The role of a department of metallurgical engineering in the South African metallurgical industry

by P. C. Pistorius*

Synopsis

The nature of metallurgical engineering—applying and optimising chemical and physical processing of ores into useful materials—is reviewed. Important trends that shape the context in which metallurgical engineers practise are identified — increased global production of primary metals, declining prices, environmental constraints, and increased property requirements of materials. A successful department of metallurgical engineering is one which employs a team of academic leaders to develop graduate engineers who are productive across the full range of metallurgical processing.

Keywords: metallurgical engineering, primary metals, commodity prices, processing

Introduction

The University of Pretoria has an independent Department of Materials Science and Metallurgical Engineering, and presents Metallurgical Engineering as a degree programme. These two entities are viable because each has a distinct identity, and because there is a demand for them. One of the tasks of a departmental head, and the other departmental staff certainly, is to define and build this identity.

On my appointment as head of this department in 2002, and in the inaugural address that followed at the end of that year, it was necessary to reflect on the department's task and position. It is indeed required by this university that the inaugural address covers the development of the discipline, how the discipline serves the community, and new vistas[1]. In this paper, I present an overview of these issues.

Three main points are covered: first, the ways in which metallurgical engineers are distinct from their colleagues from other engineering disciplines; second, the trends in the local metallurgical industry; and, third, the specific character of this academic department.

What is a metallurgical engineer?

All engineers solve techno-economic problems through the scientific and creative use of information. The university training that enables engineers to perform such problem solving is described in detail by the Engineering Council of South Africa (ECSA). Briefly, the training programme for all engineers covers basic science, mathematics, computing, engineering sciences, engineering design and synthesis, and complementary studies (these give a broader perspective of, amongst others, economics, impacts on society, communication, and social sciences)[2]. This much is common to all undergraduate engineering training; the distinction between the various disciplines is based on the detail of the engineering sciences content (engineering sciences should constitute at least 30% of the programme;[2] in this department it is just over 40%).

As an indication of the nature of the distinctive engineering science content, Table I gives the 'indicative guide' of ECSA to the desired specialized content of the training programme of metallurgical engineers. Clearly, these are very broad guidelines, which can be met in many different ways. I will return to the specific approach of this department later in this paper. Here, I present a pragmatic approach to defining a metallurgical engineer, which is to consider the context in which metallurgical engineers practise. This context renders metallurgical engineering unique: namely, processing from a mineral to an intermediate metallic product.

Metallurgists use chemical and electro-chemical reactions at high or low temperatures to free metals from compounds, and to purify them. Physical properties are the basis of mineral separation; physical processing of metals and alloys imparts the final shape and mechanical properties. This combination of applied chemistry, applied physics, and

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Table I

Specialized engineering science content of metallurgical engineering, based on the guidelines of the Engineering Council of South Africa[2]

Heat Transfer	Kinetics (metallurgical)	Mass transfer	Material processes
Materials	Momentum transfer	Particulate systems	Thermodynamics

quantification of these is the diverse and unique field of the metallurgical engineer. This diversity is also reflected in the guidelines of ECSA on practical training in metallurgical engineering, which is acceptable for registration as a professional engineer.[3] (According to these guidelines, acceptable training includes exposure to metallurgical plant operation; specification, design, erection, and commissioning of metallurgical plants; and research, development, and technology transfer in minerals engineering, hydrometallurgy, pyrometallurgy, and materials engineering.)

Figure 1 summarizes three metal extraction routes, to illustrate some of the principles (and processes) that are used. In the case of ironmaking and steelmaking (Figure 1 a), the primary aim is to break the chemical bond between iron and oxygen in the ore; the ore largely consists of iron oxide. Hence the processing route involves chemical reactions, until liquid steel has been produced. Further processing (continuous casting, hot and cold rolling) are examples of the 'applied-physics' side of metallurgy.

In contrast with the highly concentrated iron ore, even rich gold and platinum ores contain only a few parts per million (by mass) of the desired elements—so the primary task in extracting these elements (Figures 1 b and c) is to increase their concentration, a task equivalent to the metaphorical finding of a needle in a haystack. Metallurgical approaches would be to burn down the haystack, finding the needle in the ashes (pyrometallurgy); chopping up the haystack—with contained needle—finely, treating the entire volume with acid to dissolve the needle, and finally plating out the metal of the needle from the acid solution (hydrometallurgy); or passing the haystack through a magnet to retrieve the needle (minerals processing).

Extraction of platinum in fact involves a combination of all three of these steps, with minerals processing (flotation, physical separation relying on surface chemistry) serving to increase the concentration of the platinum group elements (PGEs) by one-and-a-half orders of magnitude (see Figure 1b), with subsequent pyrometallurgical concentration of the PGEs into molten sulphides (matte). (In a complex series of steps not shown in the figure, the upgraded matte is treated hydrometallurgically to extract all the valuable metals at the required purity levels.)

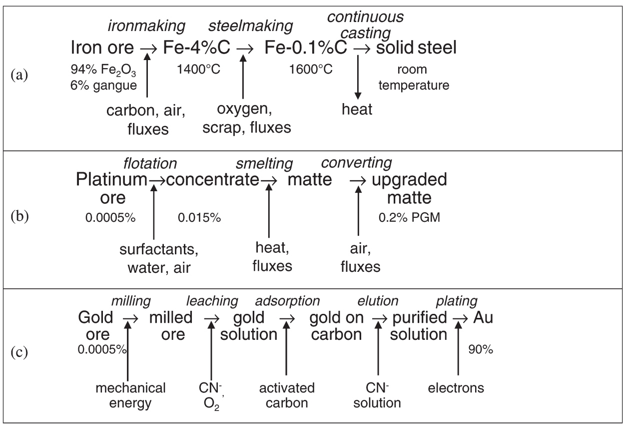


Figure 1—Summarized extraction routes for (a) steelmaking from iron ore, (b) smelting of platinum-bearing ore, and (c) leaching and electrowinning of gold

The common thread of these and other examples of metals processing is that a metallurgical engineer applies basic knowledge (of chemical thermodynamics, kinetics, electrochemistry, mechanical metallurgy, and so forth) to recover metals from their ores, to refine the metals, to process metals and alloys mechanically, and to protect the metals and alloys against mechanical failure and corrosion – using a combination of applied physics and applied chemistry. But the task is more than simply extracting the metals: extraction must be performed in an economical, safe, and environmentally acceptable way. These three requirements are growing in importance. In the next section I review some of the economic issues.

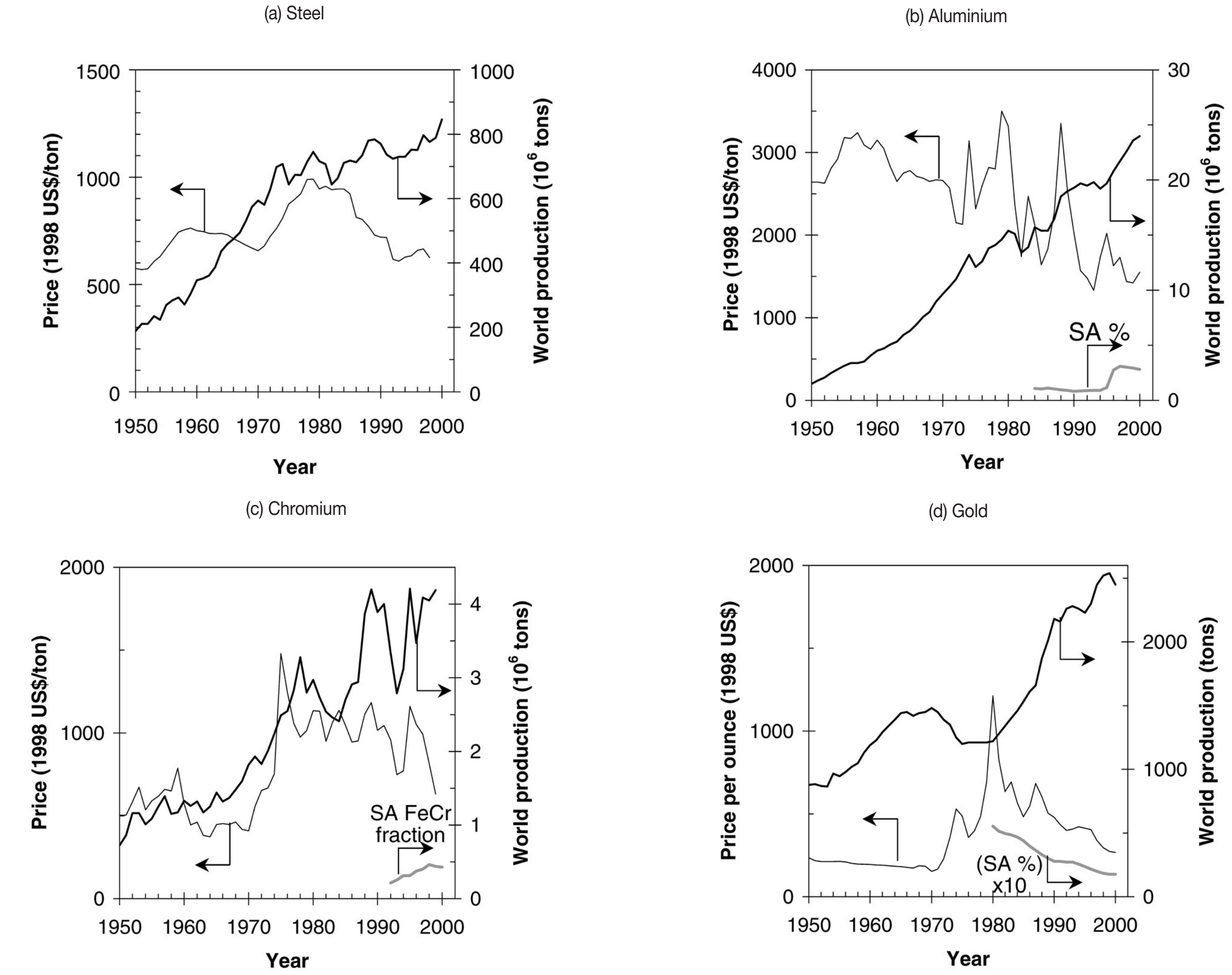
The broader context of the metallurgical industry

A remarkable feature of nearly all primary metals is the extent to which their prices—while fluctuating strongly from year to year—have shown a clear declining trend over time, even as production has risen strongly.[4] While Simon *et al.*[4] summarized data for several metals over nearly 150 years of production, I limit the data presented here to steel, aluminium, chromium, gold, and platinum, for the past 50 years (up to 2000). These data are presented in Figure 2 a) to e); in all cases, the sources of the data are the mineral commodity reports published by the United States Geological Survey (USGS)[5] and the annual reports of the (South African) Department of Minerals and Energy.[6] Note that the prices are quoted in constant 1998 US$ (that is, prices corrected for inflation); note also the very large differences in absolute production rates (for example, steel is produced in by far the largest tonnages of any metal).

The differences between the individual metal production rates aside, all metals show long-term increases in production rate: more metals are being produced and used now than at any previous time. Despite the increased production, prices are in long-term decline: with the exception of platinum, the price of the metals have generally halved (in real terms) in the past 20 years. The declining prices indicate that, at least by this economic measure, metals are becoming less scarce.[4] Not only the declines in prices indicate this; the known reserves of metals have increased with time as well.[4]

This contrasts with the reality that this planet contains a finite amount of metals—'reserves' refer to the amount of metal that could be economically extracted at a given time, and improved processing has meant that lower-grade ores have become and continue to become part of the reserve base. Sustained lowering of prices has only been possible through continued technological improvements in metallurgy.

Unlike the fairly uniform picture of increased production and declining prices, South Africa's share of the global production of metals has changed in different directions for the different metals. South Africa is the world's dominant producer of ferrochromium and platinum (Figure 2 c and e; note the remarkable recent increase in this country's share of



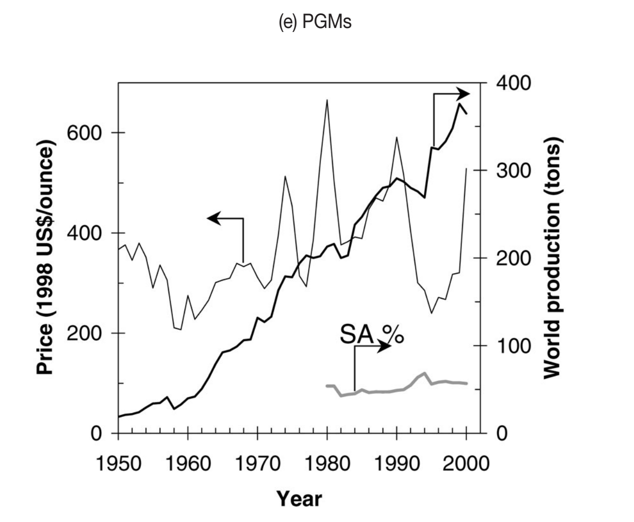


Figure 2—World production, prices (in constant 1998 US$), and South Africa's share of world production of five primary metals: (a) steel, (b) aluminium, (c) chromium, (d) gold, and (e) platinum-group metals. Compiled from data of the USGS and the DME.[5,6]

global ferrochromium production), it remains a large producer of gold (but accounting for only some 17% of world production, down from 50% at the start of the 1980s), currently produces about 3% of the world's primary aluminium (the step change in the mid-1990s is the effect of the commissioning of the Hillside smelter in Richards Bay), and only approximately 1% of the world's steel (not shown in Figure 2a).

Despite the varied trends in South Africa's proportion of world production, this country remains a major source of primary metals. This is confirmed by Figure 3, which indicates South Africa's share of global production and reserves of several commodities. This country's exceptional concentration of several metals is evident.

These, then, are the first three elements of the broader context of metallurgy: declining real prices, increasing production, and a large fraction of the world's resources in this country. A corollary to the last point is the importance of primary metals to the South African economy. Figure 4 confirms this, by plotting the contributions of primary metals, and metals-based manufacturing to gross domestic product.

A last element of the South African metallurgical environment that I wish to highlight is that of energy. For many years, the cost of electricity has been low in this country. This has driven several developments, including aluminium smelting (Figure 2b), which was established here despite the absence of local bauxite ore of suitable quality. Relevant factors are the growth of energy-intensive industries to utilize available electrical power, the inherently high energy requirements of primary metals, production, and the increased energy requirement of gold production from deeper mines. (From 1975 to 1995 the electrical energy used

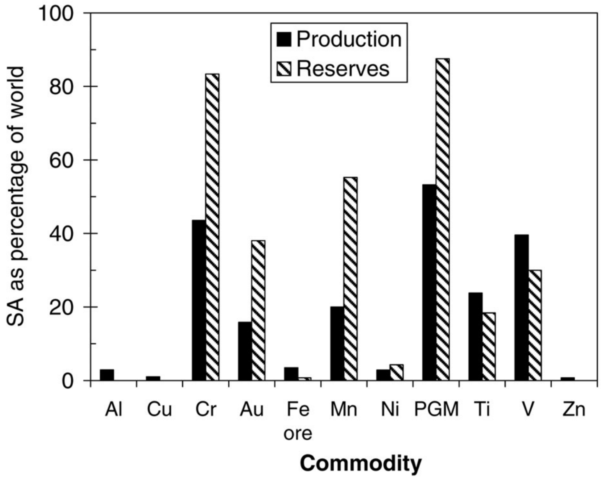


Figure 3—South Africa's share of world production of primary metals, and of the world's reserve base

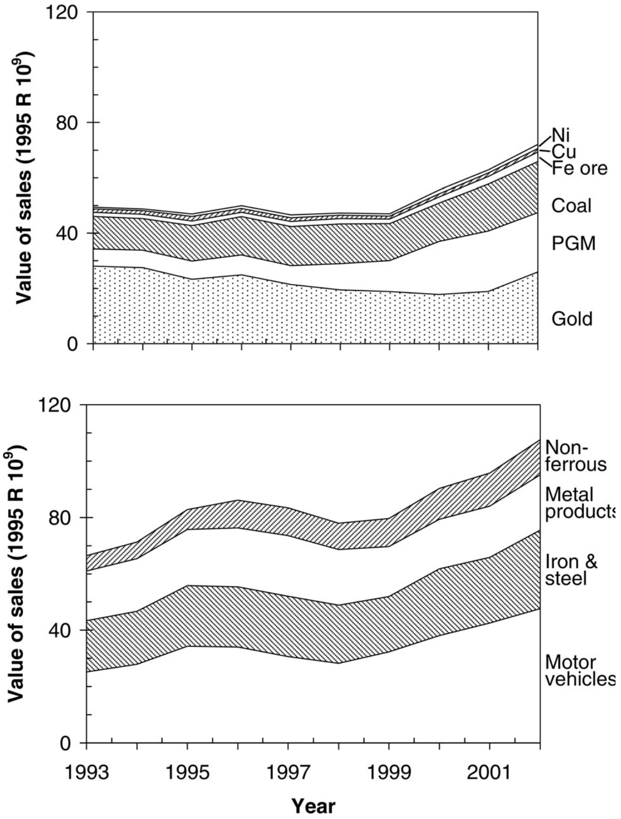


Figure 4—Contribution of primary metals (upper half of figure) and metals-based manufacturing (lower part) to South Africa's gross domestic product. Values plotted in constant 1995 rands. Note that the total gross domestic product in 2002 was some R650 billion. Source: Statistics South Africa[7]

per ton of gold more than doubled, from some 65 TJ to 150 TJ[8].) A result is that 'energy intensity' of the South African economy is high—as shown in Figure 5 a), the energy consumed per unit of gross domestic product is approximately three times as high as that of Australia and the United States of America; however, it must be noted the per capita energy consumption is still considerably lower than in those two countries.[9] The mining and metallurgical industry

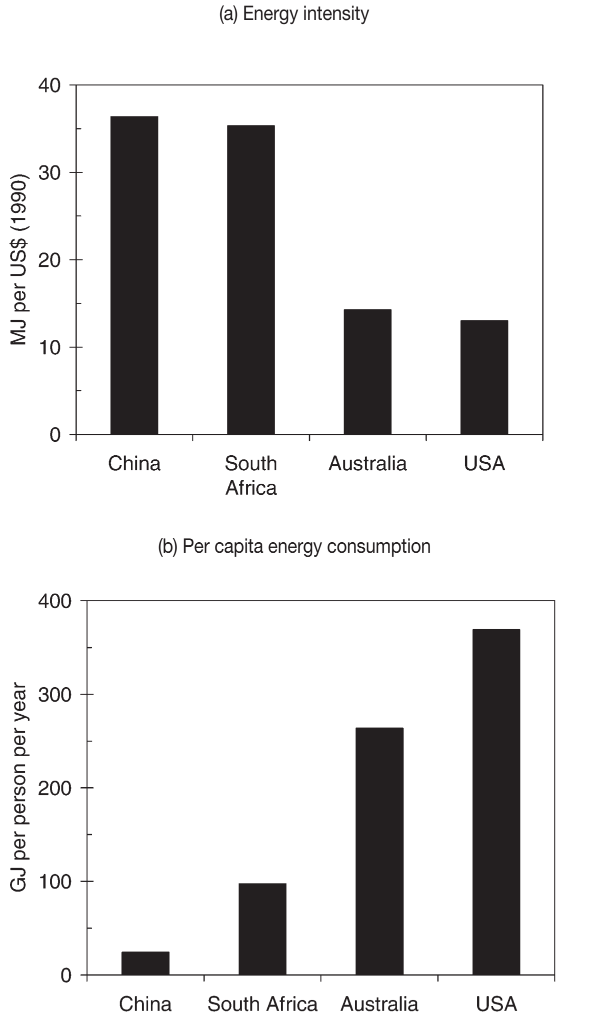


Figure 5—Energy intensity of the South African economy (1999 figures).[9] (a) Energy consumed per US$ of Gross Domestic Product. (b) Energy consumption per person per year

accounts for a large part of energy consumption (Figure 6).[8]

Much of this energy usage is met by coal-burning power stations—with the result that South Africa was responsible for 1.6% of the world's energy-related carbon emissions (1999 figure).[8] The worldwide concern with greenhouse emissions, and the aging power stations in South Africa, both imply that the availability of low-cost electrical power should not be taken as a given in future.

To summarize this section, the one fixed point in the metallurgical landscape is this country's disproportionate share of mineral resources. Little else can be taken as fixed—production rates are increasing while prices are dropping, and the strong reliance on low-cost energy may have to change in future. What is clear is that there are excellent opportunities for metallurgical engineers in this industry—the current wave of expansions, new plants, and plant upgrades in the platinum, ilmenite smelting, stainless steel and gold industries serves as an example of these opportunities (refer for more examples to a recent project investment survey[10]).

The 'Mining Charter' for South Africa, as adopted at the end of 2002, aims to create a South African mining (and metallurgy) industry with broader-based ownership.[11] This

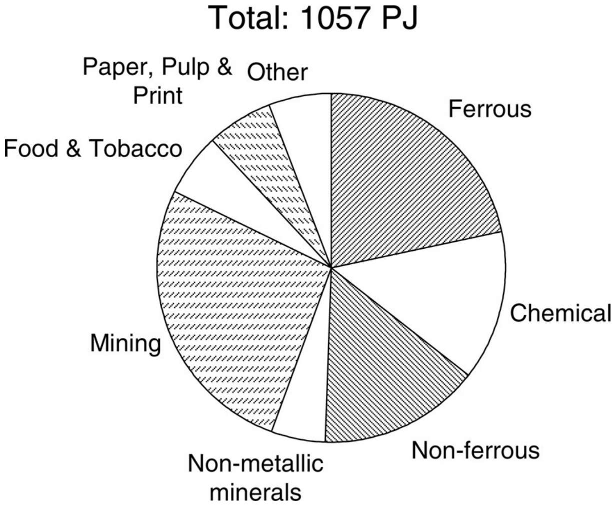


Figure 6—Industrial users of final energy in South Africa, in 2000 (industrial use was approvimately one-third of all final energy consumption)[8]

development will also offer specific opportunities for metallurgical engineers (and bodies offering training in this discipline): mention is made in the Charter of, amongst others, the need for skills development and the importance of beneficiation.

The world of processed materials is also changing. As one example, steel today is a very different material from what it was a few decades ago, with regards to impurity levels and properties. The 'ULSAB' (ultra-light steel automobile body) research programme is one instance of this; the programme has shown the remarkable reduction in mass that can be achieved, while maintaining or improving rigidity and crash safety, by the extensive use of higher-strength steels of controlled microstructure.[12] Dual-phase and 'TRIP' (transformation-induced plasticity) steels have significantly better ductility at a given strength level than conventional high-strength steels. These steels—likely to be of increasing importance in newer motor vehicle models—require close control of temperature and deformation during strip rolling.

This changing metallurgical landscape requires special skills from metallurgical engineers. The next section highlights some aspects of the approach of this department to training suitably skilled engineers.

What is a department of metallurgical engineering?

An academic department that offers training programmes in metallurgical engineering must equip graduates with skills that will remain useful throughout their careers, during which time the metallurgical industry will no doubt change in many ways. This department trains engineers to be productive in our diverse and changing industry through integrated undergraduate training, which covers the full spectrum of metallurgy, emphasizing long-term skills (fundamental knowledge, and a critical approach), with increased depth provided on postgraduate level (through research and continued education).

'Integrated training' means that all of metallurgy is covered—from minerals processing, through hydrometallurgical and pyrometallurgical extraction, to metals processing, and corrosion. Given this wide spread, not every topic can be covered in depth, hence the emphasis on skills of thinking, analysis, synthesis, and communication, rather than encyclopaedic knowledge.

The department needs to interact strongly with local industry, for three main reasons. First, most students in metallurgical engineering hold bursaries from local companies (data on this are presented below). Second, relevance of our research programme, and funding of this research, is only possible in cooperation with industry. Third, an important role of the department is to act as a technical resource for industry, a source of information and expertise. This is only possible with a strong grouping of academic staff, a point to which I return later. Interaction with industry is formalized and facilitated through an advisory board of senior technical staff from industry; the board meets twice per year to advise on all departmental activities.

First, though, some data on student numbers: this department exists primarily to train metallurgical engineers, and all our activities must follow from the mission to provide excellent education.[13]

Figure 7 summarizes the number of new first-year registrants in metallurgical engineering, the demographic and gender distribution of these students, and the number of these students who hold bursaries on the day of first registration. A number of trends are worth highlighting. The student intake fluctuates somewhat, but is on average 25. Most of these students hold bursaries when they arrive at the university: for the period shown, this proportion was 68%. This implies that many of the changes in the student body (number of students, and demographic and gender composition) are the result of the decisions made by industry when bursaries are awarded. A striking change is the sharp increase in the number of black students from 2001. This followed the decision of this department to present its undergraduate programme in English only, from that year. This has improved access by those who are not fluent in Afrikaans, while also easing the transition to the (international) metallurgical industry by students from an Afrikaans background.

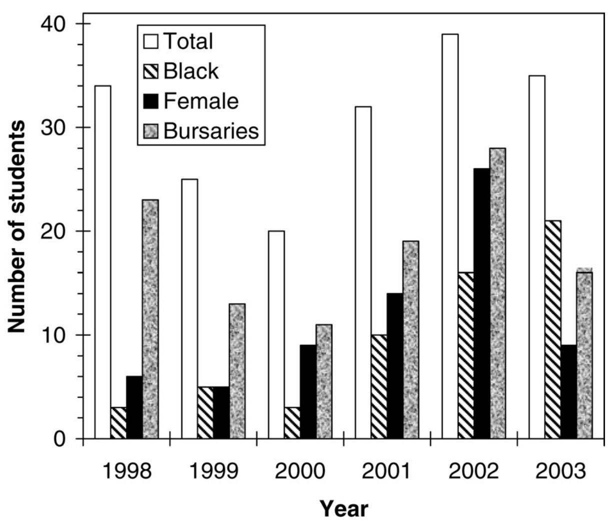


Figure 7—Total number of new first-year registrants in Metallurgical Engineering at the University of Pretoria for the years 1998–2003. The numbers of black students, female students, and students who hold a bursary upon registration are also shown

Development of undergraduate students involves more than offering a programme that meets the requirements of ECSA (Table I), covers the full spectrum of metallurgy, and provides exposure to industry. It also includes activities to develop graduates who are 'world-class people'.[13] Broader social and cultural activities are organized through the Metallurgical Students' Association.

With regards to training of postgraduate students, numbers have risen strongly in the recent past (Figure 8). Note in this figure that the 'honours' programme consists of taught coursework, whereas the master's degree and Ph.D. programmes are research based. Possible reasons for the strong growth in student numbers is the development of longer-term research programmes (rather than one-off projects) in the broad areas of pyrometallurgy, minerals processing and hydrometallurgy, and physical metallurgy. Also, technikon graduates can now follow the honours programme (with a view to continuing research on the master's and doctoral levels). In addition, all honours coursework is now presented in block-release format, which is convenient for engineers in full-time employment.

Research is a large part of this department's interaction with industry, and research provides excellent further training of postgraduate students. Attracting postgraduate students and maintaining research programmes, are hence viewed as essential.

There are some important developments in this regard. We now devote considerably more resources to teaching and research in minerals processing than in the past—since for much of the current expansions (in extraction of platinum-group elements, and heavy minerals beneficiation, as examples) minerals processing influences process efficiencies directly. This emphasis on minerals processing is an expansion—we continue to maintain strong teaching and research in hydrometallurgy, pyrometallurgy, and physical metallurgy. The companion papers in this volume give a small sample of these research programmes.

In physical metallurgy, the recent establishment of the Industrial Minerals and Metals Research Institute (IMMRI) by the transfer of equipment and staff from Iscor to this department has greatly expanded our access to equipment for electron microscopy, surface analysis, and thermomechanical simulation. The brief of the institute is to provide technical support to the metals processing industry (with a current emphasis on steel), and to research metals processing.

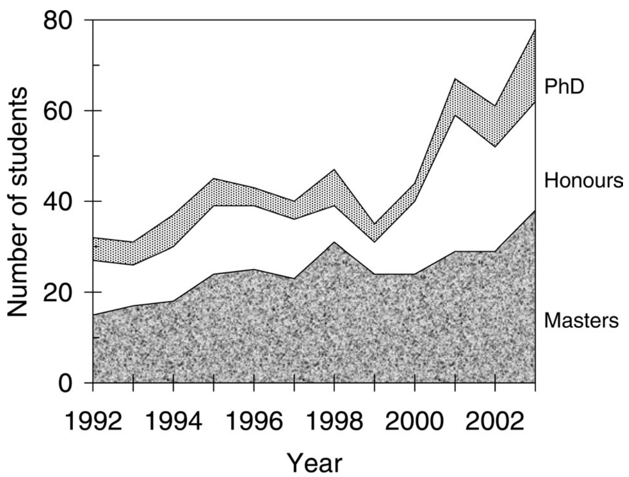


Figure 8—Total number of students registered annually for postgraduate study in the Department of Materials Science and Metallurgical Engineering, over the past decade

Dedicated academic and support staff are needed for these programmes. Indeed, in the anatomy of the university, students are seen as its lifeblood, and staff its backbone.[13] The backbone of this department includes eleven academic staff members. This group is responsible for the teaching and research, which covers all of metallurgical engineering. All academic staff members hence need to be, or are developing into, academic leaders in metallurgy.

Success factors for the department

I conclude by reiterating what some of the important success factors for the department are. Metallurgical engineers change the world through operating and optimizing plants that chemically and physically process ores into materials. This department is viable inasmuch as it provides a home to the metallurgical engineer for undergraduate and graduate training, and for research. Research supports the metallurgical industry by investigating fundamentals, and by providing graduate training. The diverse but interconnected field of metallurgical engineering is best supported by a single department, which covers all the strands of metallurgy, and which is strongly linked to industry.

Acknowledgements

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