**	**1 133**	**1 488**	**1 811**	**2 104**	**2 566**	**3 000**	**13.51**
Coloured	**326**	**214**	**227**	**243**	**186**	**241**	**304**	**297**	**299**	**288**	**–1.35**
Indian	**313**	**375**	**253**	**224**	**315**	**306**	**321**	**301**	**412**	**398**	**2.69**
Total white graduation	**2 886**	**2 558**	**2 347**	**1 729**	**1 474**	**1 601**	**1 661**	**1 621**	**1 663**	**1 820**	**–4.99**
Total engineering graduation	**4 483**	**4 188**	**4 108**	**3 562**	**3 109**	**3 636**	**4 097**	**4 323**	**4 941**	**5 506**	**2.31**

Source: DoE (1996–2005)

Note:
Totals do not in all instances add up because of rounding.

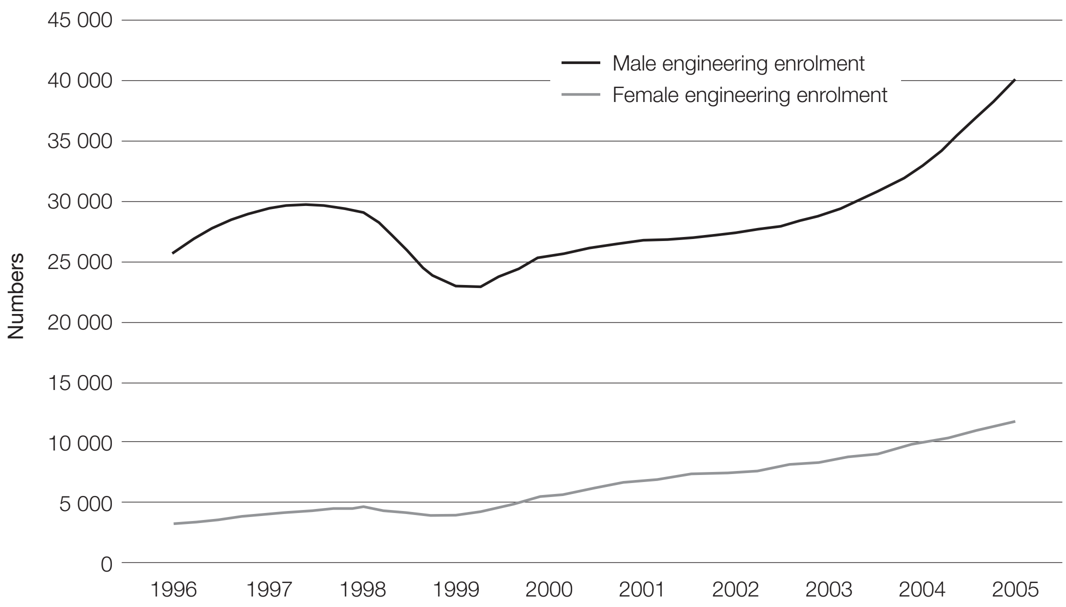
Enrolment figures, by gender

In terms of gender transformation there has been a related but more limited growth in the participation of female engineering students over the same period (1996–2005). The professional engineering environment can be described as 'a man's world'. Despite many initiatives, ranging from dedicated recruitment and selection to the establishment of support groups for female students at training institutions, women are still under-represented in the engineering field. Professor Beatrys Lacquet, first female dean of the Faculty of Engineering at Wits, holds the opinion that it is not necessary to reach for a goal of 50% female engineering students, adding the reminder that not 50% of all nurses are men.[118]

This section only reports on enrolment and graduation trends of women in engineering. Chapter 3 considers strategies to enhance women's participation in the engineering field, the factors that influence women in choosing a career in engineering, and the barriers experienced by female engineering professionals in the labour market.

Enrolment of female engineering students more than trebled from 1996–2005 (from 3 341 to 11 801), indicating an average annual growth rate of 15.05% over this period (Figure 2.15). In comparison, enrolment of male engineering students increased by an average annual rate of only 4.58% – there were 26 820 male students enrolled in 1996 and 40 142 by 2005. Proportionally, enrolment of female engineering students constituted only 11.08% of total engineering enrolment in 1996, but by 2005 more than a fifth (22.72%) of enrolments in engineering were women (Figure 2.16).

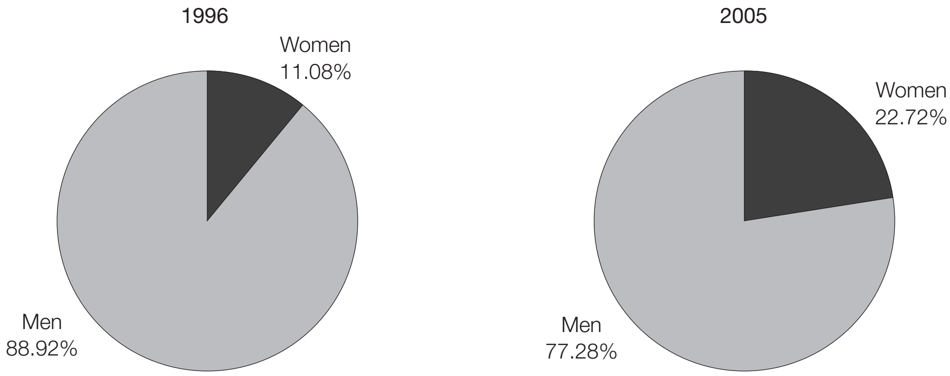
Figure 2.15 Undergraduate engineering student enrolment, by gender (1996–2005)



Source: DoE (1996–2005)

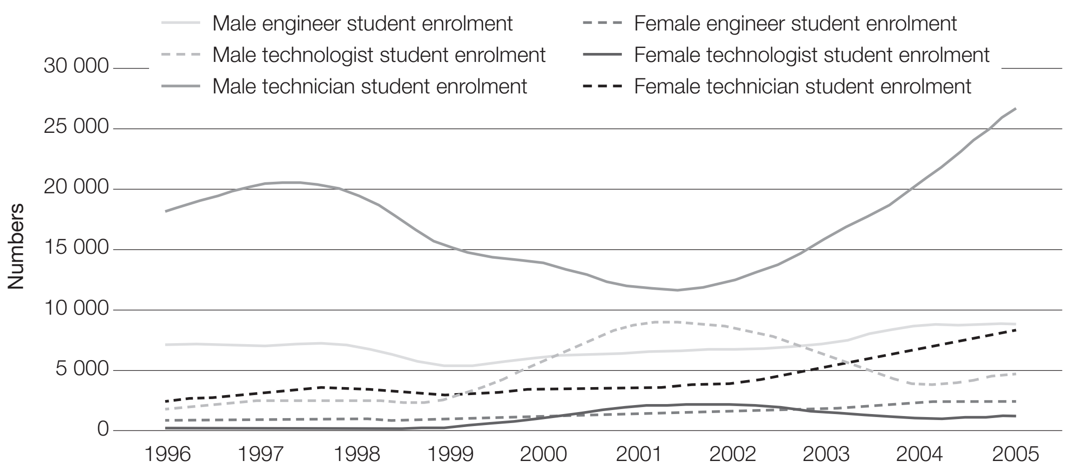
118 Meer werk as mense, sê ingenieurs se eerste vroue-dekaan [More work than people, according to first female dean in engineering], *Rapport*, 25 March 2007.

Figure 2.16 Undergraduate enrolment proportions of all engineering students, by gender (1996 and 2005)



Source: DoE (1996–2005)

Figure 2.17 Undergraduate enrolment of engineer, technologist and technician students, by gender (1996–2005)



Source: DoE (1996–2005)

Table 2.6 (see also Figure 2.17) shows the enrolment trends separately for male and female engineer, technologist and technician students and Figure 2.18 the enrolment proportions. Enrolment of female engineer students almost trebled from 1996–2005 (from 839 to 2 357), indicating an average annual growth rate of 12.17% over this period. In 1996 enrolment of female engineer students constituted just a tenth (10.62%) of all engineer students compared to about a fifth (21.12%) in 2005. Enrolment of female technologist students increased from 112 to 1 180 over the 1996–2005 period, showing an average annual growth rate of 29.92%. Proportionally, female technologist student enrolment comprised only 6.08% of total technologist enrolment in 1996, compared to almost a fifth (19.97%) in 2005. For female technician enrolment the annual growth rate over the same period averaged 14.78%. In 1996 just over a tenth (11.70%) of all technician enrolments were women, while by 2005 this figure had increased to almost a quarter (23.70%).

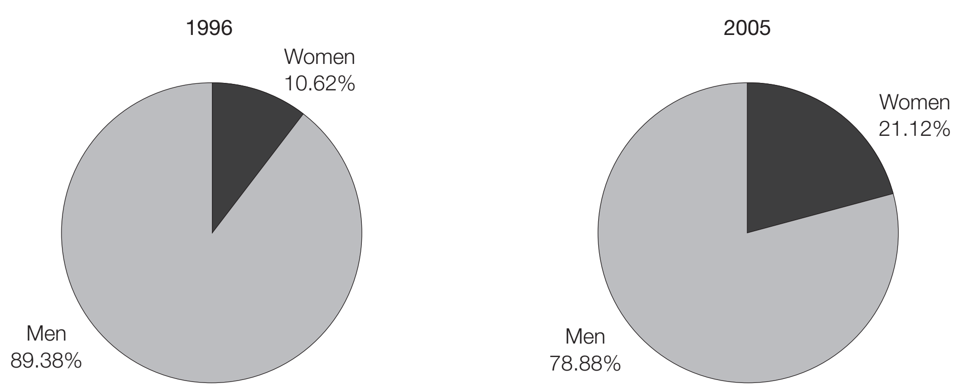
Table 2.6 Average annual growth rate: undergraduate engineering professional enrolment, by gender (1996–2005)

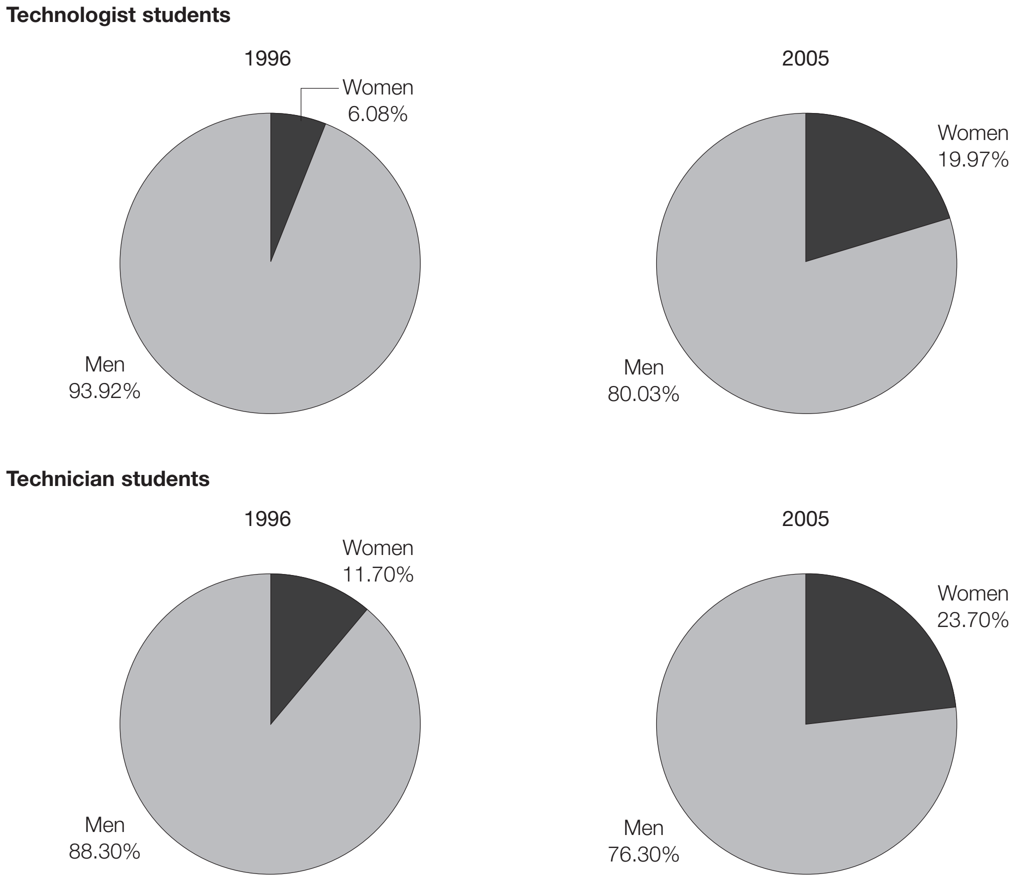
Undergraduate engineering enrolment	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Male engineer student enrolment	7 056	6 941	6 963	5 192	6 073	6 316	6 598	7 093	8 626	8 802	2.49
Female engineer student enrolment	839	909	1 003	857	1 114	1 339	1 537	1 808	2 259	2 357	12.17
Male technologist student enrolment	1 728	2 359	2 454	2 567	5 631	8 717	8 502	6 172	3 785	4 730	11.84
Female technologist student enrolment	112	144	145	271	1 004	1 960	2 101	1 440	954	1 180	29.92
Male technician student enrolment	18 035	20 165	19 446	15 133	13 719	11 676	12 208	15 750	20 258	26 610	4.42
Female technician student enrolment	2 390	3 024	3 519	2 857	3 549	3 551	3 949	5 176	6 775	8 264	14.78
Total male undergraduate engineering enrolment	**26 820**	**29 465**	**28 864**	**22 893**	**25 423**	**26 710**	**27 309**	**29 015**	**32 669**	**40 142**	**4.58**
Total female undergraduate engineering enrolment	**3 341**	**4 076**	**4 666**	**3 985**	**5 667**	**6 850**	**7 586**	**8 424**	**9 988**	**11 801**	**15.05**
Total engineering enrolment	**30 160**	**33 541**	**33 531**	**26 878**	**31 090**	**33 559**	**34 895**	**37 439**	**42 657**	**51 943**	**6.23**

Source: DoE (1996–2005)

Figure 2.18 Enrolment proportions of engineer, technologist and technician students, by gender (1996 and 2005)

Engineer students



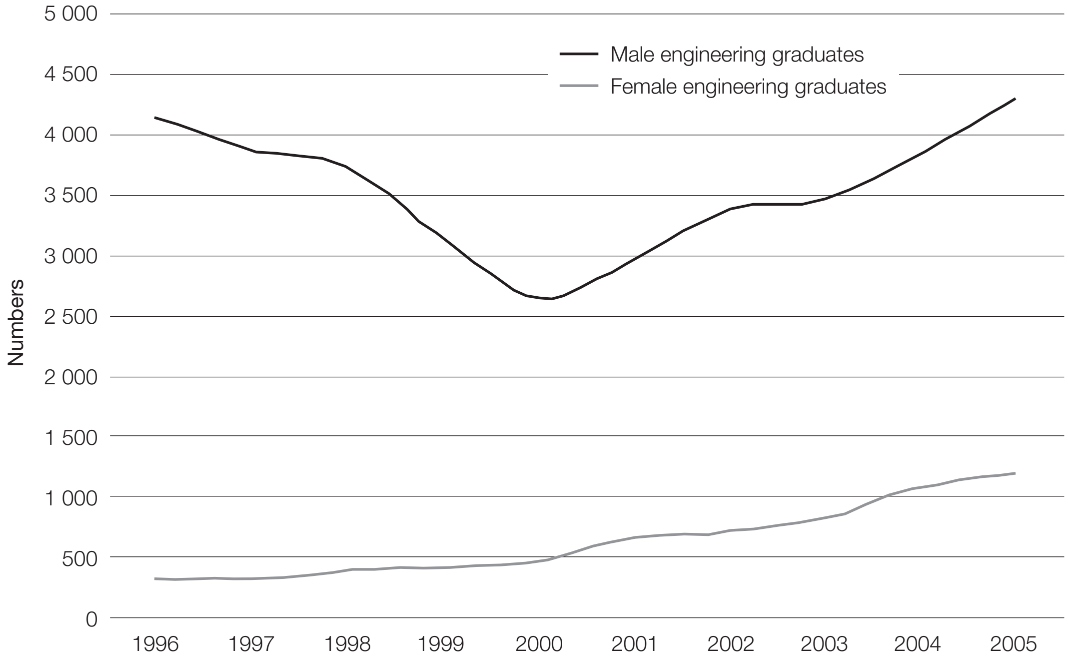


Source: DoE (1996–2005)

Graduation figures, by gender

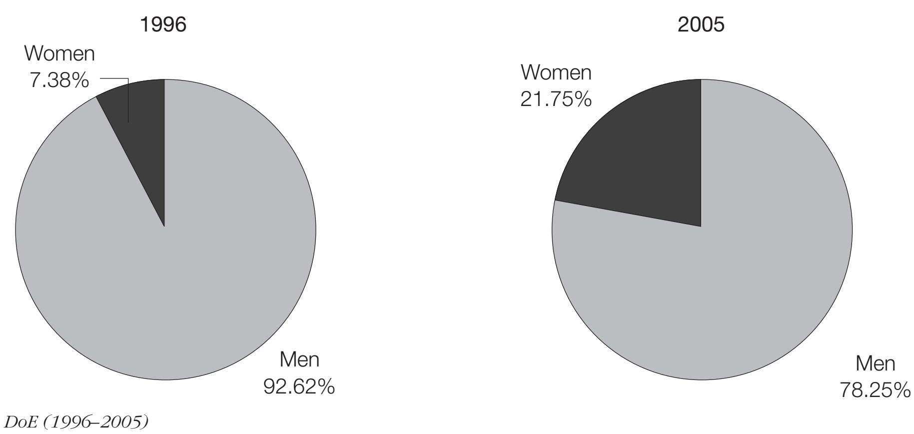
The number of female engineering graduates more than trebled from 1996–2005 (from 331 to 1 198), indicating an average annual growth rate of 15.37% over this period (Figure 2.19 and Table 2.7). While such growth sounds significant, it is worth bearing in mind that it was from a very low base. In comparison, the number of male engineering graduates increased by a low average annual rate of 0.41% – there were 4 153 male engineering graduates in 1996 and only 155 more (4 308) in 2005. Proportionally, female engineering graduates comprised less than a tenth (7.38%) of all engineering graduates in 1996 (Figure 2.20); by 2005 female engineering graduates had increased to just over a fifth (21.75%) of all engineering graduates.

Figure 2.19 Undergraduate engineering student graduation, by gender (1996–2005)



Source: DoE (1996–2005)

Figure 2.20 Graduation proportions of all engineering students, by gender (1996 and 2005)

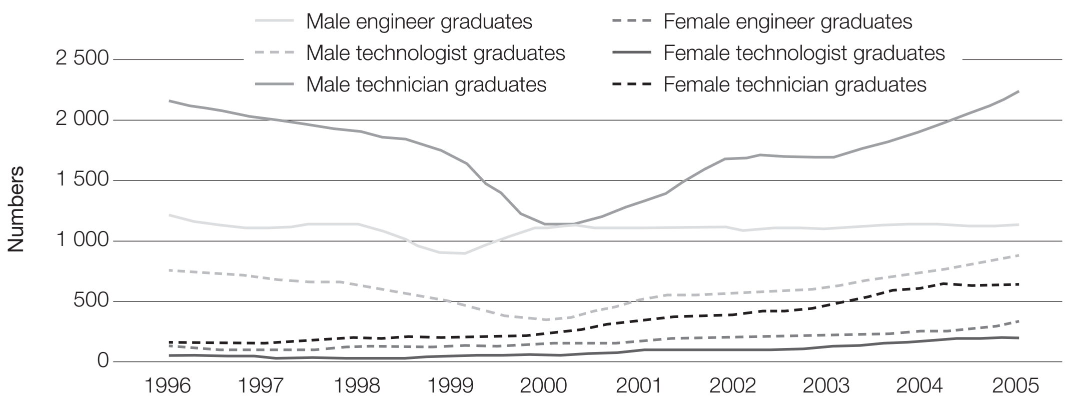


Source: DoE (1996–2005)

Figure 2.21 (see also Table 2.7) shows the graduation trends separately for male and female engineer, technologist and technician students and Figure 2.22 the graduation proportions in terms of gender. In 1996 only 129 female engineers graduated from universities. By 2005 this figure had increased to 328, indicating an average annual growth rate of 10.89% over this period. In 1996 female engineer graduates comprised only 9.64% of all engineer graduates. By 2005 this proportion had increased to a fifth (22.34%).

Only 43 female technologist students graduated in 1996 compared to 221 in 2005, indicating an average annual growth rate of 19.89%. The trend in terms of female technologist and technician graduates compared to male technologist and technician graduates as a proportion of the whole was similar to that for female and male engineer graduates – women constituted less than 10.00% of technologist and technician graduates in 1996 compared to about a fifth in 2005.

Figure 2.21 Graduation of engineer, technologist and technician students, by gender (1996–2005)



Source: DoE (1996–2005)

Table 2.7 Average annual growth rate: undergraduate engineering professional graduation, by gender (1996–2005)

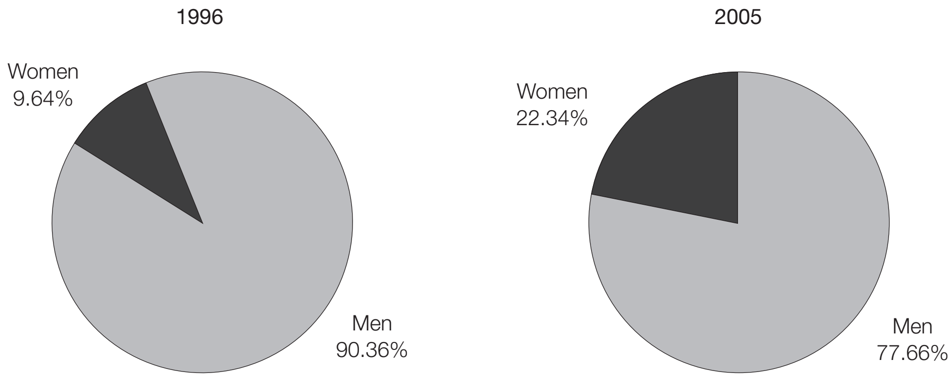
Undergraduate engineering graduation	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Male engineer graduation	1 212	1 119	1 146	920	1 130	1 098	1 103	1 128	1 156	1 139	–0.69
Female engineer graduation	129	124	132	131	162	189	204	227	268	328	10.89
Male technologist graduation	769	712	651	506	372	531	575	643	759	909	1.87
Female technologist graduation	43	44	40	58	60	110	113	129	193	221	19.89
Male technician graduation	2 172	2 036	1 926	1 721	1 157	1341	1 700	1 715	1932	2 260	0.44
Female technician graduation	159	154	213	226	228	369	404	482	632	650	16.97
Total male engineering graduation	4 153	3 867	3 723	3 147	2 659	2969	3 377	3 486	3 847	4 308	0.41
Total female engineering graduation	331	321	385	415	450	667	720	837	1 094	1 198	15.37
Total engineering graduation	**4 483**	**4 188**	**4 108**	**3 562**	**3 109**	**3 636**	**4 097**	**4 323**	**4 941**	**5 506**	**2.31**

Source: DoE (1996–2005)

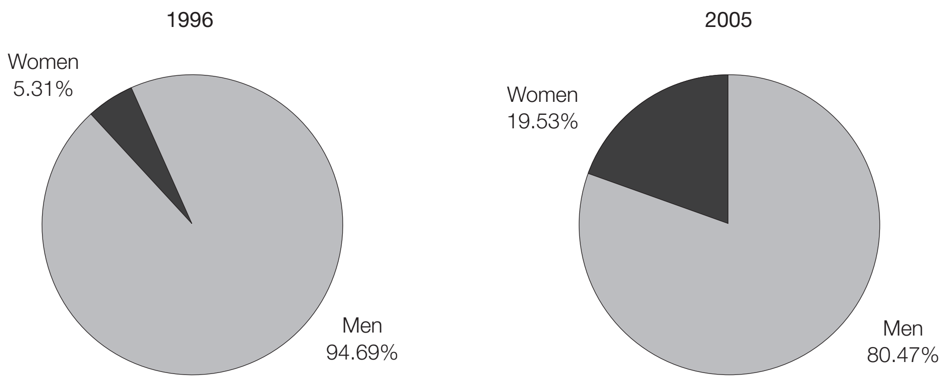
Note:
Totals do not in all instances add up because of rounding.

Figure 2.22 Graduation proportions of engineer, technologist and technician students, by gender (1996 and 2005)

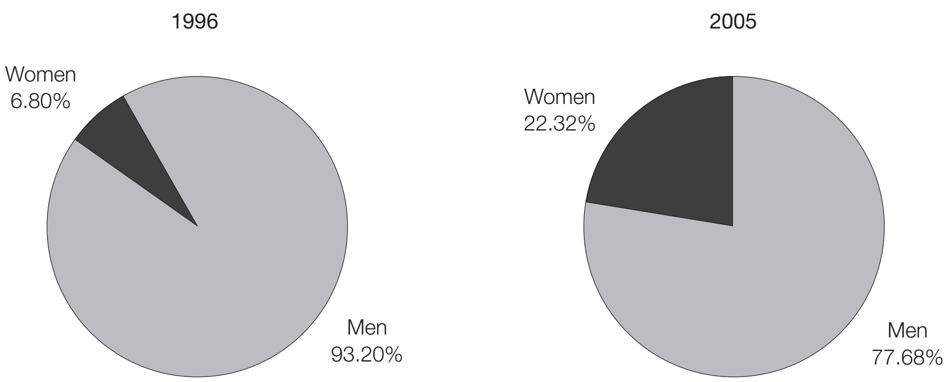
Engineer students



Technologist students



Technician students



Source: DoE (1996–2005)

Engineering programmes and the accreditation process

All engineering programmes at universities and universities of technology are accredited by ECSA as per its legislative mandate, the Engineering Profession Act (No. 46 of 2000), and the Higher Education Quality Committee (HEQC) recognises ECSA as an accrediting body for engineering programmes at higher education level. The accreditation process through ECSA is necessary in order to determine whether the engineering qualifications offered can be recognised by the Council for registration purposes. Although ECSA's focus is primarily aimed at ensuring that qualifications presented for purposes of registration meet its requirements, the Council also has a wider perspective; namely, the maintenance of quality in engineering higher education in South Africa as a pivotal driving force in promoting the interests of public safety and health, the economic viability of the country, as well as international competitiveness and recognition.

The current education structure at ECSA comprises an education advisory committee that is responsible to the Council and to the executive committee for all aspects relating to education. This education advisory committee is essentially a policy-making body, which monitors the operational activities of subcommittees acting in terms of defined powers delegated to them. These subcommittees are: the engineering programme accreditation committee, the technology programme accreditation committee, and the certificated engineers' accreditation committee.

Each of the above subcommittees has a further subcommittee, called the qualifications and examinations committee, and these are responsible to their principal committees for assessment of foreign qualifications and conducting of examinations and interviews. The three subcommittees referred to above are directly responsible for the accreditation of engineering programmes at higher education institutions.

The South African Qualifications Authority (SAQA) was established in 1994 and became the legislative body to register standards for educational offerings and to certify various bodies – termed Education and Training Quality Assurers (ETQAs) – to perform qualifications assurance. At the same time the National Qualifications Framework (NQF) was developed and established with the aim of enabling progression of learners through all levels and areas of the South African education system.

The National Qualifications Framework Bill (2008) repeals the South African Qualifications Authority Act (No. 58 of 1995). According to the Bill, a statutory or non-statutory body of expert practitioners in an occupational field must apply to SAQA to be recognised as a professional body in terms of the proposed Act. A professional body must co-operate with the relevant quality councils in respect of qualifications and quality assurance in its occupational field, while assuring that public health and safety are still being maintained.

The ESGB has the function of developing pathways for potential qualifications and standards in engineering, and of generating qualifications and standards in accordance with SAQA requirements for NQF levels 4 to 8. These would cover both whole qualifications and unit standards-based qualifications for engineers, engineering technologists and engineering technicians. Furthermore, the ESGB has to recommend qualifications and standards generated as well as criteria for registration of assessors and moderators or moderating bodies; review qualifications and unit standards; and maintain liaison with other standards generating bodies during the process of developing standards and qualifications (Council on Higher Education 2008).

In 1996 the accreditation process had to be adapted because it became necessary to meet ECSA's commitment to accommodating outcomes-based learning and appropriate quality assurance methods. Meeting the Washington Accord required a system similar to that of the American Accreditation Board for Engineering and Technology, and led ECSA to begin outcomes-based accreditation in 2001 (Hanrahan 2000). Engineering, by virtue of its professional nature, has always been outcomes-based, in the sense that an engineering professional is required to demonstrate competence. But what has happened since it became *formally* outcomes-based in terms of pedagogy is that there is coherence among the outcomes and the courses and synergy between courses. According to Jawitz (2001), the new outcomes-based form of accreditation used by ECSA poses a key opportunity for engineering academics to participate actively in educational issues.

There are two engineering programmes: the engineering degree programme and the technology programme. The engineering degree programme consists of a four-year BEng/BSc (Eng) degree at NQF level 8 (referred to as 'Professional' Bachelor's degrees) leading to registration as a professional engineer. This programme is currently offered by the following universities:

- University of Cape Town;
- University of KwaZulu-Natal – formed by the merger of the University of Natal and the University of Durban-Westville;
- North-West University – formed by the merger of the University of Potchefstroom and the University of North-West, the latter having no BEng/BSc (Eng) programmes;
- University of Pretoria;
- University of Johannesburg – former Rand Afrikaans University that merged with Technikon Witwatersrand, the latter having no BEng/BSc (Eng) programmes, only NDip, BTech and MTech programmes;
- University of Stellenbosch; and
- University of the Witwatersrand.

The technology programme consists of a National Diploma in engineering leading to registration as a professional engineering technician, and a BTech in engineering leading to registration as a professional engineering technologist. The technology programme is currently offered by the following institutions:

- Vaal University of Technology;
- Tshwane University of Technology – formed by the merger of Northern Gauteng Technikon and Pretoria Technikon;
- University of South Africa (UNISA) – former Technikon SA that merged with UNISA;
- University of Johannesburg;
- Central University of Technology, Free State;
- Mangosuthu University of Technology;
- Durban University of Technology – formed by the merger of ML Sultan Technikon and Technikon Natal;
- Nelson Mandela Metropolitan University – formed by the merger of the University of Port Elizabeth and PE Technikon;

- Cape Peninsula University of Technology – formed by the merger of Cape Technikon and Peninsula Technikon; and
- Walter Sisulu University – formed by the merger of Eastern Cape Technikon and Border Technikon.

Historically, the various engineering programmes have had and continue to have relatively good industry relations. In the university sector relations with industry have often been developed and established through research activities, while in the former technikon sector it has been found that many of the academics have better industry experience than research experience. The nature of these well-established relationships serves as evidence that the outcomes of the programmes correspond with the needs of industry.

In terms of workplace training, ECSA identified several SETAs – such as the Chemical Industries SETA (CHIETA), the Construction SETA (CETA), the Energy SETA (ESETA), the Manufacturing, Engineering and Related Services SETA (MERSETA), the Mining Qualifications Authority, and the Transport SETA – that are mandated to facilitate the skills development of engineering professionals. The Council is in the process of developing a close relationship with these SETAs and has so far signed an MoU with four of them. The MoU provides for co-operation in the area of standards generation and quality assurance in the higher education band. Although ECSA's main focus is on the higher education levels of the NQF, it recognises the need for continuity from levels 1 to 4 through levels 5 to 8.

However, despite all these developments there is for the most part little change in terms of the organisational system and delivery of these programmes within institutions. The system still consists of the old departments and faculties at universities and universities of technology.

Challenges for institutions offering engineering programmes

Institutional mergers

In 2001 the *National Plan for Higher Education* (Ministry of Education 2001) proposed institutional mergers. This plan had an arguably greater impact on the former technikon sector than on most traditional universities offering engineering. All except 3 of the original 11 technikons experienced some form of merger, while only 3 of the 7 universities offering engineering were affected. Two universities experienced mergers but retained their traditional university status (the newly formed University of KwaZulu-Natal and the North-West University), while one was reformed as a comprehensive university following a merger with a techikon (the newly formed University of Johannesburg). The University of Johannesburg is therefore the only institutional merger that has had to deal with both engineering degree and technology programmes.

The dean of the Faculty of Engineering at the University of Johannesburg highlighted the major strengths and weaknesses of the merger for engineering training at that institution (Interview 2006e). According to him, this merger had brought about transformation in terms of new management, new deans, and a more diverse university population. Although at the time of the interview the programmes were still separate because of the different learning outcomes for BTech and BEng degrees and for professional registration requirements, the opportunity now exists to design articulation pathways.

The complication of the merger lay in the complexity of engineering training at the university and the university of technology respectively. The University of Johannesburg's Faculty of Engineering is the first example in South African higher education of the management of these two different paradigms under one leadership. The two paradigms traditionally entailed different cultures and different types of organisational processes, and this has posed major challenges. This merger also caused the faculty to re-strategise their research output – university staff traditionally had a higher research output than the former technikon staff.

Financial constraints

Engineering programmes are costly for the higher education institutions to run, and the subsidy commitment of government has not been sufficient in this regard (ECSA & EASA 1995). This has caused some of the smaller departments to form often complicated arrangements with external funders (Jansen 2002). Concern has also been raised by ECSA about the quality of engineering programmes offered by some of these smaller departments (ECSA & EASA 1995). One of the major aims of the higher education mergers was to make the smaller institutions more effective. However, this process of merging and rationalising programmes seems to have been more complicated than anticipated (Interview 2006e). Recently, the government made more funds available to some of the higher education institutions through JIPSA, in an effort to increase the output of engineering graduates.

Lecturing staff

Higher education institutions also face challenges relating to the recruitment and retention of lecturing staff, staff to student ratios, research outputs and the quality of teaching by staff. In 2008, there were close to 300 vacancies in engineering departments in South Africa and one lecturer to every 56 students, where the international standard is one lecturer to every 25 students.[119]

Engineering programmes at higher education institutions struggle to secure high quality staff to teach in these programmes. This is mainly because engineering salaries in industry and commerce are considerably higher than those for engineering academics. Most engineers want a professional job after graduation rather than to work as an academic, making the pool from which to source academics very small. Related to this, the academic staff turnover is usually high because of the high demand from industry. This breaks the sustainability cycle for training institutions. An even bigger problem is attracting and keeping candidates who meet equity criteria (Interview 2006e).

Higher education institutions are increasingly focusing on research expertise when considering appointments and promotions. According to D'Almaine, Manhire and Atteh (1997), it is also required that lecturers at the universities of technology, which historically placed more emphasis on industrial experience, now have to obtain postgraduate qualifications and to publish. The objective is that research should positively influence the quality of teaching (Elton 2001).

119 Universities running on empty, *The Star*, 9 August 2008.

One of the strategies that institutions apply to address the challenges in terms of attracting and retaining staff is to 'grow their own timber'. In terms of this approach, institutions take students at an undergraduate level and place them in a developmental programme. Experience shows that such a strategy assists students to successfully complete their master's and doctoral degrees (Interview 2006e) and increases the chances of these students pursuing an academic career. Incentives in kind are also applied in an attempt to retain staff; these can range from free study fees for children and holidays, to one day off a week to do consultancy work. Some of the engineering faculties at higher education institutions have an institutional equity policy. In terms of implementation, this simply means that there is a bias and first priority goes to equity candidates, although they still have to meet the qualification and experience criteria.

The high student to staff ratios in the engineering departments are a big concern (Interview 2006e). The national benchmark is 35:1, but a ratio of 100:1 is sometimes found, especially at universities of technology. This was exacerbated by the DOE's plans to increase student numbers (Interview 2006e). Now the DoE is capping enrolment totals to address issues of quality.

Globally, over the past few decades there has been a massive increase in concern over the quality of teaching and learning in higher education programmes across the board (Biggs 1999; Ramsden 2003). Interest in engineering education has been led by organisations such as the American Society for Engineering Education (Wankat & Oreovicz 1993). In South Africa, the Centre for Research in Engineering Education was established at UCT in 1996 with the goal of promoting engineering education as a feasible research field. According to Case (2006), a national community of concerned engineering educators has been established through a series of engineering education conferences since 1997. The magazine *For Engineering Educators* also came into being and provides space for the dissemination of examples of good practice and for educational research findings, both national and international.

Shift from content-based to outcomes-based education

In recent years there has been a shift in approach to the accreditation of engineering programmes globally. Historically, standards were described in terms of the scope of the content and the proportions of theory and practice within a specific training programme. However, international and domestic developments have created an environment in which professional associations are more interested in the outcome of what students have learned than in the content of a programme – the focus has shifted to the achievement of specific learning outcomes that students will be able to use when entering employment (Jawitz 1999).

As mentioned, from 1998 onwards ECSA embraced the NQF and the idea of outcomes-based accreditation of whole qualifications. A related influence was the requirement for meeting the Washington Accord (in which outcomes-based education is favoured). ECSA began outcomes-based accreditation in 2001, operating on an interim licence granted by the HEQC. The Council compiled a list of 10 general exit-level outcomes, and has subsequently used this in all accreditation visits.

The shift from content-based to outcomes-based education for the engineering programmes at universities created the following opportunities (Jawitz 2001):

- Engineering departments started discussing the relationship between learning objectives and the learning process and assessment.
- Programmes have the liberty to define their own content, as the focus has shifted from what students know to how students can apply their knowledge.
- Attention is paid to the methodology of assessment.
- Programmes follow a process of continuous evaluation and improvement.

Universities of technology only started with outcomes-based engineering education in 2009.

Student access and mobility or articulation

Students obtain access to tertiary engineering programmes based on their results in the final, Grade 12 school-leaving examination. These results refer to a score representing the overall set of results and a specified minimum requirement for mathematics and/or physical science. Up to 2008, a higher grade mathematics symbol of A, B or C was required to study engineering at university, and for most universities of technology a minimum symbol of C (standard grade) mathematics was required. D symbols have also been accepted for extended engineering degree programmes at some universities.

However, the new National Senior Certificate examination has been in place since 2008, and for the purposes of selection to engineering the most dramatic impact has come from the ending of the former higher grade and standard grade levels at which school subjects were offered. According to Case (2006), it would seem that the new mathematics curriculum is pitched at a level roughly equivalent to the former higher grade subject, with some additional optional topics. School learners who are not taking mathematics are required to take a new subject, mathematical literacy. Case (2006) mentions further that mathematical literacy is supposed to enable all learners to master some mathematics, but it will not be possible to use it for assessment in a way that will cause candidates to be unsuccessful – the new National Senior Certificate will require learners to pass all subjects at the 30% level in order to qualify for a pass.

Only mathematics, and not mathematical literacy, is accepted for admission to engineering certificate, diploma or degree programmes, and each institution and faculty sets its own minimum entry requirements over and above minimum entry requirements into certificate, diploma and degree programmes (Pace Career Centre 2008). Although some schools have taken precautionary measures by requiring all learners to take mathematics rather than mathematical literacy, it is still very unlikely that the pool of students taking mathematics will be equivalent to the combined previous cohort taking higher and standard grade mathematics (Case 2006). Case's concern is shared by Gugu Makhanya, project leader of transformation at the South African Institute of Chartered Accountants (SAICA), who bemoans the insufficient awareness that mathematical literacy is not as acceptable as standard grade mathematics would have been and that once a school learner has chosen mathematical literacy, change to core mathematics is not possible later on (SAICA 2008). According to Case (2006), the new curriculum will not impact that much on programmes that currently require higher grade mathematics for admission.

The provision of funding is another important issue impacting on student access to engineering training at higher education institutions. Traditionally, engineering students had access to industrial bursaries or scholarships that involved work agreements with companies after graduation. These work agreements contributed to building a future workforce and, according to Case (2006), companies have recently been able to use these to change the demographic profile of the engineering professionals employed. Some of the higher education institutions also offer financial aid schemes to disadvantaged students who do not have the means to fund their studies. The introduction in 1999 of the National Student Financial Aid Scheme (NSFAS) enhanced these schemes – the state offers loans and bursaries to qualifying higher education students. Engineering students who are unable to obtain industrial bursaries can now apply for NSFAS bursaries.

Another problem in terms of access is the 'revolving door syndrome' (Case 2006). This refers to the phenomenon of students from disadvantaged backgrounds gaining access to higher education, but without the institution having provided the necessary environment in which they might succeed academically. The higher education institutions have responded by establishing academic development programmes to address this problem, and Case (2006) reminds us that it was engineering faculties at the former white, English-medium universities, encouraged by industry, that led the establishment of such academic support programmes during the late 1980s.

Some universities currently offer extended degree programmes (which have replaced the previous bridging programmes). Even though the throughput rates of previous bridging programmes and extended degree programmes have often been lower than those of the conventional engineering programmes, these programmes have clearly had an impact by providing opportunities for students who might not have met the formal entry criteria. Such programmes offer extra academic support in the early years to compensate for the schooling backgrounds of disadvantaged students (Jawitz & Scott 1997). There are now significant numbers of engineers in industry who graduated through such programmes.

The widening of access to engineering programmes for women is also an issue. Traditionally, only a small proportion of women, as described earlier, study engineering in general. However, it is found that some engineering fields of study, such as chemical engineering, attract bigger numbers of female students than others. A derivative of the increased number of black students in engineering has been an increased proportion of female students. South Africa's deputy president at the time and leader of the JIPSA initiative specifically mentioned the incidence of large numbers of female students with qualifications in the built-environment fields of study who had been applying to various infrastructural projects (Case 2006).

Case further points out that one more issue in terms of access is students who wish to study at the undergraduate engineering level on a part-time basis. UNISA does provide for part-time diploma and BTech engineering studies, although the BEng at universities is offered only on a full-time basis. The higher education sector currently also lacks a real mechanism for recognition of prior learning.

Regarding mobility, there have been relatively limited opportunities for students to move between the different kinds of engineering programmes offered at the traditional universities and those at universities of technology. This is mostly so for students holding National Diplomas or BTech degrees who aspire to enter university BSc (Eng) programmes. Case (2006) indicates that individual departments have sometimes had arrangements in place to grant credit and exemption for particular subjects but that this has generally been rather limited and arguably not very successful where it has been implemented. For students who want to change from the BSc (Eng) course to the universities of technology course, there have generally been systems in place to grant credits for particular subjects across the four semesters of the National Diploma.

The perception was that the NQF would make articulation possible between programmes. However, the main function of the NQF is only to publish the exit standards in this regard. It is up to institutions to work out articulation pathways. Case (2006) mentions that there has been strong resistance from the traditional university sector to recognising any equivalence of academic years across the different types of qualifications. She points out that there is specifically a concern about the BEng/BSc (Eng) degree and BTech being at the same level on the NQF, although both these degrees are four-year degrees. According to the *Higher Education Qualifications Framework* (DoE 2007) a 'professional' bachelor's degree at NQF level 8 has a higher volume of learning and a greater cognitive demand than bachelor's degrees at NQF level 7. Currently, there is discontent within the higher education community about the phasing out of the BTech degree because of articulation difficulties.[120]

Further education and training colleges

FET colleges in South Africa have historically offered trimester N-stream, knowledge-only, trade-based programmes which were very narrow in content and designed to meet the needs of manual low-skills, low-wages industries and were not aligned with the current industrial, technological and economic trends in the country (Mbanguta 2002). The declaration of Colleges for Advanced Technical Education in 1978 led to the establishment of the technikons, which divorced themselves from technical colleges. The technical colleges continued to offer artisan training programmes at N1–N3 levels and at the same time introduced N4–N6 levels (tertiary), leading to a National Diploma in engineering.

FET college programmes in engineering have become very limited and narrow in content, since they were designed to meet the demands of manual, low-skills, low-wages industries (Mbanguta 2003). As a result, the following problems are experienced:

- Universities and universities of technology cannot recognise FET college qualifications for articulation purposes.
- The work experience aspect cannot be enforced; therefore the uptake of students by employers is very low.
- ECSA demands that the FET college engineering education curriculum be reviewed for recognition, as the current qualification confines graduates to the status of operators, repairers and maintenance personnel – the higher education (N4–N6) levels of these programmes fall outside the binary model of higher education as promulgated in South Africa's Higher Education Act (No. 101 of 1997).

120 MacGregor K, South Africa: New qualifications framework, *University World News*, 4 May 2008.

However, the NQF, the FET Act (No. 98 of 1998), the *Education White Paper 4 – A Programme for the Transformation of Further Education and Training* (Ministry of Education 1998) and the Skills Development Act (No. 97 of 1998) gave a new interpretation and definition of a qualification based on an outcomes-based approach. This has implications for the engineering programmes offered at FET colleges as it is supposed to open up the way for easy articulation to universities of technology and universities and to enhance the applicability of FET programmes to the needs of industry. Some FET colleges already offer the National Certificate and National Higher Certificate (NQF level 5) in engineering offered by the universities of technology. These programmes are accredited and quality assured by the Council on Higher Education/HEQC (Mbanguta 2003). In 2000 about 74 000 students obtained engineering qualifications at NQF level 5. This figure was static in 2002; that is to say, there was no growth in the output of engineering qualifications at NQF level 5 at FET colleges over the 2000–2002 period.

Learnerships

Skills development in South Africa is intended to improve productivity, employment creation and competitiveness. Accredited work-integrated learning programmes, learnerships, are at the heart of the Department of Labour's skills development strategy. They are aimed at providing workplace learning in a structured form, linked to multiple sites of work experience, and culminating in a nationally recognised qualification. Learnerships were proposed to be particularly significant in occupations in economic sectors experiencing skills shortages, or in those identified as critical priorities for economic growth.

Learnerships are seen as different from apprenticeships in that success is measured by the ability of the learner to use the skills taught in the workplace. Central to a learnership is a combination of theory and practice, and assessment towards accredited qualifications is focused on performance of key tasks.

For the period 2001–2007, only 629 learners registered for engineering-related learnerships through the CETA, CHIETA, ESETA and MERSETA (HSRC 2007). Most of these (510) were at NQF level 6, while 117 were at NQF level 5. Only one learner registered at NQF level 7 (master's degree level), while one learner registered at NQF level 8 (doctorate level). The learnership fields were: analytical chemistry, chemical engineering, civil engineering, electrical engineering, electronic and computing systems, fossil power plant process control, mechanical engineering, nuclear power plant process control, polymer technology, programming, and systems support engineer.

There are requests for the conversion of the National Diploma in engineering to a learnership (Lawless 2005), in a bid to address the current shortage of experiential training opportunities – some of the universities of technology are trying to use a learnership route to support access to experiential learning. In such cases, the relevant SETA registers the learnership, the university of technology offers the learning component (which is the existing higher education programme), and the SETA locates an employer where the student can do the workplace training component. In this way the student can obtain a qualification and the employer is compensated for their training endeavour.

Conclusion

The secondary school education system in South Africa is inadequate in terms of its capacity to develop and supply a suitable pool of candidates for engineering studies at higher education institutions. Before a sufficient pool of learners with mathematics and physical science qualifications can be supplied in future for training in engineering at universities and universities of technology, the school system should do the following: identify learners with the potential to pursue mathematics and physical science; ensure that there are enough well-qualified teachers available to improve tuition in mathematics and science; create an awareness of the engineering study field for potential students through career guidance; guide the mathematics and physical science learners through the secondary school phase; and assist such learners to gain entry to engineering at a higher education institution.

South Africa needs a significant number of engineering graduates to ensure sustainable growth. Although there has been an increase in the number of those studying towards an engineering qualification at universities and universities of technology, the throughput rates to deliver engineering graduates are still poor – there has been only a marginal increase in the absolute number of engineering graduates over the past 10 years. For higher education institutions to provide enough engineering graduates to industry, entry criteria must be revisited in order to ensure better throughput rates; the scope and quality of engineering programmes must be aligned with industry needs; the number and quality of lecturers must be improved; availability of resources to fund, support and mentor students at higher education institutions must be addressed; experiential training opportunities must be arranged; and graduates must be assisted by placement agencies to access employment opportunities.

CHAPTER 3

Women in engineering

In 1945 there were no women in engineering in South Africa but by 1974 women had gradually begun participating in the engineering profession (Interview 2006a; Interview 2006f; Interview 2006k). In 1996 about 16.21% of engineering professionals participating in the South African labour market were women. However, by 2005 this figure had decreased to only 10.51% (Quantec 2007). The declining trend is not only alarming in the context of the critical shortage of engineering skills in South Africa, but also highlights the continued under-representation of women in engineering.

Strategies to enhance women's participation

The professional engineering environment can be described as 'a man's world'. Phipps (2002) emphasises that the perception of engineering as being a man's job, i.e. male identified, is a major factor contributing to the female minority. Traditionally, it is also experienced that women are not attracted by technology. Despite many initiatives, ranging from dedicated recruitment and selection to the establishment of support groups for female students at training institutions and female workers in the labour market, women are still under-represented in the engineering field.

The *Gender Gap Index* (Hausman, Tyson & Zahidi 2008) benchmarks national gender gaps according to economic-, political-, education- and health-based criteria to provide country rankings; although in terms of these criteria South Africa was the top performer in the sub-Saharan region in 2006, the country slipped down two positions in 2008 (and out of the top 20). In terms of African countries, in 2008 Lesotho took the top position (ranked 16^{th}), followed by Mozambique (ranked 18^{th}) as the only other African country in the top 20 positions (Hausman, Tyson & Zahidi 2008). Although South Africa ranked 5^{th} among 130 countries with regard to the number of women in ministerial positions, the country took only 93^{rd} position among the 130 countries in terms of economic participation by women and economic opportunities for women (Hausman, Tyson & Zahidi 2008).

The percentage of women undertaking study in engineering programmes in South Africa increased from 9.4% in 1996 to 20.2% in 2005 (DoE 1996–2005). This shows that initiatives to attract Grade 12 female school leavers to engineering studies are proving effective. However, although since 1996 women have constituted about a fifth of the engineering student population, they represent only about 10.0% of the engineering workforce (Quantec 2007). It would seem that the emphasis should be not only on recruitment, but also on retention (Roberts & Ayre 2002).

The Employment Equity Act (No. 55 of 1998) is a good example of an active labour market policy to increase women's participation in the labour market. The Act prescribes the representation of black people, women and disabled employees in organisations according to the population distribution of South Africa.

South Africa's National Research and Development Strategy (Department of Science and Technology 2002) recognises that human resources in science and technology are not being adequately developed and renewed. The strategy proposes a highly targeted approach towards increasing excellence in mathematics and the sciences among black Grade 12 school leavers and young women. New centres of excellence are being established to attract young people to sustainable careers in scientific research. Special programmes for the promotion of women in science and engineering have also been proposed.

One positive outcome of the research and development (R&D) strategy has been the establishment of the SET4Women Reference Group (Science, Engineering and Technology for Women Reference Group, abbreviated to SET4WRG) as part of the National Advisory Council on Innovation. The SET4WRG consists of female stakeholders and representatives of organisations with an interest in the progress of women in SET, and serves to monitor and advise the Department of Science and Technology (DST) on relevant issues. Another positive outcome of the R&D strategy has been the tasking of the National Research Foundation with setting up an R&D capacity-building programme for historically disadvantaged individuals.

A gender and race equity policy is at present under development for the DST through the SET4WRG. The intention is that the policy framework will guide institutions forming part of the National System of Innovation. The policy framework addresses issues of SET for women.

The European Commission (2006) report states that it is known that female engineers bring diversity to the monocultural engineering workforce and therefore extend the impact of engineering on society. Women usually show interest in the social aspects of technology and science and can make a significant contribution to social and environmental issues, among other things.

The career path of a female engineering professional starts at an early age and includes key junctures such as choosing school subjects, enrolling at a training institution, initial entry into the labour market, and progress in the labour market. In the context of the shortage of engineering skills in general, and of female engineering skills in particular, it is important to understand the internal and external influences that affect women's choices of engineering, and the barriers that serve to prevent female engineering professionals from full participation and success.

Factors influencing women in choosing engineering

A number of factors seem to influence the choice of engineering as a career option for women, including, among others: an early interest in science subjects at school level, the quality of education received in science subjects at school level, social influences such as parents or role models, and the availability of information (European Commission 2006; Phipps 2002). The desire to contribute to society emerges as a strong factor for women in choosing engineering (Isaacs 2001). Jawitz and Case (1998) found in a study in South Africa that black female engineering students were attracted to an engineering career based on the perceived role of engineers in the community. This would indicate that women tend to prefer engineering to be linked to a social context. In South Africa, the choice of following an engineering career starts as early as Grade 9, when a learner has to choose school subjects. In South Africa, especially in the case of black female school learners, there are still stereotypes around gender and the ability of women to perform in subjects such as mathematics and physical science; such stereotypes serve to keep black female learners in particular from pursuing careers in engineering.

Jawitz, Case and Tshabalala (2000) found that a positive attitude towards science at school can lead to choosing engineering as a career. The quality of mathematics and physical science education at South African schools is a problem, and the opportunity for learners to choose science subjects in order to pursue studies in engineering is affected by poor education in these subjects at school level.

Engineering is not always the exclusive choice of an individual and in many instances it is found that their families have influenced them. The European Commission (2006) report argues that the level of education of the two parents of female engineers has an important influence on their choice of engineering as a study field and career, and even more so if they have engineers in their family or close environment. A number of other studies also emphasise the positive effect of a role model on choosing engineering (Carter & Kirkup 1990; Coles 1994; Smith & Erb 1986).

The European Commission report suggests that lack of information is a major factor influencing women's consideration of a career in engineering. As stated earlier, none of the students interviewed in their WomEng project had any accurate information about the job and actual activities of an engineer; when they started their training, they lacked a good understanding of their future engineering career paths. Usually training institutions that offer engineering studies have information policies and events to inform potential students about the course. The European Commission report mentions that getting information through personal contact seems to be a decisive factor. They found in their study that the most effective opportunities for personal contact are open days at training institutions (European Commission 2006).

Labour market barriers

There is no convincing evidence that women's representation in science and engineering is limited by innate inability (Handelsman 2005). Research now tends to focus more on how both the work environment and the scientific culture itself act as a barrier to women, rather than on the notion that women as a gender inherently lack the requisite skills (Bebbington 2002).

The engineering working environment is male dominated and working conditions do not always accommodate female workers. There are a number of studies identifying the barriers that exist and that hinder female engineering professionals from fully participating and progressing in the labour market (European Commission 2006; Evetts 1994; Isaacs 2001; Rosser 2004; Taniguchi 1999).

Among the most significant barriers identified are balancing work with family, gaining credibility and respectability among male peers, the challenge of 'dual-career' relationships, lack of mentors due to small numbers of female engineering professionals, lack of access to networks, and inequality in terms of salaries and promotion opportunities.

Balancing work with family seems to be the most significant challenge that female engineering professionals face (Goldberg 1998; Interview 2006k; Maskell-Pretz & Hopkins 1997; Rosser 2004; Sonnert 1999). Among the strategies female engineering professionals apply to achieve a balance are having children later in their careers, and negotiating part-time and flexible working hours or even career breaks (Evetts 1994; Interview 2006i). Female engineering professionals report that in some of the engineering sectors it is not always easy to negotiate part-time contracts (Interview 2006k).

The phenomenon of dual-career relationships seems to be a significant problem for some (Interview 2006i; Interview 2006k). It is often found that a female engineering professional is married to a male professional – and hence the partnership is characterised by dual careers. The attitude of the female engineering professional's partner is a key factor in the dual-career dilemma. Cultures may differ but it is traditionally expected of women that they take care of children. Female engineering professionals report that they are usually the ones expected to make career sacrifices if they are married to a professional man. If the male partner's career prospects are considered more promising than the female's, preference is often given to the man's career development (Sonnert 1999). Younger generations seem to handle the challenge of dual-career relationships better (European Commission 2006).

Regarding discrimination, female engineering professionals face a number of obstacles in the workplace. These usually relate to issues such as getting recognition for the work they do, access to networks, remuneration, and promotion opportunities (Conrad 2001; Interview 2006i). It would seem that the traditional 'old boys' networks' are much more effective than the newer women's networks (Goldberg 1998; Phipps 2002); the small number of female engineering professionals does not allow the same networking opportunities.

It is clear that it is not women's insufficiencies that prevent them from entering the engineering field, but rather social and institutional structures and barriers. Some of the female engineering professionals interviewed expressed very strongly the opinion that women should know and accept the realities of the engineering workplace, accept that it is traditionally seen as a man's world, adapt, and '…just get over it', as one commented (Interview 2007c). Some of those interviewed indicated that there has definitely been a change in the corporate working environment which has become more accommodating of women, but that working realities, especially on sites in the construction industry, still pose challenges for female engineering professionals (Interview 2006i; Interview 2006j).

Graduation

There was an increase in the number of female graduates in engineering at universities from 1996–2005, as shown in Table 3.1. South African policies and labour laws are in place to address equity and transformation issues: aspiring female engineers are awarded bursaries (Interview 2006i; Interview 2006k); universities have supplementary courses in place; and cultural diversity issues are being addressed (Interview 2006g; Interview 2006h).

At universities, black female engineer undergraduates showed the strongest average annual growth in numbers (23.89%), followed by white female engineer undergraduates with 4.70%, black male engineer undergraduates with 4.27%, and a negative average annual growth in the number of white male engineer undergraduates over the 1996–2005 period. Even though there was total average annual growth of 10.89% in the number of female engineer undergraduates at universities over this period, it occurred from a small base. In 2005 men still constituted the majority of engineer graduates at universities.

Table 3.1 Graduation growth at universities (engineers) and universities of technology (technologists and technicians), by race and gender (1996–2005)

Graduates	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Technicians	2 330	2 189	2 140	1 947	1 385	1 710	2 104	2 196	2 564	2 910	2.50
Black women	103	113	166	193	206	320	367	445	591	619	22.11
Black men	967	974	967	1 096	751	864	1 161	1 265	1 473	1 740	6.74
White women	56	41	47	33	22	49	37	37	41	30	–6.58
White men	1 205	1 062	959	625	406	477	539	450	459	521	–8.90
Technologists	812	756	691	564	433	641	687	772	952	1 130	3.73
Black women	13	16	21	37	46	88	86	115	175	189	34.19
Black men	208	192	238	198	170	280	334	364	472	558	11.58
White women	30	28	20	21	14	22	27	15	18	32	0.74
White men	561	520	413	309	203	251	240	279	287	351	–5.08
Technicians & technologists	3 143	2 945	2 831	2 511	1 817	2 350	2 791	2 968	3 517	4 039	2.83
Black women	116	129	187	231	252	408	453	560	767	808	24.07
Black men	1 176	1 166	1 205	1 293	921	1 143	1 495	1 629	1 944	2 298	7.73
White women	86	68	66	53	36	71	64	51	59	62	–3.51
White men	1 765	1 582	1 372	934	608	728	779	729	747	872	–7.54
Engineers	1 341	1 243	1 277	1 051	1 292	1 286	1 306	1 354	1 424	1 466	1.00
Black women	25	38	35	46	65	69	90	97	135	169	23.89
Black men	282	298	334	263	396	415	398	417	432	410	4.27
White women	105	86	97	85	96	120	114	130	133	158	4.70
White men	930	821	812	657	734	683	705	711	724	729	–2.68
Undergraduates	4 483	4 188	4 108	3 562	3 109	3 636	4 097	4 323	4 941	5 506	2.31
Black women	141	167	223	277	317	477	543	656	902	977	24.04
Black men	1 457	1 464	1 539	1 556	1 317	1 558	1 893	2 046	2 376	2 708	7.13
White women	190	154	163	138	133	190	177	181	192	220	1.64
White men	2 695	2 404	2 184	1 591	1 342	1 411	1 484	1 440	1 471	1 600	–5.63
Postgraduates	576	682	673	728	842	826	892	932	998	1 063	7.05
Total graduation	**5 059**	**4 870**	**4 781**	**4 289**	**3 951**	**4 463**	**4 989**	**5 255**	**5 939**	**6 568**	**2.94**

Source: DoE (1996–2005)

Note:
Totals do not in all instances add up because of rounding.

Furthermore, at universities of technology, from which engineering technologists and technicians graduate, there was average annual growth of 24.07% from 1996–2005 in the number of black female technologists and technicians. Black male technologist and technician graduate numbers also showed an increase (7.73%) over the same period. However, the number of graduations of white female technologists and technicians declined (average annual growth of –3.51%), as did graduations of white male technologists and technicians (average annual growth of –7.54%) from 1996–2005. Similar to the picture at universities, in 2005 men still constituted the majority of graduates in engineering at universities of technology.

Enrolment and graduation of female engineering students are still lower than enrolment and graduation of male engineering students, but the throughput of female engineering students is slightly higher than that of males. This has been confirmed in interviews at universities (Interview 2006g; Interview 2006h). Female university students tend to be more mature, have better life skills, and be more focused, and at some of the universities women have been the top students for up to six consecutive years (Interview 2006g; Interview 2006i).

Conversely, the throughput of female technologists and technicians has decreased and the throughput of male technologists and technicians has increased at universities of technology. In 1999, a third of the female students who had enrolled in 1996 at universities of technology graduated, but in 2005, only 14.4% of the female students who had enrolled in 2002 graduated. Only 5.8% of the male students who had enrolled at universities of technology in 1996 graduated in 1999, while 15.3% of the male students who had enrolled in 2002 graduated in 2005.

The drop-out rate of engineering students has many contributory factors. Major campaigns were mounted in the early 1990s to encourage both historically disadvantaged learners and women to enter engineering studies – but without the higher education institutions providing enough information, and without selection and pre-testing to determine students' suitability for the engineering work environment and students' emotional intelligence (Interview 2006g; Interview 2006j). The incentive or motivation to study for a specific qualification must be intrinsic – and not external, through a bursary (Interview 2006g). Some historically disadvantaged students have a poor foundation in mathematics (being hitherto admitted to higher education with only a D symbol) and/or do not have an adequate command of the language of instruction (Interview 2006h). Special courses at universities are offered to improve students' language proficiency. Previously, institutions were not geared to offer supplementary programmes, although this has improved and many universities offer both foundation programmes and psychological support to historically disadvantaged entrants to help them cope with higher education (Interview 2006g; Interview 2006h). About half of the students who enrol for extended programmes eventually graduate (Interview 2006g). Previously, institutions also failed to attend to cultural diversity issues, but this is changing and higher education institutions are incorporating modules that address gender and cultural sensitivity (Interview 2006d; Interview 2006h). However, staff in most engineering departments remain predominantly white and male, and there are still not enough female role models in engineering departments at higher education institutions. Female staff at universities tend to reach a glass ceiling (Interview 2006i).

Employment

Chapter 1 discussed the employment of female and male engineers, technologists and technicians in the labour market from 1996–2005. On average, about 11.36% of women worked as engineers and technologists in the 1996–1999 period, but this figure dropped to 8.48% in the 2000–2005 period, despite the fact that the supply of female graduates (engineers and technologists) increased by an average annual rate of 13.72% between 1996 and 2005 (DoE 1996–2005). It is worth mentioning that the decrease in the employment of white female engineers and technologists over this period was primarily responsible for this negative trend. The same downward trend is evident for female engineering technicians. This is indicative of the continued under-representation of women in engineering in the South African labour market.

Differences in remuneration for women and men working at the same levels can be seen as an indication of discrimination in the labour market. Although there is still under-representation of women in engineering in the South African labour market, remuneration figures show that salaries of women in engineering in South Africa improved by an average annual rate of 16.12% between 2000 and 2005. However, in 2005 female engineering professionals still earned 17.80% less than their male counterparts.

There was negative growth in remuneration of managers in engineering over this period, but what is very encouraging is that remuneration of female managers in engineering slightly surpassed that of male managers over this period. It was confirmed during interviews that remuneration of women in engineering has indeed increased, and this applies especially to remuneration of black women as employers attempt to comply with equity requirements (Interview 2006j; Interview 2006k).

Conclusion

The capacity problem in engineering is a worldwide phenomenon. The under-representation of women in engineering specifically can be explained by the factors that influence them to choose an engineering career as well as the barriers that prevent them from fully participating in the labour market.

The data show that from 1996 there has been a significant increase in the number of female engineering graduations. However, female engineering professionals as a proportion of the whole decreased from 11.70% females in 1996 to only 8.64% females in 2005 (although there was 0.04% average annual growth in the number of female engineering professionals employed in the labour market over this period). One of the reasons for this trend may be the challenge of balancing work and family life. Most literature, as well as the interviews conducted by the researchers, reveals that this is one of the major barriers preventing female engineering professionals from full participation and progress in the labour market.

Although the proportion of women to men in engineering showed a decline in the 1996–2005 period, it looks as if efforts to attract more women (especially black women) to engineering studies have not been in vain, as both enrolment and graduation levels are on the increase. Enrolment and graduation of female engineering students are still lower than for males, but throughput figures for female engineering students are slightly better than those for males.

Various academic development programmes are opening up the engineering professions and increasing access in line with employment equity requirements. It appears that these efforts have been quite successful in addressing the quality of school leavers who make up the intake at higher education institutions, as throughput is increasing gradually. The poor quality of mathematics and science education at school level, coupled with the need to improve the school system is, however, still a challenge that should be among South Africa's highest national priorities.

The supply of female engineering graduates has increased significantly, but it would seem that many female graduates do not follow an engineering career after graduation. This may be due to various factors. It has been found that intrinsic motivation – as opposed to external motivation (such as bursaries) – is more important in choosing a career. Higher education institutions' selection of female engineering students with personalities suited to the field of study of engineering is important; comprehensive information with regard to the various engineering working environments needs to be communicated to allow aspiring engineering students to make well-informed choices.

Among the most significant barriers identified are balancing work and family life, gaining credibility and respect from male colleagues, the common phenomenon of dual-career relationships, lack of mentors and access to networks, and inequalities in remuneration and promotion opportunities. It would appear that women apply a range of strategies in an attempt to achieve a work–home balance.

South African policies and labour laws are in place to address equity and transformation, and aspiring female engineers are awarded bursaries, and offered the opportunity of participating in supplementary courses as part of their higher education studies. In addition, higher education institutions are addressing cultural diversity issues. The working environment in South Africa has changed over the past 10 years, but some sectors still need to transform to accommodate women. Equally, women themselves need to gain knowledge about the engineering working environment, and adapt and plan their careers accordingly.

CHAPTER 4

Conclusions

The capacity problem in engineering is a worldwide phenomenon, but issues such as migration, equity, lack of experiential training opportunities, shortage of mentors, and the expansion of infrastructure spending further complicate the South African situation.

There is positive growth in engineering employment, especially in the number of technicians, which bodes well for reaching the ideal ratio of engineer/technologist to technicians of 1:4. However, this study found that most engineering professionals were working in the financial and business services sectors, where they do not always apply their technical skills but rather assist with risk management in the industry through consulting agencies. It is suggested that incentives are necessary to attract these qualified engineering professionals back into the engineering environment.

The construction industry has grown over the last couple of years in response to infrastructure expansion. This has led to a demand in employment, especially in the public sector, but it will take time to overcome current skills shortages. Furthermore, given that construction work is cyclical, economic growth based on growth in the construction sector is not a sustainable strategy.

Progress in racial transformation is visible in graduation as well as employment figures. Engineering graduation figures in 2005 were two-thirds black students and one-third white. Although such transformation is encouraging, it is worth noting that there has been a major decline in the graduation of coloured and Indian engineering professionals in proportion to African engineering professionals.

Although progress has been made with regard to transformation in the labour market, a shortage of black engineering professionals will continue to be a problem for many years to come, as it takes time to gain work experience. Thus, the argument put forward here is that, rather than basing equity targets on the country's current demographics (90.31% black population and 9.69% white population [Quantec 2007]), it would be more appropriate to base *current* equity targets on the demographic profile of available engineering professionals (36.83% black and 63.17% white), and to base *future* equity targets on engineering graduations (two-thirds black and one-third white), as well as the number of suitable Grade 12 school leavers. Experienced engineering professionals are required to train and develop future engineering professionals – one cannot put old heads on young shoulders, as maturity improves over time. A major shortage of older and experienced professionals is evident, and this impacts on the transfer of skills to the younger generation of engineering professionals.

The proportion of women to men in engineering showed a decline in the 1996–2005 period and the under-representation of women in the engineering labour market remains an issue. Our research found that women and men each contribute to engineering in a unique way and female engineering students often outperform their male counterparts. Women are valuable in engineering as they bring a different angle in addressing challenges than men do, and men and women thus complement each other in the engineering environment. However, although more female engineering professionals are currently being supplied by higher education institutions than previously, there is still an insufficient number of experienced female engineers to assist with training and development. There are just not enough female engineering professionals to address employment targets. According to Professor Beatrys Lacquet (first female dean of the engineering faculty at Wits), it is also not necessary that half of all engineers should be women, as not half of all nurses are men.[121] Many female engineering graduates go into business and finance, as engineers have broad-based skills. It is important to attract engineering professionals who are working in other sectors, such as finance and business, back into the engineering environment where shortages are experienced (e.g. into ESKOM, civil engineering and local government) by addressing issues of salaries, working conditions and flexibility, especially to address women's needs with regard to planning of families and relocation.

The current increase in the number of engineering enrolments at universities and universities of technology is encouraging. However, the throughput rates to deliver engineering graduates are still low. Factors such as the poor quality of mathematics and science education at school level and the general low quality of the school system are challenges that need urgent attention if engineering skills shortages are to be addressed.

The significant number of people working in the engineering field without proper qualifications needs urgent attention, and opportunities for students to get working experience need to be provided. Another issue is the underutilisation of those with an engineering-related qualification working in non-engineering occupations. There are quite a number of people with engineering-related qualifications. Although it is not clear how many of these studied in a purely engineering field, interventions such as a transitional programme to retrain such people and provide them with experiential training where required, and a special wage dispensation to attract them back into the system, are recommended. An additional area of intervention is to address the training and certification of those with engineering-related fields of study who are currently unemployed.

Various stakeholders such as ECSA, professional associations and large employers have proposed plans to address the engineering skills shortages in South Africa. Key among these, both in terms of scope and detail, is the work of Lawless (2005).

The establishment of JIPSA formalised strategies to address the shortages of skills in general and engineering skills specifically. The JIPSA focus is, inter alia, on developing and recruiting engineering and technical skills and, in the short term, on developing a graduate employment strategy and recruiting retired specialists and expert mentors. The JIPSA interventions go as far as making a significant monetary contribution to some universities to train more engineering professionals. However, higher education institutions struggle to fill staff positions because remuneration of academics is only a third of what the private sector pays.[122] While the private sector supports JIPSA, and some companies have contributed through training programmes and placements, much more remains to be done by private firms if we compare local efforts with what is being done globally (The Presidency 2008).

121 Meer werk as mense, sê ingenieurs se eerste vroue-dekaan [More work than people, according to first female dean in engineering], *Rapport*, 25 March 2007.
122 Universities running on empty, *The Star*, 9 August 2008.

Lawless (2005) drafted a comprehensive list of interventions to address imbalances and blockages in the civil engineering profession in the long term. These suggested interventions are applicable to all engineering professions. The recommendations arising out of the present study are presented below; notably, these serve mainly to support rather than add to those of Lawless.

Recommendations

General education phase

The number of high quality Grade 12 learners competent in mathematics and physical science who can enrol for higher education training can be increased by the following strategies:

- Improve numeracy from Grade 1 through to Grade 12 with appropriate curricula.
- Increase the number of high quality mathematics and physical science teachers by improving their salaries.
- Improve the learning environment (schools) of learners by upgrading infrastructure. In his 2008 budget speech, the South African finance minister said that 'over the next three years, provinces have budgeted to spend over R18-billion on school infrastructure and equipment' (Institute for Future Research 2008).
- Increase the pool of competent black Grade 12 school leavers by identifying competent learners and giving them the opportunity to attend better schools.
- Create awareness of the engineering profession and opportunities through coordinated, nationwide career guidance initiatives at school level.

Higher education and graduate training phase

The throughput rate and the number of competent engineering graduates entering the labour market can be increased by adopting the following approach:

- Align supply and demand by disbursing higher subsidies to universities and universities of technology for scarce skills such as engineering.
- Develop a standardised model for selection of engineering students in order to ensure suitable students enter engineering training at higher education level.
- Increase investment in engineering students by providing sufficient bursary schemes that are sustainable for the duration of higher education training.
- Put monitoring systems in place to identify and address problems that students may encounter during the training period.
- Provide students with access to additional resources and support such as tutors, role models in industry, etc.
- Review curricula to better align education and the needs of the workplace.
- Improve the quality of staff, and the staff to student ratios.
- Encourage companies to enlist more National Diploma students on learnerships and provide such students with the opportunity to do their one-year experiential training so that they might graduate (the wage subsidy incentive currently being investigated by the Presidency may be one mechanism to encourage employers to provide experiential placements).
- Put efficient programmes in place to assist graduates with their transition from education to work.
- Encourage ECSA registration, to ensure the continued development of young graduates.

- Invest in and develop learnerships to ensure comprehensive workplace training for all engineering professionals.
- Establish a framework for the transfer of knowledge from older engineering professionals to the younger cohorts.

There are positive signs in the market in terms of education and training strategies. Some of the examples are the R543 million that ESKOM spent on training in the 2006/07 financial year.[123] Construction company Group Five's investment in training has almost doubled and its intake of students has trebled,[124] and the South African navy trains 650 technician recruits every year and many others are sponsored to study, according to Johannes Mudimu, South African navy chief.[125]

Furthermore, various government departments are currently offering bursary opportunities. The Department of Public Works is offering internship programmes to unemployed graduates with a BSc in mechanical, structural, civil or electrical engineering.[126] Municipalities are offering engineering bursaries – such as the initiative of the infrastructure and engineering business unit of the Nelson Mandela Bay municipality; in 2007, the unit was reportedly providing bursaries to 22 civil engineering students.[127] The Western Cape provincial government has doubled its number of engineering bursaries.[128]

There is a multimillion-rand programme to train students in mechatronics – a combination of electronic and mechanical engineering – at three of South Africa's universities of technology. The programme has been endorsed by the Department of Trade and Industry,[129] and is providing skills development in this field of engineering. As from 2007, in addition to their theoretical training in existing mechanical and electronic engineering courses, students receive in-service training of between 8 and 12 months in industrial companies. General Motors South Africa (GMSA) invested R1 million in the establishment of the Advanced Mechatronic Technology Centre, which allows students in the field to receive high quality training in the automotive sector – a good example of business providing the higher education sector with support.[130] GMSA has furthermore invested R3 million over a five-year period in the development of engineering expertise in mechatronics at the Nelson Mandela Metropolitan University by establishing a chair in mechatronics at that university.[131]

Professional phase

There are numerous strategies that can be applied in this phase to attract engineering professionals to the labour market and encourage them to remain there, as well as to attract and retain those currently working in non-professional occupations.

123 Power cuts blamed on skills blackout, *Business Report*, 22 January 2007.
124 Infrastructure spending is not on target – Group Five, *Business Report*, 14 August 2007.
125 Navy losing engineers to African oilfields, but training more, *Cape Times*, 23 February 2007.
126 The big job call-up, *The Star*, 1 February 2007.
127 Bursaries address shortage of skills, *The Herald*, 19 April 2007.
128 Engineering a response to SA's infrastructure woes, *Business Day*, 5 March 2007.
129 Offset programme gives birth to engineering course, *The Star*, 22 November 2006.
130 General Motors to invest R1m in future engineers, *The Herald*, 31 January 2007.
131 NMMU and General Motors South Africa establish chair in mechatronics, *GM South Africa media-on line*, 9 October 2008.

Remuneration
'Our project and engineering skills are all going to Abu Dhabi if we don't start offering incentives for our skills to stay here. Money talks; I think that is a natural progression of life,' according to André Vermeulen, a facilitator of eDegree's project management programme and a lecturer at the University of Johannesburg.[132]

The salaries and employment conditions of engineering professionals must be reviewed, especially at municipal level. Meaningful tax rebates could also be granted to engineering professionals in order to stem the outflow to other countries. Introducing a scarce-skills allowance could also attract engineering professionals to the labour market and help to retain them.

Dual-career paths
The approach of dual-career paths at organisations has proved to be an effective strategy for retaining technical skills. Following this approach, an engineering professional can have the same benefits and promotion opportunities working either as a manager or as a technical expert. In this way an engineering professional doing technical work could be on the same level of work and remuneration as a manager.

Flexibility, especially for women
In the case of female engineering professionals it is often found that a work–life balance is more sought after than pay increases alone. Better employment arrangements and conditions should be offered to female engineering professionals; for example, part-time and flexible working hours, career breaks and so on.

Opening up of immigration
The importation of skilled professionals not only assists in dealing with shortages but also allows for skills transfer,[133] but South African policies and practices do not make it easy to immigrate to this country.

The publication of skills quotas – which also allows for the issuing of permits, inter alia, to engineering professionals who enter the country without a formal job offer – is supposed to help source and attract skills from the international community. However, according to stakeholders this process is very cumbersome. Furthermore, the category 'science and engineering' is divided into 32 subcategories, and 5 000 places are allocated to civil engineers, but only 100 to chemical engineers (Centre for Development and Enterprise 2007). Experience further shows that if the quota system is not driven by an aggressive recruitment strategy, only a limited number of the required skilled people will make use of the opportunity.

Recruitment of retired engineering professionals
The initiative to recruit retired engineering professionals to work at municipal level, serving as mentors and training graduates, is coordinated by ECSA. This strategy is a good example of a home-grown solution and will facilitate the implementation of projects and develop the capacity needed to sustain these projects.

132 Why project managers are leaving SA, *Sunday Times*, 5 March 2006.
133 Importation of skills generates new cycle of skills transfer, *The Star*, 30 January 2007.

Recruitment of expatriates
There are several initiatives striving to recruit expatriate engineering professionals abroad. Homecoming Revolution is an online initiative that encourages – and assists – South Africans living abroad to return home. The Come Home Campaign, an initiative of trade union movement Solidarity in collaboration with the Company for Immigration, strives to bring South Africans working abroad back to the country. They help those who have previously emigrated from the country to find work in South Africa, register children born abroad, get immigration documents for spouses, have overseas qualifications evaluated locally, and more.

Creation of an employer brand/occupational brand
South African businesses are called on to attract and retain human capital. A key facet should be differentiation – in the form of a unique human resources value proposition and an employer brand that can make a company both different from and more competitive than other firms; the labour market should perceive the organisation as employer of choice, according to Professor Frank Horwitz, UCT Graduate School of Business.[134] Organisations that employ engineering professionals should apply this human resources strategy in order to attract and retain the engineering skills they need.

Adoption of a talent management approach
Engineering skills shortages are global. For South African companies to compete in this international labour market, they must change their approach and offer conditions that will attract and retain engineering professional talent.

Moratorium on employment equity in engineering scarce skills
Although the role of employment equity criteria in rectifying the racial imbalances of the past is widely accepted, there are some who argue that transformation policies are contributing to the shortage of engineering professionals in this country. Various authoritative sources indicate that restructuring and other measures associated with transformation have led to the exodus (out of the public sector, or the profession, or the country) of skilled engineers, when they could be playing an important role, including training and mentoring new black professionals. Such opinions have been articulated by the likes of Webster Ndodana, first black president of SAACE;[135] the SAIRR;[136] Ann Bernstein, executive director of the Centre for Development and Enterprise;[137] engineers seconded to struggling municipalities;[138] Dr Mamphela Ramphele, former UCT vice-chancellor and managing director of the World Bank;[139] Marius Fransman, MEC for transport and public works;[140] and Allyson Lawless, first female president of SAICE (Lawless 2005: 251; 2007: 79).

There needs to be an urgent and serious debate on a moratorium on employment equity in scarce skills. Senior staff need to be retained to address the current skills problem by shadowing junior engineers so that the latter might learn from more experienced engineers. 'We need to manage transformation responsibly by

134 Need for skills shortage solution, *The Herald (EP Herald)*, 30 November 2006.
135 'Gebruik die kundige ingenieurs' ['Use the expert engineers'], *Rapport*, 22 January 2006.
136 Beat the skills trap by employing mentors and mentees, *The Star*, 1 February 2007.
137 Our obsession with job equity could be costing our economy, *Daily Dispatch*, 18 June 2007.
138 Engineers warn of dire straits in local councils, *Business Day*, 2 March 2007.
139 Employment equity policy 'not a holy cow', *Cape Times*, 22 February 2008.
140 Engineering a response to SA's infrastructure woes, *Business Day*, 5 March 2007.

recognising and retaining exceptional engineering talent, irrespective of race or gender identity,' argues Danai Magugumela, black female engineer and CEO of BKS Consulting Engineers.[141] To manage transformation responsibly is to have knowledgeable staff with experience to assure service delivery and the transfer of skills.

141 Engineering transformation: 'Retain talent irrespective of race or gender', *Engineering News*, 23–29 June 2006.

APPENDIX

Table A.1 Undergraduate and postgraduate graduation trends in engineering fields of study (1996–2005)

Field of study	Rank	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average annual growth (%)
Electrical	1	1 538	1 488	1 503	1 347	1 176	1 388	1 610	1 785	1 917	2 150	15 902	3.79
Undergraduates	1	1 412	1 317	1 349	1 157	971	1164	1348	1517	1666	1890	13 791	3.30
Technician	1	742	745	754	733	439	644	777	890	1028	1 179	7 932	5.27
Technologist	2	169	139	139	95	90	135	159	155	207	264	1 551	5.11
Engineer	1	501	433	456	328	442	386	412	471	431	447	4 308	–1.25
Postgraduates	1	126	171	154	191	205	223	263	268	250	260	2 111	8.37
Civil	2	817	747	767	774	722	781	861	843	1004	1015	8331	2.44
Undergraduates	2	725	648	683	694	639	674	731	720	875	898	7 285	2.40
Technician	2	371	285	341	426	395	348	397	435	542	566	4 106	4.79
Technologist	2	182	179	187	135	94	148	151	139	186	209	1 608	1.51
Engineer	4	171	184	155	132	150	178	184	147	147	123	1 571	–3.60
Postgraduates	2	92	99	84	80	83	107	130	124	129	118	1 046	2.74
Mechanical	3	871	849	763	623	559	705	688	707	764	855	7 385	–0.20
Undergraduates	3	803	754	702	524	453	603	587	610	616	743	6 395	–0.86
Technician	3	362	355	337	223	129	222	250	281	278	397	2 833	1.04
Technologist	3	170	147	123	90	79	98	69	89	83	105	1 052	–5.21
Engineer	2	271	252	242	210	246	283	268	241	256	241	2 509	–1.31
Postgraduates	3	69	95	61	99	106	102	100	98	148	113	991	5.68
Chemical	4	551	462	525	356	532	600	581	620	744	760	5 731	3.63
Undergraduates	4	496	422	459	305	437	516	498	541	664	640	4 977	2.87
Technician	4	228	182	180	96	146	223	235	230	336	278	2 135	2.23
Technologist	4	83	73	56	48	53	80	64	113	135	120	825	4.18
Engineer	3	184	167	223	160	239	213	200	199	192	241	2 017	3.03
Postgraduates	4	56	40	65	51	95	84	83	78	80	121	754	8.97
Industrial	5	410	467	327	268	235	274	288	314	391	456	3 430	1.19
Undergraduates	5	347	397	264	197	154	201	208	233	309	372	2 680	0.77
Technician	5	226	257	147	62	35	49	47	64	88	97	1 072	–8.99
Technologist	5	55	70	38	43	42	58	84	83	151	170	793	13.44
Engineer	5	67	70	79	92	77	93	76	86	70	106	816	5.23
Postgraduates	5	63	71	63	71	81	74	80	81	82	84	750	3.27
Mining	6	169	191	252	165	106	95	97	106	142	231	1 553	3.57

Field of study	Rank	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average annual growth (%)
Undergraduates	7	125	142	172	99	42	39	47	53	65	156	940	2.49
Technician	8	32	47	56	31	2	6	14	18	22	49	277	4.85
Technologist	6	62	65	85	24	0	0	0	0	0	57	293	–0.93
Engineer	6	31	30	31	44	40	33	33	35	43	50	370	5.46
Postgraduates	6	44	49	80	66	64	56	50	53	78	75	613	6.24
Metallurgical	7	152	114	113	90	101	120	90	116	138	237	1 272	5.06
Undergraduates	6	137	95	102	78	85	108	77	100	111	196	1 089	4.03
Technician	7	75	45	55	44	42	53	40	62	60	110	587	4.36
Technologist	7	19	20	21	23	24	32	21	24	42	58	284	13.20
Engineer	8	43	30	25	11	19	23	16	14	9	28	218	–4.76
Postgraduates	8	15	19	11	12	17	12	13	16	27	41	182	12.06
Materials	8	97	101	130	106	72	77	91	89	96	106	965	1.00
Undergraduates	9	71	78	98	66	38	50	68	65	83	79	697	1.21
Technician	9	33	39	66	12	10	15	20	10	22	20	246	–5.44
Technologist	8	28	28	23	43	13	22	36	32	28	30	283	0.77
Engineer	9	10	11	9	12	16	13	12	24	33	29	169	12.63
Postgraduates	7	26	23	32	39	34	27	23	24	13	27	268	0.40
Surveying	9	128	116	91	110	100	73	70	77	72	86	924	–4.28
Undergraduates	8	116	110	81	108	83	68	67	75	69	83	859	–3.60
Technician	6	75	78	54	87	64	53	49	51	43	63	616	–1.81
Technologist	12	17	4	2	6	3	4	8	12	16	7	80	–9.54
Engineer	10	24	28	25	15	16	11	10	11	10	13	163	–6.60
Postgraduates	12	12	6	10	2	17	6	4	3	4	3	65	–14.35
Computer	10	47	48	102	3	15	13	60	111	179	151	729	13.91
Undergraduates	10	44	45	97	0	4	3	45	88	139	112	577	10.88
Technician	13	36	30	86	0	4	2	0	0	0	0	158	0.00
Technologist	13	8	15	11	0	0	1	5	8	14	1	63	–20.63
Engineer	7	0	0	0	0	0	0	40	80	125	111	356	***** 40.31
Postgraduates	9	3	3	5	3	11	10	15	23	40	40	152	34.08
Engineering mechanics	11	0	0	0	65	67	14	133	65	102	91	536	*** 5.63
Undergraduates	11	0	0	0	60	67	14	131	63	101	85	520	*** 5.82
Technician	8	0	0	0	34	53	1	94	12	56	28	277	*** –3.36
Technologist	9	0	0	0	26	14	14	37	50	37	48	226	*** 10.47
Engineer	13	0	0	0	0	0	0	0	0	8	9	17	****** 12.50
Postgraduates	15	0	0	0	5	0	0	2	2	1	6	16	*** 3.09
Environmental	12	0	0	0	52	57	59	39	48	43	20	318	*** –15.01

Field of study	Rank	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average annual growth (%)
Undergraduates	16	0	0	0	24	26	32	27	34	29	11	181	*** –12.38
Technician	15	0	0	0	10	8	9	16	20	12	0	75	0.00
Technologist	11	0	0	0	13	18	23	11	14	17	11	106	*** –3.63
Engineer	17	0	0	0	0	0	0	0	0	0	0	0	0.00
Postgraduates	10	0	0	0	29	31	28	12	14	14	9	136	*** –17.56
Agriculture	13	32	35	21	26	22	33	26	35	33	34	297	0.50
Undergraduates	15	29	31	15	17	16	17	21	21	16	19	203	–4.82
Technician	19	6	9	2	15	0	1	6	7	3	5	55	–2.01
Technologist	16	0	7	0	0	0	5	2	1	1	0	15	0.00
Engineer	11	23	15	13	2	16	12	13	13	13	14	133	–5.68
Postgraduates	11	3	3	6	9	6	16	5	14	17	15	94	19.16
Marine	14	13	7	26	17	13	25	36	49	51	50	286	16.15
Undergraduates	12	13	7	26	16	13	25	36	49	51	50	285	16.15
Technician	12	12	6	23	11	10	20	26	17	22	25	171	8.50
Technologist	10	1	1	3	5	3	5	10	32	29	25	114	43.00
Engineer	17	0	0	0	0	0	0	0	0	0	0	0	0.00
Postgraduates	19	0	0	0	1	0	0	0	0	0	0	1	0.00
Bio-engineering	15	0	0	0	5	8	54	72	68	12	17	236	** 22.63
Undergraduates	15	0	0	0	0	0	52	69	64	10	9	203	**** –36.42
Technician	10	0	0	0	0	0	52	69	64	10	9	203	**** –36.42
Technologist	20	0	0	0	0	0	0	0	0	0	0	0	0.00
Engineer	17	0	0	0	0	0	0	0	0	0	0	0	0.00
Postgraduates	14	0	0	0	5	8	2	3	4	2	9	33	** 9.25
Graphics	16	0	0	0	75	11	4	21	29	29	60	229	** –3.77
Undergraduates	13	0	0	0	75	10	1	21	29	29	60	225	** –3.77
Technician	11	0	0	0	75	10	1	14	24	29	38	190	** –10.84
Technologist	14	0	0	0	0	0	0	7	5	0	22	34	***** 46.48
Engineer	16	0	0	0	0	0	0	0	0	0	0	1	0.00
Postgraduates	18	0	0	0	0	1	3	0	0	0	0	4	0.00
Aerospace/ aeronautical	17	84	57	14	5	5	5	7	11	16	9	211	–21.94
Undergraduates	14	83	54	13	5	4	4	7	11	16	9	206	–21.87
Technician	14	77	48	0	0	0	0	0	0	0	1	126	–38.29
Technologist	17	6	2	0	0	0	0	0	0	0	0	8	0.00
Engineer	12	0	4	13	5	4	4	7	11	16	8	72	* 9.05
Postgraduates	17	1	3	1	0	1	1	0	0	0	0	5	0.00
Manufacturing	18	0	0	0	19	19	9	18	4	0	16	83	** –2.96

Field of study	Rank	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average annual growth (%)
Undergraduates	17	0	0	0	16	17	8	18	4	0	16	78	** 0.53
Technician	16	0	0	0	16	15	8	18	3	0	15	74	** –0.55
Technologist	18	0	0	0	0	2	0	0	0	0	1	3	*** –12.94
Engineer	17	0	0	0	0	0	0	0	0	0	0	0	0.00
Postgraduates	16	0	0	0	4	2	1	0	0	0	0	6	0.00
Engineering science	19	0	0	0	7	13	2	31	13	4	1	70	** –28.99
Undergraduates	18	0	0	0	3	0	0	27	3	3	0	35	0.00
Technician	18	0	0	0	0	0	0	11	0	3	0	14	0.00
Technologist	15	0	0	0	0	0	0	16	3	0	0	19	0.00
Engineer	15	0	0	0	3	0	0	0	0	0	0	3	0.00
Postgraduates	13	0	0	0	4	13	2	4	10	1	1	35	** –23.01
Automotive	20	0	0	0	5	5	6			1	2	19	** –17.41
Undergraduates	20	0	0	0	3	0	0	0	0	1	2	6	** –8.91
Technician	20	0	0	0	3	0	0	0	0	0	0	3	0.00
Technologist	20	0	0	0	0	0	0	0	0	0	0	0	0.00
Engineer	15	0	0	0	0	0	0	0	0	1	2	3	****** 66.67
Postgraduates	15	0	0	0	2	5	6	0	0	0	0	14	0.00
Instrumentation	21	0	0	0	6	0	0	1	2	4	0	12	0.00
Undergraduates	19	0	0	0	6	0	0	1	1	0	0	7	0.00
Technician	19	0	0	0	6	0	0	0	0	0	0	6	0.00
Technologist	19	0	0	0	0	0	0	0	1	0	0	1	0.00
Engineer	17	0	0	0	0	0	0	0	0	0	0	0	0.00
Postgraduates	17	0	0	0	0	0	0	0	1	4	0	5	0.00
Geological	22	0	1	1	2	1	0	0	0	0	1	7	0.00
Undergraduates	21	0	0	0	1	0	0	0	0	0	0	1	0.00
Technician	21	0	0	0	1	0	0	0	0	0	0	1	0.00
Technologist	20	0	0	0	0	0	0	0	0	0	0	0	0.00
Engineer	17	0	0	0	0	0	0	0	0	0	0	0	0.00
Postgraduates	16	0	1	1	1	1	0	0	0	0	1	6	0.00

Field of study	Rank	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Average annual growth (%)
Other engineering & engineering technology		150	187	147	163	113	126	169	164	199	220	1 639	4.36
Undergraduates		83	88	47	109	51	59	64	44	90	79	713	–0.57
Technician		56	63	39	61	23	5	21	9	11	32	318	–6.06
Technologist		12	7	3	12		16	8	13	8	2	81	–18.39
Engineer		15	19	4	36	27	38	36	23	70	45	314	13.07
Postgraduates		67	98	101	54	62	67	105	120	109	141	925	8.65
Total graduation		**5 059**	**4 870**	**4 781**	**4 289**	**3 951**	**4 463**	**4 989**	**5 255**	**5 939**	**6 568**	**50 164**	**2.94**
Total undergraduates		**4 483**	**4 188**	**4 108**	**3 562**	**3 109**	**3 636**	**4 097**	**4 323**	**4 941**	**5 506**	**41 952**	**2.31**
Total postgraduates		**576**	**682**	**673**	**728**	**842**	**826**	**892**	**932**	**998**	**1 063**	**8 212**	**7.05**

Note:
** 1997–2005; ** 1999–2005; *** 2000–2005; **** 2001–2005; ***** 2002–2005; ****** 2004–2005*
The term 'Rank' refers to the position obtained according to the number of graduates in the specific field of study, and according to undergraduate, postgraduate, engineer, technologist and technician graduations.

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