Technical skills—a major strategic issue

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Synopsis

A shortage of technical skills in all areas of the mining industry is being experienced worldwide. This has significant consequences for design, operations, productivity and safety and, therefore, needs to be seriously addressed, both in the short and longer term. It is therefore both a strategic and a tactical issue. Importantly, however, since mining is a long-term business, the shortage of skills must be dealt with from a strategic point of view to ensure the supply of the necessary skills for future mining. This paper will deal specifically with the provision of high level technical skills, that is, university graduates in mining engineering, and the outlook for the institutions that are currently producing such graduates.

Introduction

The world shortage of skills in all technical fields is well known and mining is no exception. In mining, this is exacerbated by the recent boom in the commodities market. A search on the Internet for 'technical skills shortage' reveals many thousands of hits. In the developed countries in particular, owing to an ageing workforce in the mining industry, the skills problem is likely to become much more acute. In South Africa, the skills deficit is regarded as a national crisis (*Mining Weekly*, 2008a). It is the opinion of a mining company CEO that the skills issue is 'the single biggest issue facing the country and one which is a major, major area of concern' (*Mining Weekly*, 2008b). Research indicates that up to 40% of the existing mining workforce in Canada could be lost over the next 10 years, and that 81 000 new people will be required in the mining industry to meet current and future needs and to fill vacancies due to retirement (*Toronto Sun*, 2008). *The Western Australian* (July 28, 2008 p. 6) reports that '… jobs in Australia's mining industry will rise from 128 000 this year to 215 000 in 2020'. In a 2006 survey of the mining industry in Australia, more than 70% of respondents indicated that the skills shortage had affected their workplace, and nearly 80% were short staffed (MRC Corp, 2008).

As a consequence of lack of skills, safety is affected (CDC NIOSH, 2008), many projects are not being developed, and those being developed or recently completed are very often over budget, behind schedule, and subsequently do not perform according to plan. In South Africa, safety in the mining and construction industries has recently deteriorated. The underlying pillars of engineering skills provision are education and research.

In this paper, mining engineering research and education in three major mining countries, South Africa, Australia and Canada, are described to illustrate the gravity of the skills situation.

The importance of high level technical skills

Mining projects have to be conceived, conceptualized and developed, designed, implemented, operated and, ultimately, closed. All of these stages require significant technical input. However, key, high level technical input is particularly required in the conceptualization, design and implementation stages. It is considered that this can best be illustrated with reference to a systematic design process and a typical project development timeline. The now well-known design process (Stacey *et al.*, 2007), based on the work of Bieniawski (1992) is illustrated in Figure 1, and a schematic project timeline is shown in Figure 2.

These two figures need to be viewed together. In Figure 2, the first stage of a project, exploration and scoping, is often carried out by prospectors and junior mining companies. Owing to the requirement for significant capital injection, the project is then

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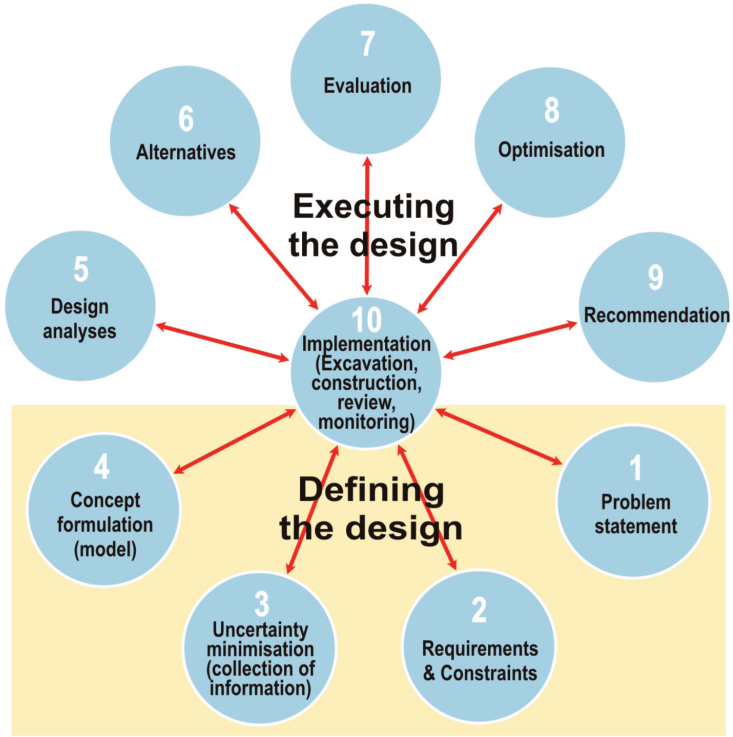

Figure 1—The engineering circle or wheel of design (Stacey *et al.*, 2007)

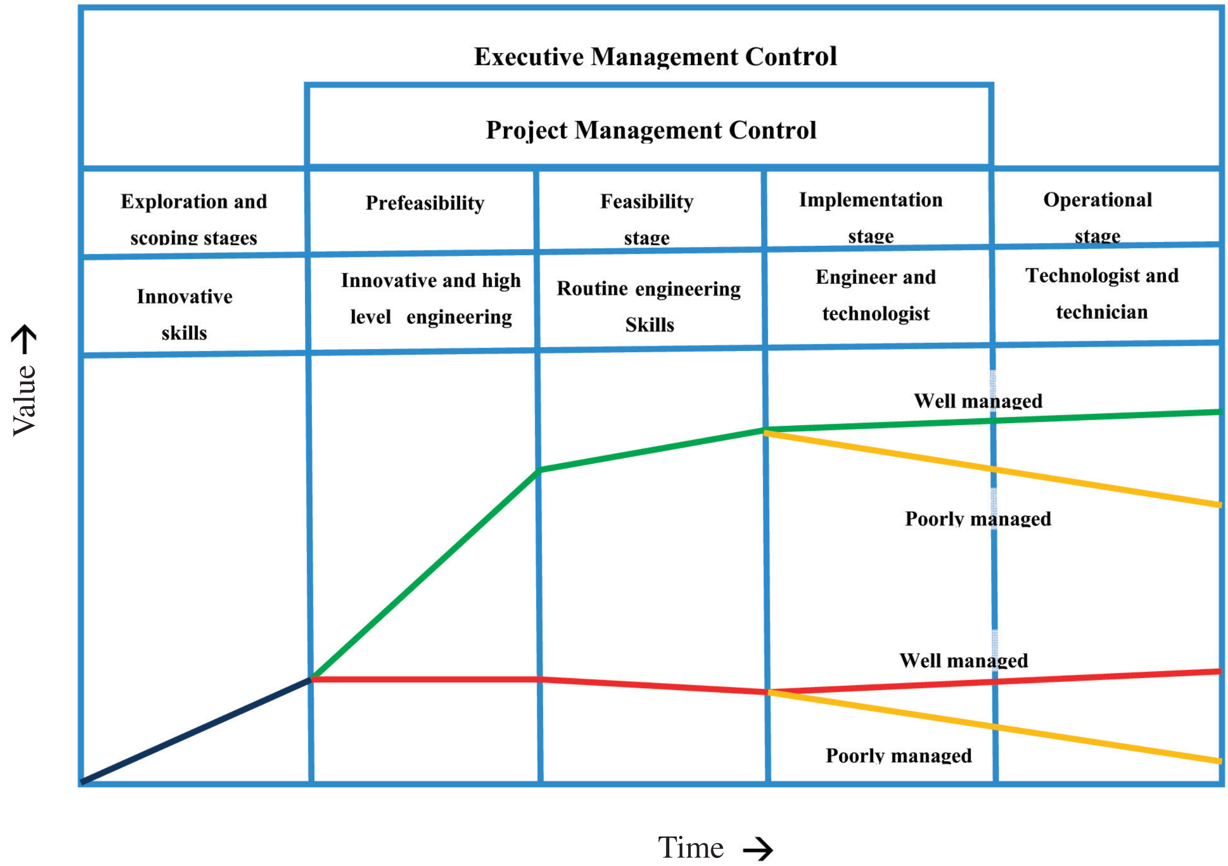

Figure 2—Project value development with time

often bought out by the majors, or some form of partnering takes place. It is in stage 2, the prefeasibility stage, that the most critical skills inputs occur. This corresponds with step 4 in the design process (Figure 1), and is the stage in which the most value is created. It requires the most innovative, high level and experienced skills that can be brought to bear on the project. As can be seen, if there is poor definition in this stage, the project is unlikely to deliver value even if extremely well implemented and operated. In the feasibility stage, corresponding with steps 5 to 9 of the design process, the required skills are high level, but more routine in nature, nevertheless requiring competent design engineers. The implementation of the project requires some engineering design skills, but more engineering management skills (technologist input). On completion of implementation, when the mining operation is in full operation and production, it is production management skills for running the 'mining factory' according to the design.

It is in the central three stages in Figure 2 that the high level 'professional engineering' skills are required. It is considered that Figure 2 demonstrates very clearly the importance of mining engineering graduates to the future of the mining industry. These graduates provide the significant 'thinking' skills. In the operational stage it is the 'doing' skills that are required. It must be emphasized that there is no implication that one such skill is better than the other. On the contrary, no project will succeed unless both skills are provided. Figure 2 shows that high level technical skills are essential if value is to be developed in a project, hence the requirement for good quality mining engineering education and research. Of course, overall management control of a project must be with the company executives, who are responsible for defining the design objectives, and monitoring project progress and operational performance at a managerial level.

The provision of high level engineering skills

In the first of this series of seminars, Phillips (2005) reviewed the demand for, and supply of, mining graduates. He focused attention on the situation in the United States, and predicted that the supply of mining engineers in the US would fall well behind the demand. He wrote (in 2005):

- 'Total employment of mining engineers in the US is 5 200.
- In the Society of Mining Engineers, which is the applicable professional body, 58% of members are over the age of 50.
- The overall retirement rate will be 4 to 5% p.a. over the next 10 years, resulting in a requirement for 225 mining engineers p.a. just to replace those retiring.
- Only 75% of mining graduates currently join the mining industry. In order to meet industry demands for 225 entrants, this would increase the required number of graduates to 300 p.a., i.e. about 2.5 times the average number of graduates produced each year for the past 5 years.'

This situation will affect all other countries that train and use mining engineers, since the US will be able to 'import' the required technical skill from these countries. The first call will be from established mining countries such as Canada and Australia, and, in turn, many technical personnel will move from South Africa to Australia—this latter movement is already common and there are currently large numbers of South African mining personnel who have relocated to Australia.

Mining research institutions are important, not only because they provide the means for fundamental and cutting-edge applied research, and resulting research outputs, but also because they provide a training ground for the development of very high level engineering skills. Many university lecturing staff and many industry employees have passed through such institutions at some time in their careers, to their own and industry's benefit.

The graduate mining engineering education and research situations in South Africa, Australia and Canada will be reviewed in this paper as an indication of the overall world situation. Table I provides some background information on demographic, economic and research data for Australia, Canada and South Africa. The information is drawn from the UNESCO Institute for Statistics.

The situation in South Africa

In South Africa there are two schools of mining engineering, at the universities of the Witwatersrand and Pretoria respectively. At present in South Africa, a major mining country, there is no research entity that has 'Mining' in its title. Large numbers of mining personnel, including many with key skills, have recently been attracted to other mining countries, particularly Australia, to satisfy the skills shortages in those countries. This has left South Africa with the tasks of mining education, training and research to be able to fill the gaps created by the emigration.

Mining engineering education

The School of Mining Engineering at the University of the Witwatersrand currently has more than 360 undergraduate students in mining engineering. In addition, there are currently 328 registered postgraduate students, 290 of whom

Table I

R & D expenditures in Australia, Canada and South Africa

Parameters	South Africa	Australia	Canada
Population (million)	48.2	20.5	32.6
GDP (US$ billion) 2006	255	780	1272
GDP/capita (US$)	10 401	31 794	33 375
R&D spend (US$ billion)*	4.0	11.4	28.1
Expenditure on R&D as % of GDP	0.9	1.8	2.0
Full-time equivalent (FTE) R&D personnel per 1 000 000 inhabitants	377	4 053	3 922

are students from industry studying part-time for postgraduate diplomas or masters degrees, mainly by coursework, and 38 who are research students (Faculty Registrar, 2008). Pretoria University has 210 undergraduate mining engineering students, 17 postgraduate coursework students and 6 research students (Webber-Youngman, 2008). All mining engineering education is in the English language, and this makes South Africa one of the major educators of mining engineers in the English-speaking world. Both schools are currently understaffed, having lost staff to industry where employment packages are significantly better.

Historically only about 50% to 60% of the undergraduate student body has ultimately graduated with a mining engineering degree. Furthermore, only some 15% of mining graduates remain in the employ of mining companies as their long-term career. Many graduates continue to be associated with the mining industry, working for contractors, consultants and suppliers of mining equipment. More recently there has been a demand for mining skills from the financial sector, and many students are contemplating a future in this area. The consequence of these figures is that, if mining companies are to satisfy their own requirements for such technical skills, they must educate and train nearly fifteen times the numbers of students than the numbers of engineers they actually require. It takes about 15 years from a student's start at university until he or she is serving in a substantive managerial capacity (Phillips, 2005). Hence the provision of such employees is a long-term activity, and therefore corporate decisions on education and training must be strategic decisions.

Mining research

The absence of a mining research institute in South Africa is relatively recent. Rock mechanics research in South Africa began at the parastatal South African Council for Scientific and Industrial Research (CSIR) in the late 1940s, in the National Mechanical Engineering Research Institute in Pretoria under the leadership of Roux and Denkhaus. The Rock Mechanics Division in this institute prospered under Hoek and Bieniawski in the 1960s and 1970s, and beyond. The Rand Mines Limited Corner House Laboratories began operating in the 1950s, focusing on rockburst and heat stress research. These laboratories subsequently became the Chamber of Mines Research Organisation (COMRO), which began operating as a mining industry funded research institute in the early 1960s, becoming a major force in mining research, particularly in rock engineering research. However, dissatisfaction with COMRO by some within the mining industry led to the 'off-loading' of this organization to the CSIR in the 1990s, and it became the CSIR's Division of Mining Technology (MiningTek). The CSIR's Rock Mechanics Division (which had moved to the National Building Research Institute) was then consolidated into MiningTek in Johannesburg. This move involved transfer of some, though not all, of the equipment, and some capability was lost. The initially successful MiningTek lost staff and capability after several years and the division disappeared as a separately identifiable mining research entity when it was recently absorbed into the CSIR Division of Natural Resources and the Environment. Office and laboratory space was downsized over several years and recently much of the original rock testing equipment and records, transferred from Pretoria to Johannesburg, were transferred back to CSIR in Pretoria, again with further loss of testing capability and retrievability of records.

In the 1970s and 1980s there were some 600 full-time researchers participating in mining research in COMRO (a substantial number were in rock mechanics research). In addition to this there were researchers in the CSIR Rock Mechanics Division, and researchers in other organizations, including the universities and mining companies. The total number of full-time researchers in the mining field was probably about 800. During this period, South Africa was an international force in mining research, and research of world class quality was carried out. It is doubtful whether there are now as many as 80 researchers in the mining field (not including metallurgy) in South Africa. This is considered to be a sorry state for a country that is regarded as a major mining country. The decay in mining research capability is perhaps illustrated by the status of the CSIR's rock testing laboratory which, in the past, was a world-class facility. It currently has no status as an accredited laboratory for commercial testing of rocks.

The deterioration in mining research capability in South Africa has occurred as a consequence of lack of long-term investment by the mining industry, and lack of recognition by the State of the research value of the existing entity and its facilities. Furthermore, there has been a lack of foresight on the part of both the State and industry that has allowed the 'destruction' of the national asset that this fundamental and applied research entity provided. The state of mining research is perhaps reflected in the overall status of research in South Africa. The GDPs for South Africa and Australia are not too dissimilar, but the R&D spend in Australia is almost three times that in South Africa, and the difference in the percentages of populations participating in research is greater than a factor of 10. This emphasizes the problem of the funding of mining research in South Africa.

If there is no investment in research by an industry, there is no long-term future for that industry. Investment in research is an investment in the long-term success of an industry, and decisions on such investments must therefore be strategic decisions.

The situation in Australia

There is no doubt that in the new millennium, the minerals industry has become Australia's main economic engine. It generated \$112b or 50% of Australia's total export in 2007, and this level of exportation is increasing at a rate of over \$1b a year. The industry direct and indirect tax contributions exceeded \$7b in 2007. It is estimated that the minerals industry accounts for over 19% of Australia's fixed and natural capital (Chamberlain, 2007).

As the mining industry is experiencing an unprecedented boom in Australia and globally, mining research and education are also in a period of high activities. There are currently at least five universities in Australia offering a formal mining engineering degree, whilst other universities are providing more generic engineering or science degrees with some kind of mining options. Australia has a strong history of mining research and, in particular the CSIRO, has played a major role in spinning off new research initiatives in the mining domain.

Technical skills—a major strategic issue

The current mining boom has generated unprecedented mining activities in Australia and at the same time has created a skill shortage. In the past, this conjuncture would have produced a 'spike' in the safety statistics, with more injuries and fatalities. It is observed that this boom did not bring such negative 'collateral' damage. The safety statistics have maintained a slow but consistent incremental improvement trend during the last few years (Figures 3 and 4). This may be due to the robustness of the safety procedures and culture implemented in the Australian mining industry.

Mining engineering education

As it is the case elsewhere, the rapid expansion of the industry in Australia has created a skill shortage at all levels from senior management to skilled workers, including mining engineers. The immigration from South Africa in particular, as mentioned previously, has assisted in partly mitigating the problem. The enrolment in the mining engineering programmes is also on the rise throughout the country. Nevertheless, the current and future supply of mining engineering is far from being balanced and most mining companies active in Australia are currently operating with several vacant mining engineering positions.

In Australia, the mining engineering education has been consolidated in 2006 under Mining Education Australia (MEA), originally including the three largest mining programmes at the following universities: Curtin University in Perth, The University of New South Wales in Sydney and The University of Queensland in Brisbane. In 2007, this consortium has produced 113 of the 130 new graduate mining engineering students in Australia. MEA has recently (2008) expanded its membership with the addition of the University of Adelaide, reflecting the growing mining activities in South Australia. In 2009, it is projected that the four university members of the MEA will have 230 third-year mining engineering students enrolled in the four universities (source MEA website). The MEA members offer a common curriculum for the 3rd and 4th year engineering programme. This is to facilitate an alternate pathway to mining engineering as students who would be enrolled in other engineering disciplines (civil, mechanical, chemical, etc.) at other universities could easily transfer to a mining programme at anyone of the four MEA universities.

The 10 to 15 % Australian mining engineering graduates produced outside the MEA consortium are from the University of Wollongong and other tertiary institutions that offer generic engineering programmes with a mining specialization. For example, the University of Western Australia offers a Bachelor of Engineering (BE) in Mining Systems within the School of Civil and Resource Engineering, and the University of Ballarat in Victoria offers a Bachelor of Engineering Science with a Mining Engineering option. All these programmes are also experiencing growth as a result of the expanding career opportunities and advantageous conditions offered by the industry. It is interesting to note that only a few years ago, the discussion was on the rationalization of the mining schools in Australia while now they are all in full expansion mode. This looks like an all too familiar situation for the cyclic mining industry.

It is also most interesting to notice that the current discussion on mining engineering education is generally at a tactical level, i.e. how can we produce enough engineers to satisfy the demand? There appears to be very little strategic planning happening. Items as simple as defining the industry long-term demand for mining engineers are not assessed so the educational system is condemned to react to short term demand and will inevitably become off-cycled sooner or later, depending on the duration of the boom.

Mining research

Mining research in Australia has historically been quite vibrant, especially in the last decade or two where several new initiatives have come to fruition producing a network of vigorous mining research activities in the country. In addition to the internationally reputed institutions in existence for several decades and involved in mining research such as AMIRA, CSIRO Mining and Exploration and the JKMRC, the industry, in partnership with governments (commonwealth and states, including universities) have facilitated a number of new research programmes. In 1990, the CSIRO and Queensland government created the Queensland Center for Advanced Technologies (QCAT). In 2001, CSIRO, Curtin University and the Western Australian government created a somewhat similar infrastructure in Perth called the Australian Resource Research Centre (ARRC). The CSIRO have also initiated a number of major multi-million dollar research programmes under the umbrella of initiatives such as 'The Glass Earth' (2003) and more recently 'Minerals Down Under' (2007).

The Australian federal government developed a national Cooperative Research Centre (CRC) scheme in 1991 and, since its inception, this programme has had at least one of its centres focusing on mining research. Originally called the

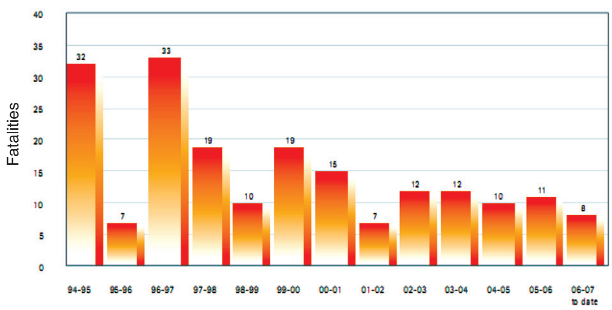

Figure 3—Fatality statistics in the Australian mining industry between 1994 and 2006 (Minerals Council of Australia, 2008)

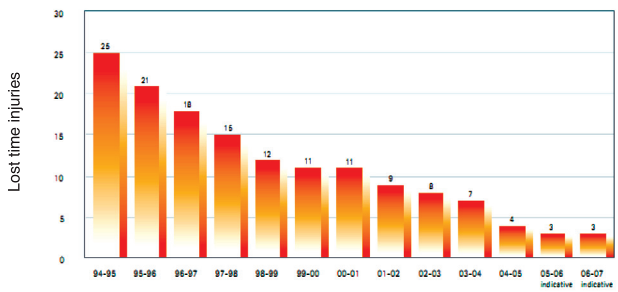

Figure 4—Lost time injury statistics in the Australian mining industry between 1994 and 2006 (Minerals Council of Australia, 2008). The occupational injuries expressed as a rate per million hours worked

Centre for Mining Technology and Equipment (CMTE), the Centre successfully secured a second round of funding in 2002 under the name of CRC Mining.

Amongst other important mining related research organizations, the Australian Centre for Geomechanics was created in 1992, with a focus on research and professional development education in mining geomechanics, as a joint venture between Curtin University, the CSIRO and the University of Western Australia, where it is currently based. In 2001, The University of Queensland regrouped six of its research centres involved in mining related activities into the Sustainable Minerals Institute.

With all these research initiatives and activities, Australia has become one of the world leaders in mining research. The total investment during the last decade alone is easily in the hundreds of millions of dollars. Australia has hosted some of the largest global cooperative research projects in recent years including the International Cave Mining project (ICM), the Large Open Pit project (LOP) and the Mass Mining Technology project (MMT). Australia has positioned itself as a leading provider of mining expertise with exports from the mining technology and services sector estimated to be over $2.5b per annum (Chamberlain, 2007).

The situation in Canada

Canada has a long tradition in mining. The current global boom in commodity prices has, however, brought to the forefront certain shortcomings. The first is a major human resources crisis. There is a severe shortage of qualified personnel to fulfil the requirements of industry. The situation is even more critical for highly qualified personnel. Mining schools have failed to provide a constant level of graduates and industry has failed to retain them.

Canada is host to a wealth of associations, interest and professional groups that aim to address some of the recurring challenges. A main characteristic of these groups is their good intentions and the capacity to work in parallel and independently from each other. A recent encouraging development is the Canadian Mining Innovation Council (CMIC), which has brought together all the stakeholders aiming to develop a Pan-Canadian Research and Innovation Strategy, Lucas *et al.* (2008).

Mining engineering education

Although education is a provincial responsibility, engineering education in Canada is regulated by the Canadian Council of Professional Engineers. This is the national organization of the provincial and territorial associations that licenses the professional engineers practising in Canada. Currently there are 9 accredited programmes that offer undergraduate degrees in mining/mineral engineering.

Traditionally, enrolment in mining engineering is very low when compared to other engineering programmes in Canada. The more reliable data are provided by the Canadian Council of Professional Engineers (2006). In 2005 mechanical, electrical, civil, computer and chemical engineering programmes, accounted for 70%, 37 964 students out of the 54 854 enrolled in engineering. In comparison there were only 323 students in mining or mineral engineering, which is less than 0.6% engineering students in Canada. Enrolment in mining engineering is more susceptible to cyclical fluctuations than other engineering fields. Archibald *et al.* (2002) demonstrated that undergraduate recruitment often follows a cyclic pattern strongly linked to the economic viability of the industry and the capacities of mining companies to offer student employment. This makes it difficult to provide employment opportunities when the industry is in a slow cycle, and there are not enough graduates to fulfil demand when the industry is at its peak. This situation is neither to the advantage of industry nor to the long stability of mining programmes.

Another way to assess engineering education is through the engineering degrees awarded in Canada. Mining or Mineral Engineering is arguably less inviting than other engineering domains. The number of foreign students, in spite of common misconceptions, is relatively low at the graduate level.

Mining research

University research in Canada is financed by the Natural Science and Engineering Council of Canada in the form of research grants to professors and scholarships to post-graduate students. Mining is comparatively a lower priority as there are fewer mining academics and fewer graduate students. Another source of funding is through individual mining companies, in the form of research contracts, or in the development of consortiums. The Canadian Mining Industry Research Organization (CAMIRO) supports underground hard rock mining research, while the Surface Mining Advanced Research and Technology (SMART) supports surface mining research. These contracts tend to be of smaller duration.

Table II

Accredited mining/mineral engineering programmes in Canada

Accredited programme	Department	Host institution	Province
Mining Engineering	Civil and Environmental Engineering	University of Alberta	Alberta
Mining Engineering	Mining Engineering	University of British Columbia	British Columbia
Mining Engineering	Civil and Resource Engineering	Dalhousie University	Nova Scotia
Mining Engineering	School of Engineering	Laurentian University	Ontario
Génie des mines et de la minéralurgie	Mining, Metallurgical and Materials Engineering	Université Laval	Quebec
Mining Engineering	Mining and Materials Engineering	McGill University	Quebec
Génie des mines	Génies civil, géologique et des mines	École Polytechnique	Quebec
Mining Engineering	Mining Engineering	Queen's University	Ontario
Mineral Engineering	Civil Engineering	University of Toronto	Ontario

The Canadian government also conducts research and development in mining through the CANMET Mineral Technology Branch (MTB), which is the science and technology arm of the Minerals and Metals Sector of Natural Resources Canada. A major provincial initiative was launched in 2007. The Centre for Excellence in Mining Innovation (CEMI) is funded by the private sector and the Ontario Government and aims to address research priorities, Duff *et al.* (2008).

The strategic necessity of planning the provision of high level technical skills

The effects of skills shortages are, and will be felt in many areas, but perhaps the most significant effects in mining will be:

- ➤ Deterioration in safety, with an increase in the numbers of accidents
- ➤ Inability to develop new projects
- ➤ Declines in productivity and profits as a result of the inability to operate, manage and maintain existing mines satisfactorily.

All of these effects can be explained by lack of skills or core competencies, which develop from education, training and experience.

In any strategic planning exercise (and all mining companies do, or should, carry out such exercises on a regular basis), one of the steps in the process is to identify key uncertainties. Ilbury and Sunter (2005), in their book dealing with strategic planning (they have developed a strategic conversation process in which business is considered to be a game that has to be understood [defined] and played as part of the process), identify one of the key uncertainties as 'core competencies'. Quotes from this book include: 'Do I possess the core competencies to play the game as it is played now?' ….. 'Is my training and development program geared to produce the requisite core competencies in each of the countries I'm operating in …?' …. 'If not, where in the world am I going to obtain suitable recruits?' … 'Or will I have to acquire them by forming some form of commercial partnership/relationship with another company?' … 'Do I look around for a suitable takeover target and do all these things at once?' These are the kinds of questions that mining companies should be asking themselves in a strategic planning process.

The looming shortage of skills has been known about for many years and the above questions should have been a part of mining company strategic planning. Yet just a few years ago one mining company in South Africa stated that it would not be mining gold in South Africa in ten years' time and therefore did not need to train mining engineers. Students' bursaries were terminated and students were released from their bursary commitments. With the increase in the gold price this company outlook has changed and skills are now being desperately sought.

The commodities boom, which developed rapidly, has certainly accentuated the skills requirements. Such 'sudden' events (or shock events in Ilbury and Sunter's (2001) terminology), and for example electricity power cuts (as occurred in January 2008 in South Africa, leading to a 10% cut in supply to mines), and the oil price are scenarios that certainly could have been foreseen and should have been taken into account in regular strategic planning sessions. Regarding the cuts in electricity in South Africa, the warnings were there, and had mining companies implemented strategically planned contingency measures, they would not have had their production affected and hence experienced a loss of profit. Regarding the oil price, it is interesting to quote from Ilbury and Sunter (2001): 'In the event, they chose the 'second shock' scenario [in the mid-1970s], the oil price soared to over $30 a barrel and …' Then in 2005 (Ilbury and Sunter, 2005), '… lack of new oil discoveries to keep up with demand push the price of oil into the stratosphere at around $100 a barrel.' Now, just three years later the oil price has exceeded $140 a barrel and an opinion that the price will exceed $200 has been voiced.

The planning for shock events and for skills provision is a long-term commitment. As indicated above, it takes 15 years to produce an adequately experienced engineer. The education and training pipeline does not have a tap that can be turned off and on at will. The reservoir is dry at present and the tap is just producing a trickle. Cutting of education and training budgets, including student bursaries, to satisfy company short-term cost-cutting and profit policies destroys value in the long term. Companies need to develop a long-

Table III

Engineering degrees awarded in Canada from 2001–2005, data drawn from the Canadian Council of Professional Engineers (2006)

	2001	2002	2003	2004	2005
Undergraduate degrees in mining or mineral	127	97	74	102	78
Total Undergraduate degrees in engineering (all disciplines)	8733	9295	10031	10306	10418
Master' degrees in mining or mineral	29	22	27	39	41
Master' degrees in mining or mineral (foreign students)	5	3	5	6	10
Total Master' degrees in engineering (all disciplines)	2063	2209	2782	3482	3802
Total Master' degrees in engineering (foreign students)	294	592	745	672	705
Doctoral degrees in mining or mineral	18	11	23	21	27
Doctoral degrees in mining or mineral (foreign students)	7	2	8	3	7
Total Doctoral degrees in engineering	459	461	505	592	663
Total Doctoral degrees in engineering (foreign students)	94	152	136	123	142

term strategy to provide and retain the skills that they require. It is to be noted that the ability of mining companies to retain engineers in their employment is not good, and they need to change their approaches to treatment of staff, and develop strategies to improve retention. Owing to the shortage of 'experienced' skills and the ageing work force, it will be critical to retain the services of 'pensioners' so that they become part of the training and mentoring programmes, and are able to pass on their skills to the new generation. The use of the 'pensioners' to provide only the skills (which they can do) without the involvement of the new generation is a short-term and unsustainable solution to the skills problem—the interaction of both generations and the passing on of experience is essential for long-term benefit.

The State has a major role to play in the provision of skills. Universities and research institutions are usually parastatal bodies, depending significantly on state funding for their sustainability. In return they develop the people and infrastructure, both of which become national assets. The long-term strategy of the State needs to ensure that such institutions are adequately funded and resourced so that they are sustainable in their defined roles, and can continue to develop the national assets required for the material and intellectual growth of the country.

Conclusions

It has been shown that the shortage of skills is critical in the three major mining countries, South Africa, Australia and Canada. The crisis is partly due to the short-term focus of the mining industry, which is commonly the case. The degree of crisis is different in the three countries. In South Africa, large numbers of mining engineering graduates are being produced by the two universities. However, only a small percentage of graduates remain in the industry as mining company employees. South Africa is also losing mining personnel with significant skills to other countries, notably Australia. In South Africa there is a crisis in mining research, and there is currently no research institution with 'mining' in its title.

In Australia, the mining engineering education system is in a reactive mode. Only a few years ago, it was downsizing, and currently it is back to a full expansion mode trying to satisfy the short-term demand of the mining industry. The strategic planning seems to be lacking and the risk of staying in the traditional 'off-cycle trap', where the offer is off-cycled compared to the demand, is almost inevitable. On the mining research side, Australia is currently reaping the benefits of the sound long-term strategic investments made during the last two decades in mining research by governments and the industry.

The challenges facing mining education in Canada seem to be changing. While a few years ago student placement and low enrolments were the main problems, currently it is the shortage of graduates to fill all available opportunities. Certain mining programmes are currently faced with limited instructors and inadequate facilities to accommodate the increased student enrolment. Even if there is an increase in funding, in the absence of a long-term strategy, it risks being squandered.

The problem of the shortage of engineering skills in the mining industry cannot be solved in the short term. It requires long-term strategies from both mining companies and the State to ensure the adequacy of funding of mining engineering education and research, and the continued supply of the necessary engineering skills.

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