TRAINING STRATEGY FOR MINING ENGINEERS AT THE UNIVERSITY OF PRETORIA

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Mining engineers have a high potential to reach very senior positions in mining companies. This exposes them to making decisions in risky situations with incomplete information. The whole thrust of training mining engineers for industry begins with recruiting leaders, and then providing them with the foundations to become decision makers. The departmental vision is thus to provide the mining industry with mining engineers who will lead the industry into a new era of safety and prosperity with flair. This vision, together with minimum requirements for engineering curricula outlined by the Engineering Council of South Africa, industry requirements, international developments in engineering education, and emerging engineering disciplines, all combine to shape the mining engineering curriculum and the way that it is taught. The general objective of mining engineering training at the University of Pretoria therefore emphasises understanding rather than memorizing, in order to stimulate creative thinking and the development of innovative skills amongst mining engineering students. Together with good staff-student communication, and student participation in extra-mural activities offered by the university, the correct foundation for leadership and technical excellence has been put in place.

Introduction

Mining is at least as old as agriculture, with the earliest records of gold mining coming from the Middle East and Asia Minor before 3000 BC (Handley, 2000). It never enjoyed much scientific attention until Agricola's (1556) book on the subject. Agricola's text, originally written in Latin and entitled *de re Metallica*, is considered a classic, because of its completeness and scientific approach to the subject matter. The former United States president HC Hoover and his wife LH Hoover translated it into English in 1912. This translation is still available from Dover Publications.

It is interesting to review Agricola's (1556) words, as rendered in the Hoover translation, on what miners should know: Furthermore, there are many arts of which the miner should not be ignorant. First, there is Philosophy, that he may discern the origin, cause, and nature, of subterranean things: for then he will be able to dig out the veins easily and advantageously, and to obtain more abundant results from his mining. Secondly, there is Medicine, that he may be able to look after his diggers and other workmen, that they do not meet with those diseases to which they are more liable than workmen in other occupations, or if they do meet with them, that he himself may be able to heal them or see that the doctors do so. Thirdly follows Astronomy, that he may know the divisions of the heavens and from them judge the direction of the veins. Fourthly, there is the science of Surveying that he may be able to estimate how deep a shaft should be sunk to reach the tunnel which is being driven to it, and to determine the limits and boundaries in these workings, especially in depth. Fifthly, his knowledge of Arithmetical Science should be such that he may calculate the cost to be incurred in the machinery and the working of the mine. Sixthly, his learning must comprise Architecture, that he himself may construct the various machines and timber work required underground, or that he may be able to explain the method of construction to others. Next, he must have knowledge of Drawing, that he can draw plans of his machinery. Lastly, there is the Law, especially that dealing with metals, that he may claim his own rights, that he may undertake the duty of giving his opinion on legal matters, that he may not take another man's property and so make trouble for himself, and that he may fulfill his obligations to others according to the law.

Agricola's words remain relevant today some 450 years after they were first written, despite the huge advances in science and technology that have since taken place. The term "miner" in the text implies either the owner of the mine, or the leader (manager) of the operations at the mine. A miner must therefore be a leader in addition to possessing skills relevant to his profession. These basic tenets, world trends in engineering education, the demands of the mining industry, and the requirements of the Engineering Council of South Africa (ECSA), have shaped the structure of the mining engineering qualification offered by the University of Pretoria.

The purpose of this paper is firstly to communicate the department's training strategy for mining engineering undergraduates to the industry, and secondly to create a working document that provides guidance to department staff in teaching mining engineering to students. In addition to this, it will serve as a useful summary of the B.Eng (Mining) Degree and its contents to interested parties in the mining industry as well as to prospective students. It will also serve as the starting point from which future changes in the content, or education strategy can be planned as the need arises. It covers the vision of the Department of Mining Engineering and all the factors, which presently govern the contents of the B.Eng (Mining) degree. It addresses student selection requirements stipulated by the university, and concludes with future directions in education as seen in the context of economics, development, mining, and educational requirements.

Factors shaping the b.eng (mining) degree

The general objective of Mining Engineering Department at the University of Pretoria is to emphasise understanding rather than memorising, in order to stimulate creative thinking and the development of innovative skills amongst students in mining engineering. The department follows a problem-driven approach as far as possible. Student-centred co-operative learning and teaching methods are applied during lectures, tutorial classes and practicals, in order to develop the above-named skills. Students are expected to participate in discussions during lectures and tutorial classes. This approach also stimulates the development of communication skills, interpersonal skills, and group dynamics.

The Department of Mining Engineering at the University of Pretoria therefore sets itself a challenge with the following vision: Produce mining engineers who will lead - within the constraints of the law, economic factors, and environmental factors - the mining industry into a new era of growth and prosperity by their ability, education, balanced judgment, and decision-making capability. This vision, itself shaped by external factors, and together with these factors, determines the content and structure of the B.Eng (Mining) degree. Each is discussed separately in the following sections.

The Higher Education Act and the South African Qualifications Authority Act

The Higher Education Act No. 101 of 1997 set up the Council on Higher Education, which performs quality assurance on all higher education programmes through the Higher Education Quality Committee. The act specifically states that quality assurance must be performed against standards registered within the National Qualifications Framework (NQF), which is defined in Chapter 2 of the regulations under the South African Qualifications Authority Act No. 58 of 1995.
The Higher Education Act No. 101 of 1997 provides that the Higher Education Quality Committee may, with the concurrence of the Council on Higher Education, delegate any quality assurance functions to other appropriate bodies capable of performing such functions. A process, underway since 2000, will set up a Memorandum of Understanding between the Higher Education Quality Committee and the Engineering Council of South Africa (ECSA), which has the appropriate degree programme accreditation mechanisms (Hanrahan, 2000). This agreement means that ECSA accreditation of university engineering degree programmes will be recognized by the Department of National Education.

The Engineering Council of South Africa

The Engineering Council of South Africa is the successor to SACPE (The South African Council of Professional Engineers), which was established in 1969. This organization underwent several changes to meet the demands of the profession until 1990, when it was renamed the Engineering Council of South Africa after the promulgation of the Engineering Profession of South Africa Act No. 114 of 1990. Because of the untiring efforts of Professor HE Hanrahan, ECSA was admitted as a full signatory of the Washington Accord in November 1999 in Sydney, Australia. This means that guidelines, standards, and accreditation procedures employed by ECSA are in line with those of the other signatories, and international best practice. ECSA is now a statutory body established in terms of the Engineering Profession Act No. 46 of 2000.

Accreditation of Degree Programmes by ECSA

ECSA protects the public interest in relation to the work of professional engineers, primarily safeguarding public health and safety from adverse consequences of engineering activity (Hanrahan, 2000). This brief extends to the quality of training that engineers receive, because training has a major impact on the potential for adverse consequences from engineering activity.

Table 1: Minimum university curriculum content by knowledge area

Knowledge Area	**Minimum curriculum content (%)**
Mathematics	10
Basic Sciences (physics, chemistry, etc.)	10
Engineering Sciences	30
Design and Synthesis	12
Computing and Information Technology	3
Complementary Studies (the “soft” sciences)	10
Subtotal	75
Discretionary	25
Total	100

ECSA has established a standards and procedures system to audit the quality and content of engineering programmes offered by tertiary institutions in South Africa. The University of Pretoria engineering degree programmes undergo an accreditation process overseen by ECSA every five years, the next one being scheduled for August 2002. The standards and procedures system of ECSA have issued a suite of documents that govern the accreditation process (ECSA, 2000b). The background for the accreditation of bachelor degrees in engineering appears in form PE-60 (ECSA, 1998), and clear directives for the programme content in form PE-61 (ECSA, 2000a). The minimum programme content, shown in Table 1, is spread across six knowledge areas (ECSA, 2000a).

These minima have been set to accommodate university programmes in transition to the above six outcomes-based criteria, and they will be reviewed as experience grows with the application of the new system (ECSA, 2000a). The discretionary component may be applied by the institution at its own discretion according to the nine principles and assumptions outlined in Document PE-60, (ECSA, 1998). The way in which the course content is measured against the minimum requirements in Table 1 will be outlined below when discussing the degree programme.

Recent Trends in University Engineering Education

In addition to the statutory requirements sketched in broad outline above, the contents of the B.Eng (Mining) degree programme is influenced by the departmental vision, industry demands, developments and trends in tertiary education, and emerging fields of engineering. Each of the four factors mentioned will be dealt with under separate sub-headings below.

Departmental Vision

The departmental vision, quoted at the beginning of Section 2, requires explanation since it affects every facet of training, beginning with selection. Mining engineers must be leaders, since they will eventually manage mining operations employing hundreds, perhaps thousands of people, with annual turnovers measured in millions of Rands. This requires considerable technical ability, well developed leadership skills, and the ability to work in a team environment.

The mining companies themselves select a significant proportion of prospective students for these traits, for the award of a study bursary. These prospective students must then meet the university selection criteria, which are academic achievement at school and the ability to communicate in writing. In 2000, 30% of the first year mining students were head prefects at school, 22% were deputy head, and a further 22% were prefects. Thus, 74% of the students had been identified and selected for leadership positions at their respective schools (Fourie, 2000). In the 2004 intake 14% were head prefects, 31% prefects, and 21% filled other leadership positions in their final school year (van der Merwe, 2004). This continues at University level, where a mining student has been elected to the Students' Representative Council every year from 1996 to 2001. During the last two years, two mining students have been university hostel committee chairmen, while several others were house committee members and members of the Rag Coommittee.

Mining engineers need to be able to work in teams. This cannot be selected for, but can be developed with the correct approach. Teamwork can easily be a negative experience if teams are made up of incompatible members. To avoid this, third year mining students are divided into teams by using the Myers-Briggs selection method as practiced by Douglass J Wilde at Stanford (see reference for contact details). Seven years' experience at Stanford University's Mechanical Engineering Design Division has shown that student project team performance, as measured by prizes won in a national competition, can be markedly improved by taking account of student preferences when constructing the teams. These preferences are expressed on short questionnaires, usually samplings of the Myers-Briggs Type Indicator used widely by educators to study learning styles. The approach is valuable not only for building better teams, but also for teaching practical human relations to engineering students, who will need such knowledge in their careers.

The teams are normally made up of four students comprising of the four preference groups, corresponding to the following eight Jungian cognitive modes:

(1) Introverted Sensing (IS) - Practical, knowledgeable implementers
(2) Extraverted Intuition (EN) - Speculative, idea-oriented creators
(3) Extraverted Thinking (ET) - Organization-minded coordinators
(4) The five remaining cognitive mode possibilities lumped together, namely (4.1) Introverted Thinking (IT) – Analysts, (4.2) Extraverted Feeling (EF) –Team-builders, (4.3) Extraverted Sensing (ES) – Experimenters, (4.4) Introverted Intuition (IN), and (4.5) Introverted Feeling (IF).

It would be unusual to have a class of students evenly distributed in each preference group (PG), so students favouring the fourth group of learning modes are selected to augment the first three. This group selection method has enhanced the output and quality of the design projects given to third and fourth year students to such an extent that all other group related projects are done on the basis of the above-mentioned selection

method. This approach has proved successful in the final, but most important group project, of the degree, namely the mine design project, which is completed in the second semester of the final year.
The mine design project is similar to a pre-feasibility study, where each group is given borehole details of an orebody, from which they should create a report of approximately 100 pages on the preliminary feasibility of establishing a mine. This is the final synthesis of all that the students have learned to date: the report must contain an analysis of the value of the orebody, commodity market analysis, selection of mining method, a preliminary life-of-mine plan, financial analysis, and conclusion on the feasibility of the project. This project therefore exercises the technical capabilities as well as judgment and decision-making capabilities. It also builds group skills, management, and interpersonal skills for group work.
Balanced judgment and decision-making skills are exercised by the groups in the above project in the most realistic way possible. These skills still remain the more difficult objectives to meet within the confines of the curriculum since these skills develop with experience. Nevertheless, the department encourages students to exercise them in both technical and non-technical courses wherever this is possible in order to foster their development from the beginning.
Extra-mural activities assist further to develop judgment and decision-making. The department encourages student participation in extra-mural activities, particularly those offered by the University, such as sport and student politics. The department also maintains a close relationship with the students, with staff members participating in several social functions with them during the academic year. All staff members practice an open door policy with students, providing them with advice and mentorship as required. The objective is to produce a person who is well rounded, who will embark on life-long learning, and who will hone interpersonal, technical, and judgment skills throughout his/her career.

Industry Demands

The great mining houses, which had acted as investment and administration vehicles for the mines in South Africa for a century,

started unbundling in the 1990's and have now disappeared from the scene, leaving focused mining companies. With their departure, the culture of maintaining a complete set of skills in-house has virtually disappeared. Today's mining companies prefer to concentrate on core business only, and to contract out all peripheral activities, such as training and services.
Mining companies now require graduate mining engineers to be as proficient as possible when commencing employment, that is, they should require a minimum of further practical training to be productive within the organisation. This is a difficult goal to meet in an academic institution, where practical exposure to mining beyond a few one-day visits to different mines during the academic year is generally not possible. Mining companies and the university address this problem in five ways:

- Excursions to nearby mines during practical periods where practical work is done as part of the curriculum requirements;
- Compulsory one-day visits to local mines during the academic year;
- A mining tour in the July recess for third and fourth year students, during which they are exposed to as broad a spectrum of mining as possible;
- Mining engineering students are required to work on a mine during the university summer recesses, and then report on that work during the following academic year;
- The mining company identifies potential mining engineers through offers of bursaries, and then employs them for one or two years prior to sending them to university.

The university has allocated 54 credits to recess work on mines and for the reporting thereof. Credits will be discussed in more detail in Section 3.

The department emphasises communication and problem solving skills throughout the mining student's career at university, culminating with the dissertation, which is completed in the fourth year, and based on recess work done on a mine at the end of the third year of study. Considerable groundwork is done to prepare the student for the dissertation, namely:

- Inclusion of mine financial related subjects in the 3rd year of study to enhance the quality of dissertations;
- A detail planner proposal as pre-requisite for students before they start their recess work;
- A weekly time allocation during the 2nd semester in the third year to introduce the students to a problem solving strategy;
- A standard procedure available on presentation skills;
- A standardised "dissertation layout" that enhances the quality of report writing.

The final year dissertation is thus a practical exercise in problem solving and reporting in a mining environment.

Developments and Trends in Tertiary Education

Lumsdaine and Lumsdaine (1995) begin their introduction with the following words: *We live in a world that is changing rapidly, and in times of change, creative thinking is the key that lets us cope, adapt, and succeed.* Tertiary engineering education traditionally confined itself to the technical aspects of engineering, neglecting the complementary aspects such as communication, and management. These aspects have become an important international accreditation criterion, and have been integrated into the engineering curricula at the University of Pretoria (Horak and Pienaar, 2000, and Pienaar, 2001). ECSA requires that 10% of the engineering curriculum be devoted to complementary studies. Currently the mining engineering curriculum incorporates innovation and basic skills, communication skills, technological entrepreneurship, project management, engineering management, and health and safety. More details appear in Section 3.

Emerging Fields of Engineering

There have been major developments in mining rock engineering in the last fifty years. In South Africa, the major driver was the increasingly unacceptable rock-related injury rate experienced by the deep gold mines of the Witwatersrand. The major developments include:

- Formalised pillar design (mainly for coal mines);
- Yielding support for rockburst-prone mines (rapid yielding hydraulic props, yielding timber props, and yielding tendons);
- The measurement of in-situ stress in rock;
- Static and dynamic numerical methods to assess rock stress, rock deformation, rock failure, mining excavation stability, pillar stability, and the stability of geological structures;
- Mine seismology and the development of practical mine-wide seismic monitoring systems.

These developments lift the practice of rock engineering from an obscure science to an emerging engineering discipline (Handley, 1996), necessitating adjustments to the mining engineering curriculum to accommodate them. Both Handley (1996) and Esterhuizen and Gurtunca (1996) note that there is a lack of training in rock engineering at tertiary level, and that this should be addressed by specialised training on a structured basis at tertiary institutions.

Ventilation and refrigeration engineering in gold deep mines has grown tremendously in the last sixty years, mainly because of the increase in tonnage milled in the industry in general, and the increasing average depth from which ore is being recovered. The East Rand Proprietary Mines Limited has been a leader in ventilation and refrigeration innovation for many years; see for example Hill and Ranson (1948) and Muller and Hill (1966). Since this discipline is also emerging as a new engineering discipline, the mining department pays a lot of attention to the content of mining environmental courses as new developments are reported. For example, lecturers and post graduate students in the mining department are involved in the FutureMine initiative, which manages research on several aspects (including environmental aspects such as ventilation and refrigeration) of deep level mining. This exposes the University of Pretoria to the industry needs and developments, enhancing the quality of education and research output.

Mine Environmental Engineering (incorporating occupational hygiene) is now established as an important module (spread over two years as Mine Environmental Engineering I and Mine Environmental Engineering 2) in the mining engineering curriculum. The courses have been restructured over the last four years to keep pace with new developments, and are now fully applicable to the current industry needs.

There is still no specialised rock engineering degree curriculum in place nor a refrigeration and ventilation degree curriculum, although South African universities have significantly increased the rock mechanics and refrigeration and ventilation content in mining curricula in the last ten years.

Structure of the b.eng (mining) degree

The Department of Mining Engineering at the University of Pretoria seeks to comply in full with all the provisions and guidelines that pertain to universities for accreditation as laid out by ECSA (ECSA, 2000b). In addition to this, the department wishes to remain abreast with developments both nationally and internationally in the mining industry, and in education. These objectives guide the curriculum content and revisions to the curriculum content.

The global structure of the mining engineering curriculum appears as a diagram in Figure 1. The numbers in brackets indicate the number of credits allocated to each area of knowledge. One credit is defined as being equal to 10 notional hours of contact time and study time. A typical 16-credit course given in one semester would consist of 160 notional activity hours, divided into 36 lecture hours (3 lectures per week over 12 weeks), 36 practical hours (3 hours per week over 12 weeks) and 88 study hours. The credit is defined by SAQA, or South African Qualifications Authority to represent 10 notional activity hours for the student.

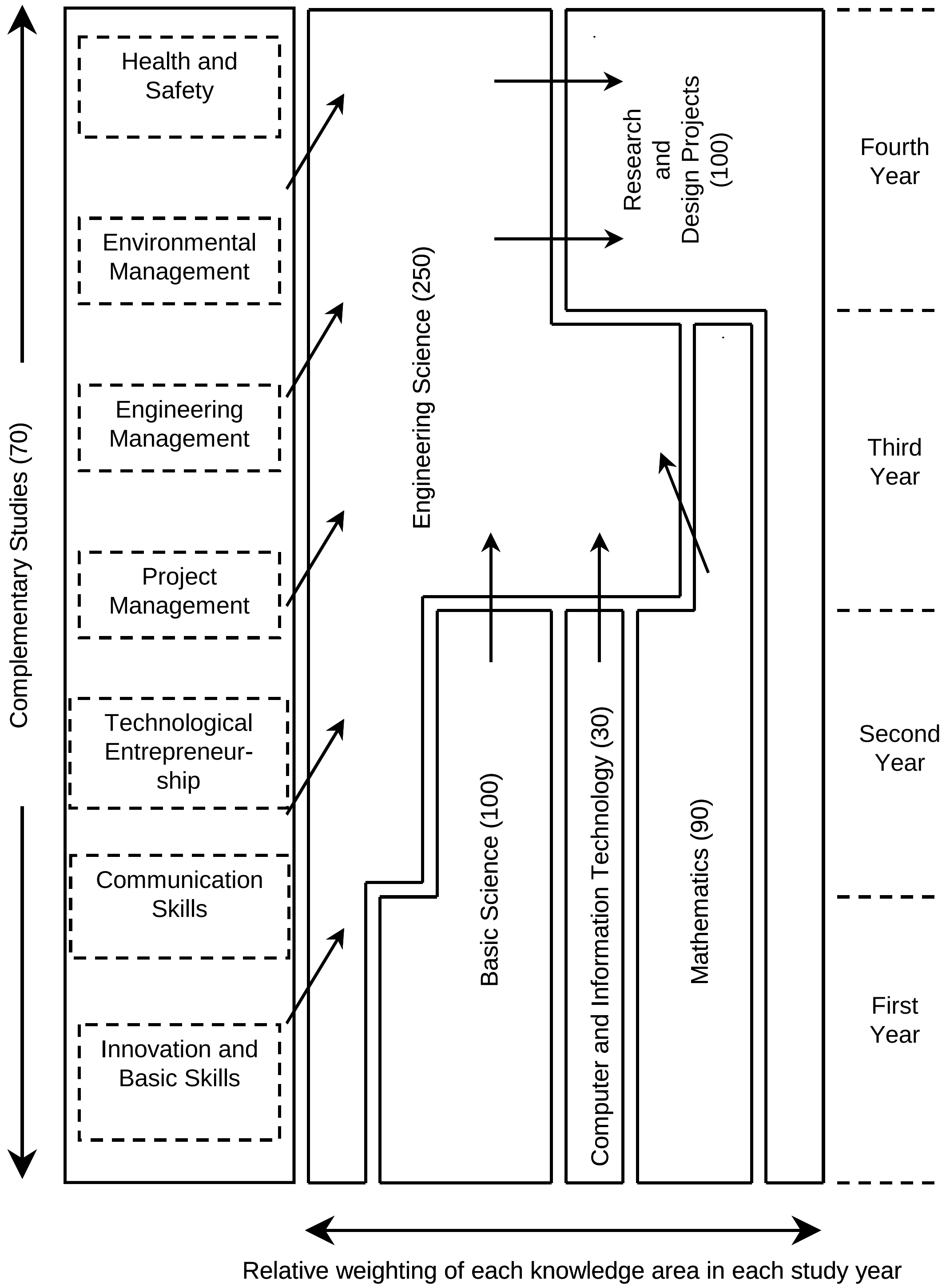

Figure 1: Diagrammatic Scheme of Distribution of Credits amongst the Different Knowledge Areas for Mining Engineering (after Pienaar, 2001)

ECSA specifies a minimum of 560 SAQA credits for an engineering degree, spread over four years at 140 credits per year. This amounts to 5600 notional activity hours, or 1400 hours per year (ECSA, 2000a). The general layout of the B.Eng Degree for mining appears in Figure 1 above. The numbers in brackets in Figure 1 denote the number of credits allocated to each knowledge area (after Fourie, 2000 and Pienaar, 2002). The relative weighting of courses in each year of study provides an indication of the curriculum content as the student progresses. For example, the diagram shows that the basic sciences and computer and information technology are taught in the first two years, while mathematics is taught in the first three years. The engineering sciences have the greatest weighting in the third year, while the fourth year is almost equally divided between engineering science and research and design projects.

The number of credits allocated to each knowledge area has been rounded because few of the subjects taught lie exclusively in one knowledge area. For example, the third year rock mechanics course introduces new mathematics and mathematical notation, thus it straddles the mathematics and engineering science knowledge areas. The credits have thus been allocated according to detailed course content after Fourie (2000) and guidelines provided by the Faculty of Engineering, Built Environment and Information Technology (Pienaar, 2002).

The width of the box containing the complementary studies in the left of the diagram does not represent the proportion of the academic loading placed on the student in credits, but has been drawn to accommodate the information given. As shown, complementary studies are distributed more or less evenly throughout the curriculum. In the first three years, they are taught as independent subjects, and then appear as sub-sections of fourth-year engineering science subjects (e.g. environmental management and health and safety).

Table 2: Comparison between Curriculum Content and ECSA Requirements

Knowledge Area	**ECSA Requirements**		**Mining Curriculum**	
	%	**Credits**	**%**	**Credits**
Mathematics	10	56	11	64
Basic Sciences	10	56	21	137
Engineering Sciences	30	168	34	218
Design and Synthesis	12	67	16	105
Computing and IT	3	17	8	50
Complementary Studies	10	56	10	64
Sub-total	75	420	100	638
Discretionary	25	140	0	0
Total	100	560	100	638

A comparison between ECSA requirements and the mining engineering curriculum appears in Table 2. The mining curriculum credits come from a revised degree programme released by the faculty at the beginning of 2002 (University of Pretoria, 2002a). There are discrepancies in figures between Figure 1 and Table 2 because Figure 1 is a schematic layout for which Table 2 represents a "best fit". The figures in Table 2 show that the ECSA requirements are exceeded in all areas, firstly because the full 25% discretionary content has been distributed amongst the knowledge areas, and secondly the number of notional activity credits allocated to the degree curriculum exceeds those required by ECSA. In addition to the 638 credits allocated to the degree programme shown in Table 2, there are a further 54 credits for recess work and report writing, adding up to 692 credits for the degree. This differs slightly from with the 687 credits quoted in the *Regulations and Syllabi 2002* (University of Pretoria, 2002b). The differences arise because of changes in course structures and content. There are plans to reduce the engineering course content by 40-60 credits, to bring it more in line with the Massachussetts Institute of Technology degree.

Conclusion

The Mining Department of the University of Pretoria intends to produce well educated, well rounded mining engineers who will lead the mining industry with flair in the future. The curriculum content not only complies with the requirements of the Engineering Council of South Africa, it is structured to provide the most benefit to the students during their short careers at the University. This, together with staff-student communication and encouragement to participate in extra-mural activities, provides a solid foundation on which good leadership, good decision-making qualities, and life-long learning can flourish during a career in the mining industry.

References

Agricola G (1556): *de re Metallica.* Translated from the original Latin by Herman Clark Hoover and Lou Henry Hoover in 1912, and republished by Dover Publications in 1950.

Budavari S and Phillips HR (1996): Centennial reflections of the Department of Mining Engineering, University of the Witwatersrand. *Centennial Symposium of the Department of Mining Engineering, University of the Witwatersrand*, Sturrock Park, Johannesburg, 8th August 1996.

Department of Mining Engineering, University of Pretoria (2001): *Annual Report 2000.* Department of Mining Engineering, University of Pretoria, Pretoria, March 2001.

Engineering Council of South Africa (1998): *Background to Accreditation of University Engineering Bachelor Degrees.* Engineering Council of South Africa Standards and Procedures System, Document PE-60 Revision 0, 16 April 1998.

Engineering Council of South Africa (2000a): *Standards for Accredited University Engineering Bachelor Degrees*. Engineering Council of South Africa Standards and Procedures System, Document PE-61 Revision 1, 20 July 2000.

Engineering Council of South Africa (2000b): *Policy on Accreditation of University Bachelors Degrees.* Engineering Council of South Africa Standards and Procedures System, Document PE-70 Revision 0, 11 August 2000.

Esterhuizen GS (1996): Training and education of rock mechanics for the South African mining industry. Symposium on *The Human Element in Rock Engineering*, SANGORM, S. Afr. Nat. Group of the International Society for Rock Mechanics, Goldfields Group Training Centre, Kloof Gold Mine, 8 February 1996, pp. 59-62.

Fourie GA (2000): *Presentation to Minerals Education Trust Fund on 24 July 2000.* Department of Mining Engineering, University of Pretoria, July 2000.

Handley JRF (2000): *World Gold Resources – A Global View in Space and Time.* PhD Dissertation, Faculty of Engineering, University of the Witwatersrand, Johannesburg, 14 April 2000.

Handley MF (1996): Rock engineering: from obscure science to engineering discipline. Symposium on *The Human Element in Rock Engineering*, SANGORM, S. Afr. Nat. Group of the International Society for Rock Mechanics, Goldfields Group Training Centre, Kloof Gold Mine, 8 February 1996, pp. 19-22.

Hanrahan H (2000): A nationally integrated model for qualifications, registration, and licensing in the engineering profession. Proceedings of the 2nd *Southern African Conference on Engineering Education*, Vanderbijlpark, South Africa, 28-29 September, 2000, pp. 208-213.

Hill FG and Ranson EC (1948): A major change-over in the ventilation of a deep level mine. *Association of Mine Managers of the Transvaal Papers and Discussions*, 1942-1945, Vol. 1, pp 479-523. Johannesburg: The Transvaal Chamber of Mines, 1948.

Horak E and Pienaar G (2000): Re-structuring a civil engineering curriculum to accommodate environmental engineering. Proceedings of the 2nd *Southern African Conference on Engineering Education*, Vanderbijlpark, South Africa, 28-29 September, 2000, pp. 144-149.

Lumsdaine E and Lumsdaine M (1995): *Creative Problem Solving: Thinking Skills for a Changing World*. New York: McGraw-Hill, Inc., 491p.

Muller FT an Hill M (1966): Ventilation and cooling as practiced on East Rand Propietary Mines, Ltd. *Association of Mine Managers of South Africa Papers and Discussions*, 1964-1965, pp. 37-55. Johannesburg: The Transvaal and Orange Free State Chamber of Mines, 1966.

Pienaar G (2001): The integration of complementary studies into the university education of engineers. *South African Journal of Higher Education,* Vol. 15 No. 3, pp.162-167.

Pienaar G (2002): Personal communication. University of Pretoria, 21 January 2002.

University of Pretoria (2002a): *Internal faculty document*. Faculty of Engineering, Built Environment and Information Technology, University of Pretoria, Pretoria.

University of Pretoria (2002b): *Regulations and Syllabi 2002.* Faculty of Engineering, Built Environment and Information Technology, Part 1, University of Pretoria, Pretoria.

Van der Merwe JN (2004): *Departmental Annual Report 2003 – Advisory Council*. Department of Mining Engineering, University of Pretoria, March 2004.

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