Developing and Sustaining Capability in Process Mineralogy

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Abstract

There are a number of disciplines in the minerals industry for which concern has been expressed regarding the sustainability of human capital. The boom-bust cycles that occur in the industry, the trend in tertiary education towards consolidation or in some cases cessation of minerals related programs and the increasing frequency of fly-in fly-out operations can all contribute towards a decline in the number of professionals with basic skills in process mineralogy. This paper describes approaches taken by the authors to incorporate process mineralogy into three levels of education, namely undergraduate, recent graduate and experienced professionals. The primary objective in designing the learning activities is the development of authentic learning experiences that provide participants with relevant skills in process mineralogy. Selected examples of approaches used by other education groups globally to address this issue are also provided.

Keywords

Education, process mineralogy

Introduction

The boom and bust cycle of the mining industry has trickle down effects in tertiary education in terms of the ability of universities to consistently provide high quality graduates with relevant skills. When the commodity price surged in 2002 skills shortages in critical resource related professions were reported and despite investment in skill development there was a view from employers that not enough young people were graduating from relevant education programs (PricewaterhouseCoopers, 2012). At the time this signalled positive growth for engineering disciplines catering to the mining industry, however during the downturn cycles, most recently since 2012, graduates exiting from the discipline can find employment difficult and this contributes to reduced enrolments in subsequent years. From an AusIMM (Australasian Institute of Mining and Metallurgy) members' employment survey conducted in 2013, more than half of the graduates exiting from disciplines related to mining and minerals were not confident of finding employment (AusIMM, 2013). In the long term the concern is not only how to sustain enrolment and graduate numbers but also to provide the opportunity for students to acquire the professional skills that they require to make them attractive to industry.

Maintaining and sustaining core competencies in the minerals discipline is an ongoing challenge. There have been a number of recent papers on this issue presented at international conferences (e.g. McCaffrey et al, 2014; Drinkwater and Napier-Munn, 2014) and there is general agreement that one of the ways in which the deficit in foundation concepts can be addressed is through workplace development. Drinkwater and Napier-Munn (2014) presented data from a survey of industry professionals that indicated that more than 90% of respondents undertook on average 30 days of training each year of which approximately 5 days was professional short courses.

Munro and Tilyard (2009) indicated that there was a clear need to provide graduate metallurgists with basic skills during their undergraduate training. They articulated changes observed in the roles and capabilities of metallurgists (including graduates) based on 40 years' experience in the industry and noted that despite the information revolution and the opportunities that has provided, real improvements in process have not been realised. Trends in the industry (boom and bust cycles), trends in tertiary education (the consolidation or cessation of metallurgy based degrees due to enrolment numbers cycling in response to industry), and the trend towards fly-in fly-out operations raise serious questions about the sustainability of human capital in the industry. These fundamentals include an understanding of the basic data requirements for managing a mineral processing plant such as mass balances for solids, elements, minerals and water, knowledge of how minerals impact the process and the ability to transform data into information that can be acted on.

One of the challenges observed by undergraduate students in the discipline is the decline in opportunities for vacation work (AusIMM, 2013) and the increasing difficulty in finding placements for students in industry contexts, that provide relevant experiences and skills that they will use in their future careers. The number of students that have on-site industry experience by the time they reach the final year of their undergraduate course has changed dramatically from 20 years ago when the majority of a cohort of 21 students undertaking Mineral Processing Engineering had done vacation work in a mineral processing plant by the start of their third year, to only one student from a cohort of 36 from third year Chemical and Metallurgical Engineering class at the University of Queensland in 2014.

This paper seeks to highlight what is currently being done at the University of Queensland to close the process mineralogy knowledge gap and put in place mechanisms to maintain and sustain this capability in three spheres of learning namely: undergraduate, graduate and professional development. Examples from other education providers globally are also provided.

Context – The Data from Professionals

As eloquently described by Schouwstra and Smit (2011) “mineralogy in the mining industry is not just about identifying minerals – it is the application of the knowledge of the behaviour of the minerals and mineral phases during processing”. Making use of the data analytics created by web-based professional networking sites such as LinkedIn (https://au.linkedin.com/) it is possible to get some sense of the background and educational setting of those who list mineralogy as one of their skills. Close to 28 000 of those registered on LinkedIn listed mineralogy as one of their skills and Figure 1 shows the top 10 additional skills that were listed and the percentage of respondents listing those skills. Unsurprisingly this highlights the strong linkage between mineralogy and geology. The majority of respondents work in mining companies (shown in Figure 2), with some portion also from the service and technology sectors. In terms of their educational background, of those who provided this information, the majority were graduates of South African based universities followed by universities in Canada and Australia (shown in Figure 3), again not surprising given the global distribution of mineral resources.

Figure 1: Skills in addition to mineralogy that were listed on LinkedIn (Top 10 responses)

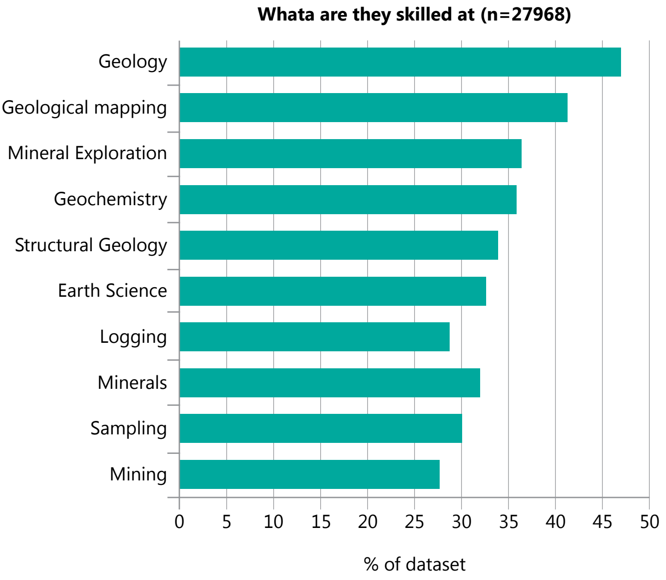


Figure 2: Workplace (Top 10 responses)

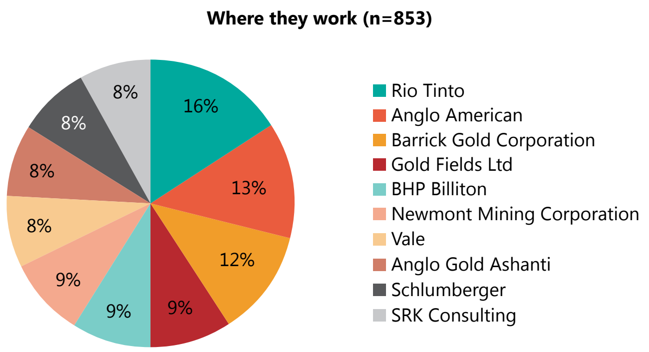
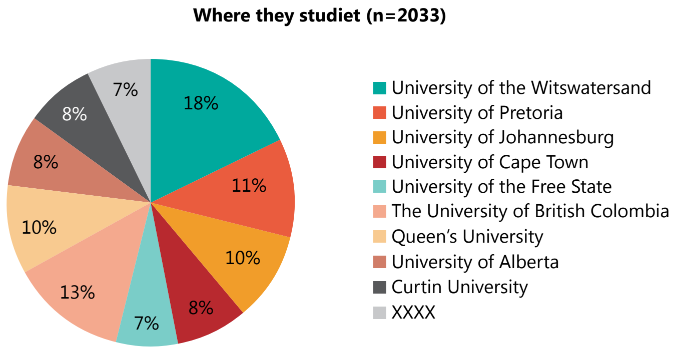


Figure 3: University attended (Top 10 responses)



Undergraduate Curriculum

Based on the data from Figure 3, the courses and programs offered at selected universities in South Africa, Canada and Australia were reviewed to get a sense of which programs offered courses in mineralogy and what type of content was offered in those courses. Again unsurprisingly the majority of the mineralogy courses form part of a geology related program. The mineralogy courses offered are predominantly at an introductory level with the content designed to provide foundational knowledge on crystallography, the physical and chemical properties of minerals and how to recognise and identify common minerals. However in some instances mineralogy is offered as part of a metallurgy program. Table 1 summarises the courses identified at five universities: two from South Arica, two from Canada and one from Australia.

At the University of Queensland (which interestingly does not appear in the data from LinkedIn), mineralogy related courses are offered through Earth Sciences and Chemical Engineering. The Earth Sciences course is similar in content to those in other countries shown in Table 1 in geology related disciplines. In the Chemical Engineering program the courses offered explicitly cover process mineralogy with a basic introduction provided as part of a third year compulsory course for those studying Chemical and Metallurgical Engineering. An advanced fourth year elective is also offered.

The aims of the third year course, taken from the course profile, are to (https://www.uq.edu.au/study/course.html?course_code=MINE3219):

- Develop an understanding of ore characteristics and how valuable minerals are liberated from ores for recovery through the process of rock breakage - comminution.
- Provide an understanding of the following key concepts:
    - The physical and chemical properties of minerals are determined by the bonding of species within these compounds and the respective crystal structures.
    - The physical and chemical properties of minerals are determined by the bonding of species within these compounds and the respective crystal structures.
    - The degree of liberation that must be achieved through ore breakage is a function of the subsequent separation processes that are to be employed.
    - Rock and ore breakage characteristics are dependent on the comminution technology employed and the ore characteristics.
    - The ore characteristics and degree of liberation can be predicted or assessed using quantitative process mineralogy techniques.

- Overall process optimization from orebody to product is achieved through assessment and appropriate integration of all operations in the overall process

Whilst the aims of the fourth year course are to enable students to (https://www.uq.edu.au/study/course.html?course_code=MINE3211):

- Deconstruct and critically analyse process performance in grinding, classification and flotation in a mineralogical context.
- Constructively engage with problem solving activities in a team environment.

The learning objectives for this course include:

- Plan a metallurgical survey that follows industry best practice by: obeying relevant sampling rules, using Gy's sampling theory to determine the minimum sample mass required and selecting the most appropriate sampling equipment.
- Conduct a mass balance for solids, elements, minerals and water and use this to diagnose the circuit performance.
- Conduct a mass balance for solids, elements, minerals and water and use this to diagnose the circuit performance.
- Examine a number of different unit operations within a circuit and use mineralogical data to calculate their performance with respect to the valuable minerals and other minor minerals which may impact downstream processes.
- Assess the implications of an ore change to the entire circuit e.g. how throughput impacts separability and the implications for smelting and tailings disposal.
- Diagnose the cause of changes in circuit performance (i.e. ore or process), recommend and justify mitigating action.

By putting these courses in place within the Chemical and Metallurgical Engineering program the University of Queensland is working towards addressing the knowledge gap in process mineralogy at the undergraduate level. The courses have been designed to provide an environment that promotes peer to peer learning and widens participation. Opportunities for active learning associated with experiential, problem and project-based learning promote collaboration among students have been provided by using realistic problems or situations and as a result a deeper understanding of the relationship between theory and practice can be developed (Crosling et al, 2009). Implementing these types of authentic learning experiences are a mechanism for providing the industry with high quality graduates and enhancing student retention, both of which will contribute to sustaining the skills pipeline.

Table 1: Summary of undergraduate courses related to mineralogy

Institution	School/ Department	Course name	General course content
University of the Witwatersrand (http://www.wits.ac.za/)	Geosciences	Geology II	Introduction to mineralogy. Recognition and identification of common minerals.
University of Cape Town (http://www.uct.ac.za/)	Science	Mineralogy and crystallography	Introduction to mineralogy. Recognition and identification of common minerals.
	Engineering and built environment	Mineral and metallurgical processing	Introduction to mineralogy and liberation analysis.
University of British Columbia (https://www.ubc.ca/)	Earth, ocean and atmospheric studies	Introductory Mineralogy	Introduction to crystallography, physical and chemical properties of minerals. Recognition and identification of common minerals.

Institution	School/ Department	Course name	General course content
Queen's University (http://www.queensu.ca/)	Geological sciences	Introduction to mineralogy	Introduction to mineralogy. Recognition and identification of common minerals.
Curtin University (http://www.curtin.edu.au/)	Metallurgical engineering	Process mineralogy	Basic principles of mineralogy and analytical methods. Emphasis on how the mineralogy and textures impact on ore processing.
	Applied geology	Mineralogy and geochemistry	Crystal chemistry of rock-forming minerals. Optical properties of minerals. Introduction to transmitted light microscopy.
	Applied geology	Process mineralogy and analysis	Introduction to mineralogy as applied to mineral processing. Instrumental methods for analysis.

Graduate Programs

There are a number of examples of graduate programs for metallurgists that are either accredited or industry funded. In some cases mineralogy is incorporated into these programs and this is described in the following sections.

Accredited Programs

An example of an accredited graduate program is the EMerald Erasmus Mundus Masters in Georesources Engineering (http://www.emerald.ulg.ac.be/). This is a two year program developed by four partner universities namely: Université de Liegè, Nancy Université, Luleå University of Technology and TU Bergkademie Freiberg. Process mineralogy is one of the courses taught in the first semester of the program.

Industry Funded Programs

Two examples of industry funded graduate programs for metallurgists are briefly described here. The first was initiated in 2002 and was put in place by Anglo American Platinum to provide a structured training program for metallurgical graduates and is known as the Anglo Platinum Graduate Development Program (AGDP) (Sweet et al, 2012). The program was developed in conjunction with the University of Cape Town and incorporates foundation and basic technical courses with structured site-based practical exercises. The second example is the more recent MetSkill program developed by JKTech in conjunction with the University of Queensland (Drinkwater & Bianco, 2012). The program is modular and has been designed to fast-track skills development in recent graduates and process mineralogy is one of the specialist topics offered.

Professional Development

Face-to-face

The University of Cape Town has offered a professional development (PD) short course in process mineralogy since 2005 (http://www.cmr.uct.

ac.za/cmr/news/process-mineralogy-course-2015). The week long course provides problem based learning experiences, encourages peer to peer learning and offers a range of active learning experiences related to working with rocks and minerals in a mineral processing context. To allow participants to extract the most value from the experience, the course is limited to approximately 18 delegates.

JKTech also offers short courses in process mineralogy. A series of modules covering the basics to more advanced case-study based applications, can be adapted for delivery either to a wide range of participants or targeted for specific operations. The courses have been developed and are delivered by specialists from the University of Queensland who form part of the JKTech extended faculty. One of the other impacts of the boom-bust cycle in industry is the lack of discretionary funding to allow professionals to travel. In response to these financial pressures and to make PD more available globally and to a wider range of participants in 2015 the decision was made to develop an online process mineralogy course.

Online

Online learning offers a wide range of benefits for learners, teachers and educational institutions. In order to maintain (or even improve) the quality of learning compared to that offered in a face-to-face environment a number of factors need to be considered, among these is how to translate content offered in a face-to-face context to an online setting. While the course content is, for all intents and purposes, the same, it has to be presented differently in the online environment. The team developing the course included subject matter experts, educational designers and other technical experts in visual design, multi-media and software development and involved collaboration between the University of Queensland (through UQx and the JKMRC) and JKTech. In adapting the course content, principles of good practice in education (Caplan, 2004) were followed.

Supporting the learner to actively take part is facilitated by providing them with authentic activities (i.e they have real world relevance, can be complex and ill-defined and extend over a period of time, provide the opportunity to examine the task from different perspectives, to reflect and collaborate) an approach which is advocated by a number of authors (Herrington et al 2003, Johnson and Aragon, 2003, Huang 2002). According to Hrastinski (2009), enhancing online learning can be achieved through enhancing participation. Strategies for encouraging learners to take part include avoiding information overload by limiting content and organising instruction around the learning cycle i.e. providing a learning guide/organiser; addressing individual differences in learners by providing content in multiple formats and incorporating games and multimedia (Johnson and Aragon, 2003). Rather than being superfluous, technologies selected for course delivery should be engaging and support both leaners and teachers (Caplan, 2004)

In addition to an appropriate mix of activities in online learning appropriate structure and leadership are crucial for online learners to take a deep and meaningful approach to learning (Garrison and Cleveland-Innes, 2005). The content for the online course was designed to encourage contact between participants and facilitators, use active learning techniques and providing prompt feedback.

Table 2 shows how the course content has been adapted from the face-to-face to the online environment. These changes take into account best practice from the literature and include the use of technologies, multi-media, chunking of content (including video content that is less than 10 minutes in length), active learning opportunities, feedback from formative quizzes and links to other resources. This is provided in a supported framework with structured learning experiences with major components of the online learning design including appropriate pathways and sequencing with predefined pathways provided to explore and discover different facets of the content while providing options to minimise information overload (Sims et al, 2010; McLoughlin, 2010). To promote interactions between participants, discussion board topics were created within the course content. The discussion board was also used to facilitate interactions between the participants and program leaders. The course is designed to allow self-paced, asynchronous learning and is open to participants over a period of approximately eight weeks.

Table 2: Comparison content in face-to-face and online process mineralogy course

Introduction	A short presentation (approximately 20 minutes)	Welcome video (3 min) Navigating the online environment (3 min video) Pre-course survey
What do metallurgists need to know about minerals?	A series of presentations Excel based learning activities (3 hours)	Two short videos (less than 8 min each) Two formative quizzes Drag and drop activities Interactive slide box activity
Current tools for characterisation	A series of presentations Excel based learning activities (2.5 hours)	Two short content videos (less than 8 min) A virtual lab tour Links to other web based resources Formative quiz
Managing and using the data	A series of presentations Excel based learning activities (4 hours)	Four instructional tutorials (9 min videos) Formative quizzes Excel based activities
Transforming data into information	A series of presentations Excel based learning activities (4 hours)	One content video (8 min) Links to web based resources Circuit analysis activity

Summary and Conclusions

As Schouwstra and Smit (2011) pointed out "universities cannot provide the training needed to produce an experienced mineralogist but they can provide the required background knowledge". In the context of process mineralogy there are opportunities (albeit limited to a few education providers) at both undergraduate and graduate levels. In the professional development arena the online environment provides exciting opportunities for reaching much wider range of participants. Despite the challenges associated with building and maintaining capability in process mineralogy, not all doors are closed, options are available and individuals need to make use of every opportunity to continue learning.

References

AusIMM members' employment survey (2013), viewed 23/05/2014, http://www.ausimm.com.au/content/docs/prof_emp_survey_summary.pdf

Caplan, D. (2004). Chapter 7 in Theory and Practice of Online Learning, Anderson T and Elloumi F (Editors), Athabasca University, Canada.

Crosling, G., Heagney, M. and Thomas, L. (2009). Improving student retention in higher education, Australian Universities' Review, Vol 51 No 2, 9-18.

Drinkwater, D. and Bianco, N. (2012). Developing technical excellence in young Australian metallurgical professionals – a new graduate development program, Minerals Industry Education and Training (IMPC), IIME.

Drinkwater, D. and Napier-Munn, T. (2014). Why good professional development is key to profitability in the mining industry, In Chapter 20 Proceedings: XXVII International Mineral Processing Congress, Santiago, Chile, 28-37.

Garrison, D. R. and Cleveland-Innes, M. (2005). Facilitating cognitive presence in online learning: interaction is not enough, American Journal of Distance Education, Vol 19, No 3, 138-148.

Herrington, J., Oliver, R. and Reeves, T. C. (2003). Patterns of engagement in authentic online learning environments, Australian Journal of Education Technology, Vol 19, No 1, 59-71.

Hrastinski, S. (2009). A theory of online learning as online participation, Computers & Education, 52, 78-82.

Huang, H-M. (2002). Towards constructivism for adult learners in online learning environments, British Journal of Education Techology, Vol 33, No 1, 27-37.

Johnson, S. D. and Aragon, S. R. (2003). An instructional strategy framework for online learning environments, New Directions for Adult and Continuing Education, No 100, 31-43.

McCaffrey, K., Giblett, A. and Dunne, R. (2014). Sustaining metallurgical competencies, In Chapter 20 Proceedings: XXVII International Mineral Processing Congress, Santiago, Chile, 15-27.

McLoughlin, C. (2010). Learner support in distance and networked learning environments: ten dimensions for successful design, Distance Education, Vol 23 No 2, 149-162.

Munro, P. D. and Tilyard, P. A. (2009). Back to the future – why change doesn't necessarily mean progress, Tenth Mill Operators' conference, Adelaide, South Australia, 12-14 October, 5-11.

PricewaterhouseCoopers. (2012). Mind the gap, solving the skills shortage in resources, viewed 23/05/2014, http://www.pwc.com.au/industry/energy-utilities-mining/news/mind-the-gap.htm.

Sims, R., Dobbs, G. and Hand, T. (2010), Enhancing quality in online learning: scaffolding planning and design through proactive evaluation, Distance Education, Vol 23 No 2, 135-148.

Schouwstra, R. P. and Smitt, A. J. (2011). Developments in mineralogical techniques – what about mineralogists?, Minerals Engineering, 24, 1224-1228.

Sweet, J. A., Harris, M. C., Franzidis, J-P., Plint, N. and Tustin, J. (2012). The AGDP in 2012 – nine years of exceptional graduate training, Minerals Industry Education and Training (IMPC), IIME.