Metallurgical engineering education - how do we sustain and grow our talent pool?

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Globally we face critical challenges associated with climate change, sustainable energy generation and storage, and electric vehicle transportion. The transition to sustainable energy and industrial practices is leading to increased demand for the critical metals required for the advanced materials used in the new, sophisticated devices. To achieve the sustainability targets, perversely, we need to invest in increased metals production as well as recycling in the short term, and also to invest in significant step change technological developments. The common thread linking these requirements is the need for a future educated workforce – a workforce that possesses the knowledge and skills to implement the required technological improvements in productivity, and the specialist expertise to be able to design and develop new technologies that meet the future needs of our industries and societies.

In short, in addition to investing in technology, we need to invest in education. But, as we understand from the present shortage of metallurgists, this is not a commodity that can be readily bought off the shelf in the short term. It requires strategic investment over the long term at all levels of the education value chain, by individuals, institutions and industry. In this paper, I explore some ideas and options for attracting young people into careers in metallurgical engineering.

INTRODUCTION

The issues of finding and retaining metallurgical engineers are once again attracting the attention of management as the global demand for minerals and metal products increases. Concerns about the decline in enrolments in geosciences, mining and mineral processing are not new. This shortage of graduates is not a recent phenomenon; it has been so for decades. The minerals industry has identified the need for these key professionals in a number of reports and studies over the years (MCA (1998), IMPC (2018). The fact that the problem still exists is not that there are no solutions to the problem – rather that the appropriate actions have not been implemented.

Governments around the world have invested significantly in education in recent decades. In particular, the proportion of people who have completed tertiary education is higher now than it has ever been. The proportion of students taking courses in science, technology, engineering and maths (STEM) has remained relatively low particularly in African nations (Tikly *et al.*, 2018), although efforts are being made to improve these numbers. In reality there is much more to be done to raise the general levels of education to those enjoyed by Organisation for Economic Co-operation and Development (OECD) countries and other major economies worldwide. Governments can provide general support for the education system but, given the demands from all professions, it is very difficult politically to pick out specific disciplines and industry sectors for additional funding.

The sources of trained metallurgical engineers from UK, USA and Europe have declined over the past several decades as these countries have moved away from the primary processing of ores and minerals, and universities in these countries have realigned their programmes towards downstream processing, advanced materials production and manufacturing.

Let us be clear about the educational objectives and outcomes we seek. The minerals and metallurgical processing industries need professionals with:

- Knowledge and competency in STEM fundamentals
- Specialist skills in process and metallurgical engineering
- Ability to work productively and professionally in engineering practice.

With the increase in digitalisation, skills in data analysis and the use of computer-based tools for process modelling and description are of increasing importance for the workforce of the future. Since new technologies will be required to address the challenges faced in the coming decades, we need scientists and engineers who can drive innovation and implementation of new technologies. Deep learning and competency requires support, practice in application and problem solving, and time to absorb and understand new concepts. Short-term band-aid measures will not provide long-term competency and quality outcomes. Development of these attributes in individuals requires creating opportunities and support; it takes time, effort and a range of activities and practical experiences.

What attracts students to professions/ careers/ programmes?

There have been many studies undertaken to determine the factors that influence career choices made by students at high school and universities. The bulk of these studies have been focused on investigating career decision making by students in OECD countries (OECD, 2020). Since each country has a different social and industry profile it is likely there will also be differences in attitudes and perceptions. A recent paper (Abe and Chikoko, 2020) examined factors that influence the career decision of STEM students at a university in South Africa. Three key themes that emerged from the analysis in this study were interpersonal factors, intrapersonal factors and career outcomes expectancy. Interpersonal influence was identified to be principally from interactions with families or high school teachers. Intrapersonal factors are those of self in the decision-making process. A significant proportion of individuals identified with the ‘champion mentality’ often citing wanting to ‘save’ or ‘change’ the world. Half the respondents identified their passions, dreams, aspirations, desire, and curiosity to study a career to be important in the decision-making process. Also included in intrapersonal factors were individual’s personality, reasoning or aptitude, inquisitive approach to life, desire to develop themselves with knowledge and skills, self-confidence, and personal morality and values. Career outcomes expectancy included financial issues, career opportunities and job prospects; most students perceived a career in STEM as economically very rewarding.

A notable feature of these surveys from my point of view is that, almost completely absent, is the influence of potential employers and the respective industry sectors. The mineral industry’s involvement in the educational process has changed markedly over time. Prior to the expansion of publically funded tertiary education in the middle of the last century, ‘learning on the job’ in various formats was the predominant means of knowledge and skills transfer. Over time, the connections between our educational institutions and industry have been weakened and in some cases, completely lost. This lack of connection, I believe, is an important factor and one that can be readily addressed in a variety of ways.

Awareness and Attraction

Students at high school and at universities are largely unaware of the importance of metals and metallurgical processing, and the wide range of opportunities for jobs and careers within the industry. They are unaware of the key role that this discipline plays in sustaining our technologically-based societies. This lack of visibility is one of the principal reasons that few students enrol in the discipline.

The general public still holds a negative view of the mining industry stemming from poor environmental and employment practices of the past. Unfortunately, they are not aware of the positive aspects of modern metallurgical processing operations; the new technologies now in place for primary production from minerals, metals production recycling and refining, and the manufacture of novel advanced metal compounds required for modern manufacturing practices. These issues need to be addressed if we are to attract smart young people into the industry.

The climate emergency (COP28) and the need for increased demand for critical metals offers an opportunity to radically change the narrative, raise the profile, develop a positive forward-looking view of the discipline and to present the profession to undergraduates as an attractive career path.

If it has the mind to, industry can demonstrate its commitment to improved environmental and social outcomes and increase metallurgy graduate numbers by proactively engaging and supporting educational initiatives.

High Schools

Knowing that this generation of students are motivated by interactions with teachers and experiences at high school, and that a significant proportion of individuals identified with the champion mentality often want to 'save' or 'change' the world, there are opportunities to do more to help teachers and high school students understand the importance of metallurgy in our society. Some of these issues, focused particularly on STEM education in Africa, have been identified and actions recommended by Tikly *et al.,* (2018). Roehrig (2023) describes the application of a framework for the integration of STEM into the teaching and learning of high school chemistry. The paper identifies seven characteristics of the approach: (a) focus on real-world problems, (b) centrality of engineering, (c) context integration, (d) content integration, (e) STEM practices, (f) 21st century skills, and (g) informing students about STEM careers. Roehrig says: "Unfortunately, integrated STEM classroom activities tend to focus on the technical aspects of engineering related to the design of 'things', such as designing cars and rockets, which perpetuate male dominance in STEM and negatively impact girls' interest in STEM careers. Girls are motivated by projects with a communal goal orientation that highlight how STEM can improve the human condition related to societal issues such as health and the environment. Thus, an approach grounded in care and empathy that engages students in considering the societal implications, as well as technical considerations of their design solutions is an important consideration." In the case of metallurgical engineering, to attract greater numbers of women into the profession, projects could include topics such as recycling of end-of-life manufactured goods and metals recovery, improvements to the environment through treatment processing streams before releasing into the environment, and critical metals for renewable energy generation technologies.

Industries and metallurgy academics can support these kinds of initiatives by:

- Providing project topics for high school teachers and students
- Supplying equipment that enables simple experiments to be undertaken by students
- Providing teachers with examples and explanations of metals processing that can be incorporated into learning activities
- Visits by engineers to high schools to explain the smart science and engineering underlying industrial processes
- Visits by high school teachers and students to industrial operations.

In general, schools welcome any additional resources that can help support student learning. Simple things can make a difference in stimulating the curious minds of STEM students: such as supplying a range of mineral sands that students can separate by size, density and magnetic techniques; samples of colour-coded particles of different sizes; ion exchange resins to investigate the selective separation of metal ions from aqueous solutions. Metallurgical and geological optical microscopes encourage students to explore the relationship between composition, microstructures and properties in ores and metals. Visits to companies would demonstrate how in practice the science can be used to transform natural resources into useful and valuable materials.

University programme structure and content

The structure and content of major engineering disciplines e.g. chemical, mechanical, materials engineering, are designed to produce graduates for a wide range of industries. Similarly programmes in chemistry, environmental or earth sciences are generic rather than specific in focus. These are appealing to students who do not have a clear direction in the early stages of their tertiary education. They are also appealing to tertiary institutions who want to reduce operating costs by increasing class sizes and reducing the range of course offerings. These generic programmes provide a sound platform of the basics but do not in most cases provide the specialised knowledge and skills required by the minerals and process metallurgy industries.

Flexible entry

In many instances, the students enrolling at university for the first time are required to select the department, school or area of specialisation at this entry point; this applies to both engineering and sciences. This is a major disadvantage for metallurgical engineering since most students are completely unaware of the discipline and its significance at this point in their life. Empirical evidence from student surveys shows that at least half of the students entering first year engineering studies at university are unclear about the branch of engineering they actually want to pursue in the long term. Students choosing science programmes in chemistry, environmental or earth sciences are also likely to be unaware of career options in minerals and metallurgical industries. University administrations should be encouraged to allow, and offer advice on, transfers between programmes during or following completion of years 1 and 2 until the start of year 3 of a 4-year programme. This flexibility in selecting the area of specialisation allows the student time to identify and experience what might be their future career direction.

Programme content

A simple but important step in raising awareness of the discipline for first and second year engineering undergraduates is to provide an elective introductory level course that covers the value chain of the minerals industry and outlines the challenges and opportunities in studying the discipline. Prerequisites to the course should be kept to a minimum with the only requirements being basic competence in first year maths, physics and chemistry. Experience has shown that a high proportion of students taking this type of elective go on to choose either further studies in metallurgical engineering or eventually seek employment in the minerals industry.

Developed in consultation with industry, the IMPC Mineral Processing Education Roadmap (2018) provides a list of recommendations for key competencies and specialist knowledge in mineral and metallurgical processing sought by the industry. The roadmap that can be used:

- by education providers, to review and evaluate their programmes
- by employers to assist with selection of personnel
- by employers to develop continuing development programmes for their young professionals
- by young professionals to manage their career progression.

In practice, the emphasis placed on different specialist areas and the detailed course content varies with institutions, and in general, reflects the needs of the local industry. Periodic assessments and accreditations should be undertaken to ensure that teaching, learning practices and outcomes of the programmes are maintained in line with national and international professional engineering standards.

University programme structures

The number of universities that offer metallurgical engineering degree programmes has been gradually decreasing in OECD countries. However, although not the preferred option, there are other ways in which these specialist courses can be presented to students. Where specific metallurgical engineering degree programmes cannot be offered, specialist courses can be provided as sub-programmes to be taken in, for example, the third and fourth year of engineering. These potential programme structures and their integration with kindred disciplines have been previously discussed by Hayes (2018). For example, at the University of Queensland, metallurgical engineering is offered as a major within the chemical engineering degree programme (Jak and Hayes, 2023) (see Figure 1).

The programme consists of a general first year of engineering mathematics, computer programming, engineering thermodynamics and chemistry with elective courses to enable students to broaden their understanding of other engineering disciplines. The second year provides a sound background in engineering sciences and process engineering fundamentals. Included here is the first course in metallurgical engineering, a general introduction to the whole value chain from ore, through metal production, to metal recycling.

Years 3 and 4 of the programme provide advanced courses in process engineering, and the application of physical and chemical fundamentals to metallurgical processes through specialist courses in process mineralogy and comminution, mineral processing separations, hydro- and electro-metallurgy, pyrometallurgy, and metallurgical plant design.

The major provides the core engineering science and process engineering, knowledge and skills associated with conventional chemical engineering programmes. The systems approach, and with it the use of process modelling tools, provides the ability to quantitatively describe and analyse material flows in complex integrated plant operations. In this way, the core process engineering competencies are provided to students through a conventional chemical engineering programme, and these are supplemented with specialist metallurgical engineering courses in year 3 and 4 of the programme.

UQ Metallurgical Engineering program plan				
Year 1 Sem. 1	Professional Engineering	Calculus & Linear Algebra	Thermodynamics: Energy and the Environment	General Elective
Year 1 Sem. 2	Computer Programming	Multivariate Calculus & ODEs	Chemistry	General Elective
Year 2 Sem. 3	Mass & Energy Balances	Investigation & Statistical Analysis	Fluid Dynamics	Physical Chemistry for Engineering
Year 2 Sem. 4	Process Equipment & Control Systems	Chemical Thermodynamics	Heat & Mass Transfer	Metal Production and Recycling
Year 3 Sem. 5	Unit Operations/ Process Control	Reaction Engineering	Major elective	Major elective
Year 3 Sem. 6	Process Systems Analysis	Dynamic Modelling & Control	Process Mineralogy and Comminution	Physical Separation Processes
Year 4 Sem. 7	Impact/Risk in the Process Industries	Professional Business/Practice	Pyrometallurgy	Hydrometallurgy and Electrometallurgy
Year 4 Sem. 8	Process Engineering Design Project		Major elective	Major elective

Figure 1. The courses and the current structure of the four-year BE programme in chemical engineering, majoring in metallurgical engineering at the University of Queensland. (Jak and Hayes, 2023)

Industry's role in developing a metallurgy workforce for the future

Establishing contacts with industry

Recognising that the majority of students entering engineering at universities are not clear about the range of opportunities available to them and their preferred career directions, industry can step up to boost enrolments in metallurgical engineering by

- Offering quality work experiences
- Providing vacation work to first and second year engineering students, preferably as part of project teams with third/fourth year students and a supervising engineer
- Offering paid part-time work experience/internships with professional engineers between classes during semesters
- Facilitating student visits to operating plants to observe at first hand and experience operations
- Awarding fee and living scholarships to students taking up studies in the discipline.

- Supporting and making presentations to student societies and activities
- Supporting mentor schemes for undergraduate engineering and science students.

Many professional metallurgical engineers cite their visits to industry and employment experiences as undergraduates, as key factors determining their decisions in selecting their degree studies and in the directions of their future careers. While those students living close to industrial operations may have already had the opportunity to visit metallurgical processing operations when at high school and know professionals working in the field, many students from urban locations have no idea of the processes or the scale and challenges of industrial operations, and what metallurgical engineers actually do.

First impressions are important. These initial contacts by students, whether brief or extended visits, can have a lasting impact and shape attitudes to the profession and/or the company. The aim is to attract smart and creative people to join us, so the presentations and experiences should inspire and encourage them.

In my view, vacation work is the single most powerful way of attracting students to take up studies in metallurgical engineering. These activities should start with students in their early years – students make up their mind about their choice of discipline in years 1 and 2 at university. Waiting to third or fourth year is too late - at this stage they are already committed. To maximise recruitment the number of places offered should be increased so that all students seeking work experience in the early years receive an offer. Word spreads. These students act as ambassadors to the student cohort back at university; telling their peers of their experiences – good and bad.

Vacation work structured around the delivery of an engineering project for the company as part of a project team provides experience of working in a team environment and engaging with engineers and professionals from other disciplines. A project team consisting of first and second year engineering students, third/fourth year students and a supervising engineer enables the junior engineering students, who may not yet have the technical or specialist background, to learn from other team members.

These placements have advantages for both students and employers. The students gain practical experience of applying their knowledge and skills into industrial practice, develop skills in professional practice, develop professional networks, meet potential mentors and obtain advice on career directions and choices from those who have already been down this path. These experiences improve self-confidence and provide additional personal motivation. The student should be encouraged to take on a number of different types of placement during their studies so that they form a clearer idea of future career directions. For the employer, if planned appropriately, the placement provides an additional pair of hands to undertake valuable tasks that need doing. This early engagement provides the opportunity for companies to review the qualities of the students and evaluate their potential as future employees.

The provision of part and full fee and living scholarships to students taking up studies in the discipline, in addition to providing an important method of recruitment and raising the profiles of sponsor companies, also serves to demonstrate to the student body the importance of metallurgical engineering to the industry.

The remuneration received by the student for undertaking these activities provides additional financial support that can be used to cover the costs of their education. This is particularly important for students from disadvantaged socioeconomic backgrounds.

While some companies are active in undertaking and funding these types of activities, unfortunately, many do not give these issues priority. The solution is to convince senior management that education and workforce development are important investments that bring improvements to efficiency and productivity, and thereby contribute to the long-term sustainability to the company.

Retention
While graduates acquire the basic knowledge and skills as part of their tertiary studies, they need to understand more about the realities of industrial operations and be exposed to broader life experiences. These experiences increase the skills and productivity of the individuals, increasing their value as employees to the company. Retaining skilled and motivated professionals brings the advantages of developing a workforce with detailed knowledge of the operations and adding to valuable corporate memory. Most companies would have in place a human resources department who can provide advice on career development within the organisation. Companies can support development of their junior staff through:

- Offering graduate programmes that provide experience across the business so that they fully understand the value chain, and the impact of each stage on the overall efficiency and economics of the operation.
- Encouraging participation in professional societies
- Providing access to ongoing education and professional development.

To remain competitive companies need to be aware of engineering developments elsewhere around the globe and be willing to invest in the latest technologies. However, investment is not just about machines and processes – it is also about investing in the people who can identify opportunities and who can implement the necessary changes. These experienced staff can be recruited from elsewhere or developed in-house, through supportive knowledge development within the company. Strategies that encourage retention of staff and progression to these senior R&D roles include:

- Providing clear career pathways and opportunities for personal development,
- Ensuring that working environments are conducive to encouragement and support of innovation.

CONCLUSIONS

The minerals and metallurgical industry is faced with both short and projected long-term shortages of metallurgical engineering professionals. The industry can no longer rely on the supply of expatriate workers from various parts of the world to fill the roles.

Governments throughout Africa are making investments to increase the proportion of students studying STEM courses as this has been identified as a key factor in enabling economic and social development in the region. The proportion of students taking higher degree studies is increasing; these are encouraging trends.

In my view, the onus is now on industry to solve this skills shortage problem. The situation can be resolved by modest and targeted investments by industry to actively engage with students at high schools and universities. The key factor is the connection of the industry with its future workforce. There are isolated examples where this is being done but, for significant change, the actions need to be implemented more broadly across the minerals industry. This requires a coordinated strategic approach by senior management and company boards to facilitate and sustain collaborative actions over the long-term.

The awareness and the importance of metallurgical engineering in helping to achieve environmental and sustainability goals needs to be brought to the attention of students in high schools and universities. This can be done by making clear to these students direct links between metal supply and solving the problems of climate change, sustainable energy generation and storage, and electric vehicle transportion, metals conservation and recycling, and environmental conservation. These issues and words are now well known. What needs to done is to demonstrate that there are reliable and rewarding careers in metallurgical engineering; careers that meets students' personal goals and expectations.

REFERENCES

Abe E.N. and Chikoko V. (2020) Exploring the factors that influence the career decision of STEM students at a university in South Africa. IJ STEM Ed. **7**, 60. https://doi.org/10.1186/s40594-020-00256-x

COP(2023) https://www.cop28.com/en/

Hayes P.C. (2019) The world needs metallurgical process engineers. JOM 71(2):463–468.

IMPC Mineral Processing Education Roadmap (2018) based on Proc. Symp. on Education: Mineral Processing for the Future, XXVIII International Mineral Processing Congress (IMPC 2016) Quebec City, Canada. https://impc-council.com/publications/impc-publications/

Jak E. and Hayes P.C. (2023). Options for Sustaining Metallurgical Engineering Education. In: Reddy, R.G., Anderson A., Anderson C.G., Fleuriault C., Spiller E.D., Strauss M., Vidal E.E. and Zhang M., New Directions in Mineral Processing, Extractive Metallurgy, Recycling and Waste Minimization. TMS 2023. The Minerals, Metals & Materials Series. Springer, Cham. https://doi.org/10.1007/978-3-031-22765-3_10

MCA (1998) Back from the Brink – Reshaping Minerals Tertiary Education, Minerals Council of Australia.

OECD (2020) Dream Jobs - Teenagers' Career Aspirations and the Future of Work https://www.oecd.org/berlin/publikationen/Dream-Jobs.pdf

Roehrig G. (2023) Interdisciplinary approaches to chemistry education, African Journal of Chemical Education—AJCE, 13(2), 93-115. Special Issue ISSN 2227-5835 93

Tikly L., Joubert M., Barrett A. M., Bainton D., Cameron L., and Doyle H. (2018). Supporting secondary school STEM education for sustainable development in Africa. Bristol Working Papers in Education, https://www.bristol.ac.uk/media-library/sites/education/documents/Supporting%20Secondary%20School%20STEM%20Education%20for%20Sustainabale%20Development%20in%20Africa.pdf

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Prof Hayes' research encompasses experimental studies on:

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He was the foundation director of the Pyrometallurgy Innovation Centre (PYROSEARCH) at the University of Queensland and developed strong research and development collaborations with the metallurgical industry. A feature of the research has been the focus on fundamental science in support of industrial processes and process development.