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Bridging the skills gap: a blueprint for enhancing ground control capabilities

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Abstract

The skills shortage in the mining industry is a critical challenge, particularly for organisations seeking geotechnical expertise, and can be attributed to several interrelated factors. Firstly, the number of universities offering specialised technical programs in specific areas, such as geotechnical engineering, mining engineering, and geology, has reduced over recent years. This is primarily due to a lack of awareness/interest by a new generation who demand meaningful and flexible work arrangements in combination with career development opportunities over traditional remunerative benefits. Compounding this issue is the fact that regulatory frameworks governing mining operations have become increasingly stringent, while the risk tolerance of mining executives has declined in response to diminishing public tolerance for industrial accidents. Consequently, the stress experienced by geotechnical professionals is often high, causing some to leave the discipline for other opportunities.

Another reason for the skills shortage is the fact that larger geotechnical teams are becoming a necessity to meet the growing demands of the technologies that are being implemented to manage geotechnical risks. For example, the advent of slope stability radars ushered in a new era of monitoring within the mining industry, but introduced an additional set of demands that had to be met by the geotechnical community to ensure the effectiveness of these tools. Finally, a significant proportion of the mining workforce in specific regions is anticipated to retire over the next 5–10 years putting further pressure on the industry (Stutt 2023).

Together, these factors have intensified the industry's struggle to secure the necessary technical expertise, meaning that company-specific development programs which offer a comprehensive learning experience for professionals have become more important than ever before. This paper will discuss a process for creating a geotechnical capabilities development program that can be applied to any mining organisation. It is hoped that by making this information publicly available, companies will adopt this process, or a similar process, thereby increasing the likelihood of a capable and thriving geotechnical community.

Keywords: *geotechnical, ground control, capabilities, development, advancement program, framework*

1 Context

The mining industry is a critical driver of global economic growth and is essential for the transition toward a more sustainable and renewable future. It relies heavily on technical professionals to ensure the safety and efficiency of operations. Geotechnical engineering, a discipline focused on managing the stability of excavations, is essential for managing hazards such as rockbursts and falls of ground. Despite its importance, the industry faces a skills shortage, driven by several factors including a poor industry perception created by environmentalists and mainstream media, a lack of awareness/interest, a reduction in academic programs and risk tolerance, as well as regulatory complexity and an aging workforce.

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Vale Base Metals (VBM) has been directly affected by this skills shortage across its 7 underground mines and 4 surface mines in Canada, Brazil, and Indonesia. This skills shortage has been enhanced by economic and operational challenges. Consequently, geotechnical professionals must adapt to a business environment where technical expertise is complemented by business acumen and collaborative efforts. To address this challenge, the Ground Control Capabilities Advancement Program (GCCAP) was developed for the business to achieve the following goal:

- create a more resilient and flexible business
- enhance skills and develop teams
- turn ground control professionals into future business leaders
- make ground control more attractive
- allow better management of vendors and partners
- increase individual and team efficiency
- increase engagement
- provide mobility opportunities.

While this paper focuses on developing a capabilities advancement program for ground control professionals, it is acknowledged that this is just one component of a broader, integrated approach to managing geotechnical risk. Organisations are also encouraged to implement a ground control management system (GCMS) that connects a people-focused framework with a future vision, while also integrating technology, decision-making, and assurance frameworks into a unified system. The VBM GCMS is illustrated in Figure 1.

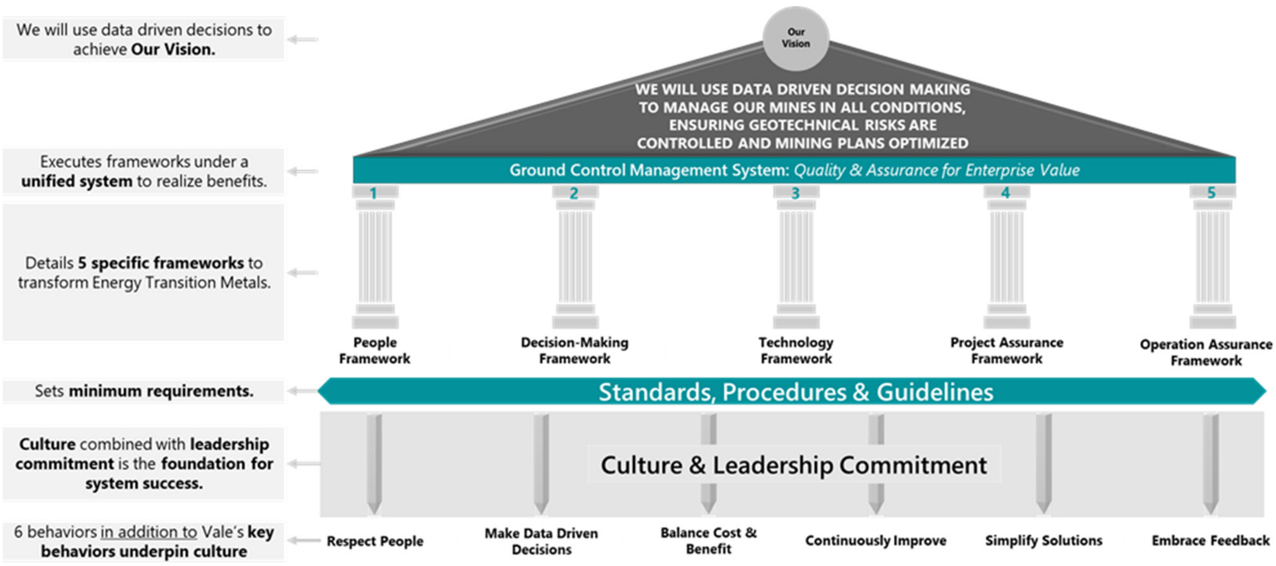


Figure 1 The Vale Base Metals ground control management system

2 Ground control management system

The VBM GCMS was developed as a comprehensive system to address geotechnical risk management within the business and is composed of 5 frameworks: people, decision-making, technology, project assurance and operations assurance.

These frameworks are built on a foundation of standards, procedures, and guidelines, underpinned by leadership commitment and a culture driven by key behaviours, as illustrated in Figure 1. The key behaviours include:

- respect people
- make data-driven decisions
- balance cost and benefit
- continuously improve
- simplify solutions
- embrace feedback.

By integrating these frameworks, the GCMS aims to create a cohesive and effective approach to managing geotechnical risks, ensuring that all aspects of the business are aligned and working towards common goals.

3 People framework

Integral to the GCMS is the people framework, which was developed primarily to support the geotechnical community within VBM. As shown in Figure 2, the people framework encompasses a range of initiatives designed to improve communication, roles and responsibilities, capabilities, career progression, and collaboration.

Figure 2 The components of the people framework for the Vale Base Metals ground control management system

The people framework is designed to embed initiatives that drive growth, stability, and adaptability directly into operations and capital projects. By aligning the people framework with the GCMS, it ensures that skills development is not treated in isolation but as a core element of a unified strategy for managing geotechnical risk and improving business performance.

A major deliverable of the people framework is to create a comprehensive GCCAP that aligns with corporate goals, to ensure capabilities within the business today are understood and to build the skill sets of tomorrow.

Before embarking on the creation of a GCCAP, it is essential to define what constitutes a good development program. A good development program should:

- address the growing skills gap for both present day and future capabilities
- ensure the program is suitable for all ground control professionals across all levels, regions and mines of the organisation
- balance the technical career minded and those who aspire to become managers; developing technical, business and soft skills
- identify both active and passive learning opportunities for ground control professionals throughout their career.

4 Skills gap

The skills gap in the mining industry is a multi-faceted issue. A major factor is the lack of awareness/interest by a younger generation that is driven by meaningful and flexible work arrangements in combination with career development opportunities, refer to Figure 3. Unfortunately, this has resulted in a noticeable reduction in the number of academic programs and therefore a reduction in the size of the talent pool. Additionally, the ongoing retirement of professionals from the mining workforce has led to a loss of institutional knowledge without adequate transfer to younger workers. Furthermore, the rapid evolution of technologies and increasing regulatory requirements necessitate continuous professional development, which many organisations lack the resources to support. These factors collectively contribute to a growing gap in the skills and knowledge required for effective geotechnical risk management.

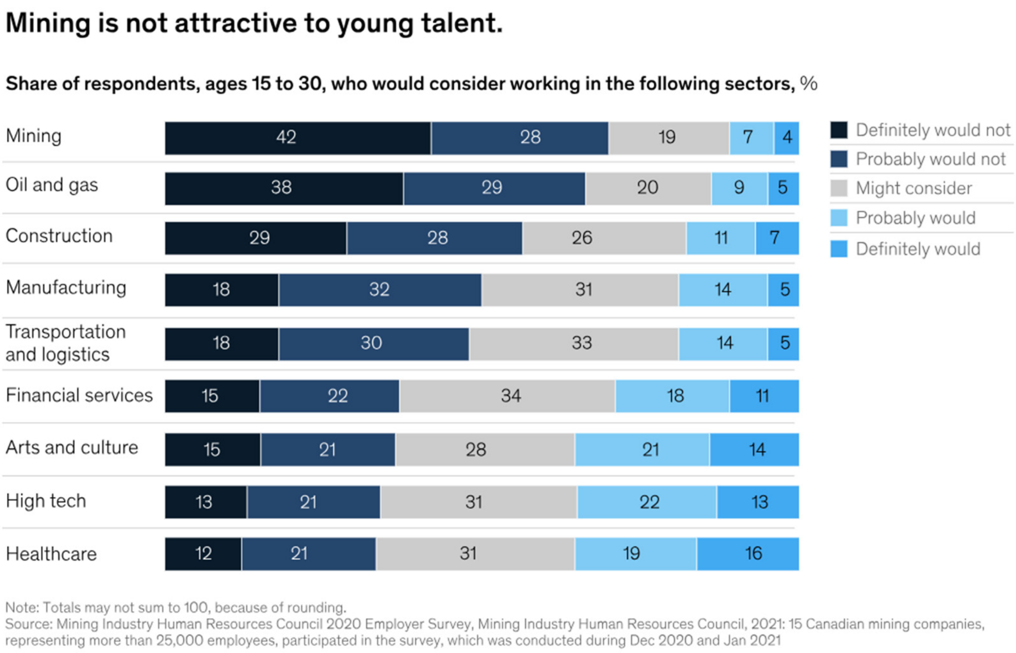


Figure 3 Survey results on individuals' willingness to work in various sectors (Mining Industry Human Resources Council 2021)

At VBM, the skills gap has been identified as a key challenge, both internally and by its Underground Geotechnical Review Board, across multiple operations. Recognising the strategic importance of addressing this issue, VBM has also identified the broader value of investing in employee skills. Deloitte (2022) discusses this value in detail and stipulates that organisations which prioritise and invest in skills are 57% more likely to anticipate and respond effectively to change, 107% more likely to allocate talent efficiently, 98% more likely to retain high performers, and 52% more likely to innovate.

To address this gap and realise the associated benefits, VBM developed the GCCAP. The program includes a skills referential, self-assessment tool, upskilling toolbox, and an online learning platform offering modules in a variety of formats to suit different learning preferences. Several other companies have also recently launched similar initiatives. For example, Rio Tinto recently launched a geotechnical capability development program in partnership with the Mongolian University of Science and Technology and The University of Queensland (Rio Tinto 2021). Similarly, Harmony Gold launched a pilot training program in partnership with the University of Pretoria, aimed at offering training tailored to a level comprehensible to all employees. This training program embraces the 70–20–10% approach discussed by Lombardo & Eichinger (1996). Furthermore, Holcim launched a global learning and development program for its employees to develop skills and qualifications autonomously in various languages and formats (Holcim 2025). Finally, BHP Billiton has launched multiple initiatives to address skills shortages, including its Mining School of Excellence (MSoE) the Future Fit/Future Tail Academy, and the BHP School of Rock (Creagh 2019).

5 Learning taxonomy

The VBM GCCAP has a defined learning taxonomy which is split into 3 areas; capabilities, skills and knowledge areas – as shown in Figure 4. Capabilities are a combination of people, processes, and technologies that define what a company does to fulfill business strategy and satisfy stakeholders. A skill is a learned ability that enables someone to accomplish a specific task effectively. It is possible for someone to be technically skilled to do a job, or possess soft skills that impact interpersonal relationships. Finally, a knowledge area can be taught in the classroom theoretically as a passive learning module, or on the job as an active learning module. An organisation's capabilities are made up of skills which are in turn made up of knowledge areas.

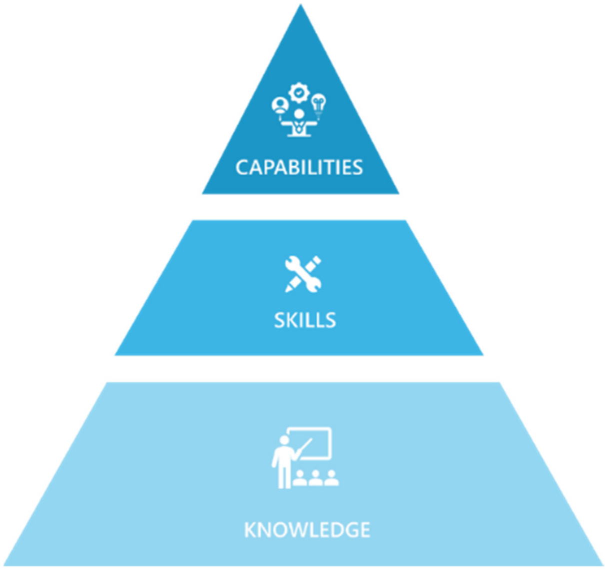


Figure 4 Learning taxonomy

6 Organisational baselining

To build a capabilities advancement program for any organisation, it is first necessary to understand the community that would benefit from such a program. Therefore, a community mapping exercise is required to understand the organisation's ecosystem. Refer to Figure 5 for the results of a community mapping exercise at VBM.

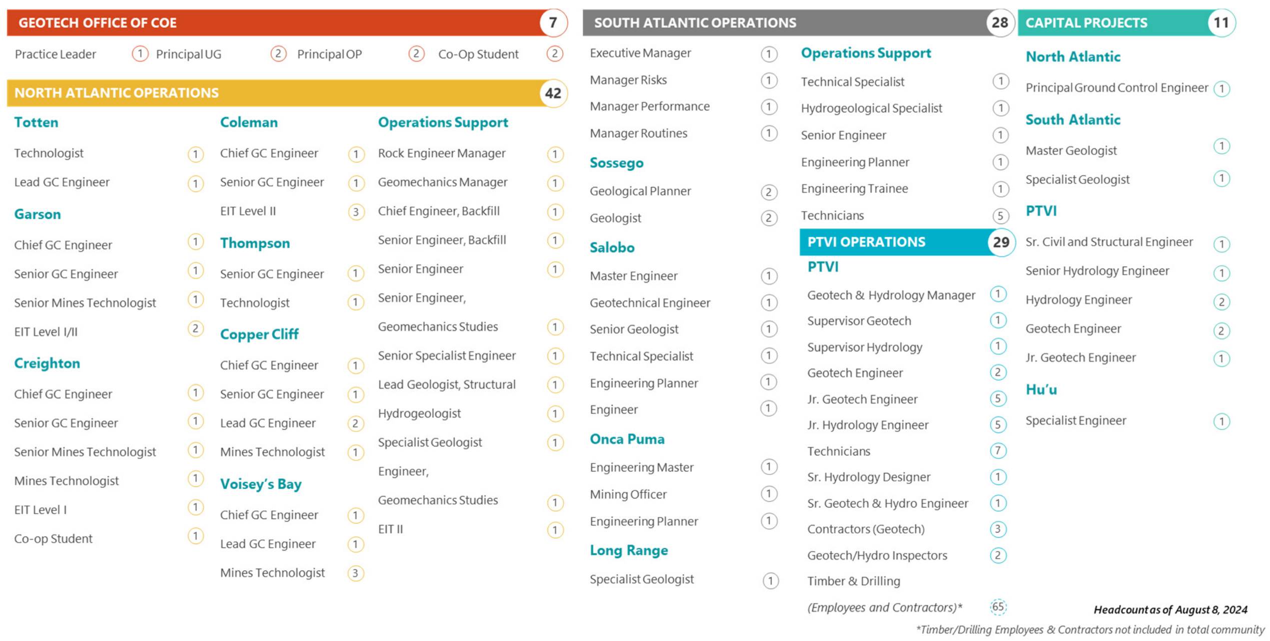


Figure 5 Community mapping exercise example

It can be seen from Figure 5 that there are a wide variety of role titles. This is not uncommon for a large, global organisation which operates in multiple jurisdictions, and to build a GCCAP, these roles need to be grouped to simplify the process.

7 Deliverable-based skills mapping

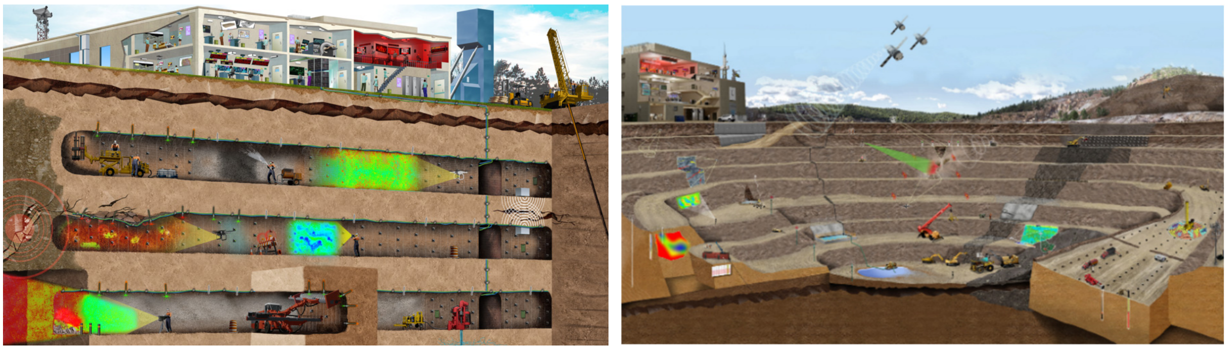
Once the community has been identified, it is necessary to define all deliverables that a professional must carry out to manage geotechnical risks successfully. Clearly defined deliverables provide a structured framework that guides work and ensures the GCCAP is aligned with the overall objectives of the business.

Over the course of several workshops, the deliverables of the ground control community at VBM were identified, as well as the interfaces for various deliverables. These deliverables and their interfaces were then mapped to various technical, business, and soft skills that were deemed important by workshop participants.

For the VBM GCCAP, geotechnical skills were defined as skills that ground control professionals use as part of their everyday jobs, to achieve tangible geotechnical related objectives or provide decision-making knowledge to others. Business skills were defined as skills that ground control professionals must know to practice ground control activities in the broader context of the organisation and to be able to embrace trade-offs and achieve business objectives. Finally, soft skills were defined as skills that ground control professionals need to know to work effectively and harmoniously with others inside and outside the organisation.

The geotechnical, business, and soft skills were aggregated to form a comprehensive list. This list was subsequently cross-referenced with a skills inventory derived from external research, which encompassed a wide array of sources, including job descriptions, databases, and relevant publications. By integrating diverse sources, the final list of skills made was comprehensive and aligned with industry standards and expectations.

Subsequent work sessions were then conducted to anticipate future changes and determine the horizon at which these changes might occur. These sessions also focused on how work may be performed in the future, what the ground control professional of the future may look like, and consequently, what skills will be required to meet these evolving demands. Refer to Figure 6 for the future visions created for the management of geotechnical hazards at VBM for underground and open pit assets.



(a) (b)

Figure 6 Illustrations of the technology roadmaps for (a) underground mines and (b) open pit mines at Vale Base Metals

Based on the visions above, the following future shifts in geotechnical work have been anticipated at VBM:

- a pivot away from in-field to remote operations with an emphasis on analysis and decisions
- the broad expansion of data collection and utilisation
- a focus on data-driven decision-making in real time
- the use of advanced tools and dynamic scenario-based models to balance uncertainty
- a reward-adjusted view of risk to support integrated planning
- collaboration continues to be critical for technical excellence.

Once identified, the skills were systematically organised into groups, which were then categorised by themes to create a detailed skills map. Refer to Figures 7 to 9 for the resultant geotechnical, business, and soft skills respectively; these were identified for the ground control community within VBM.

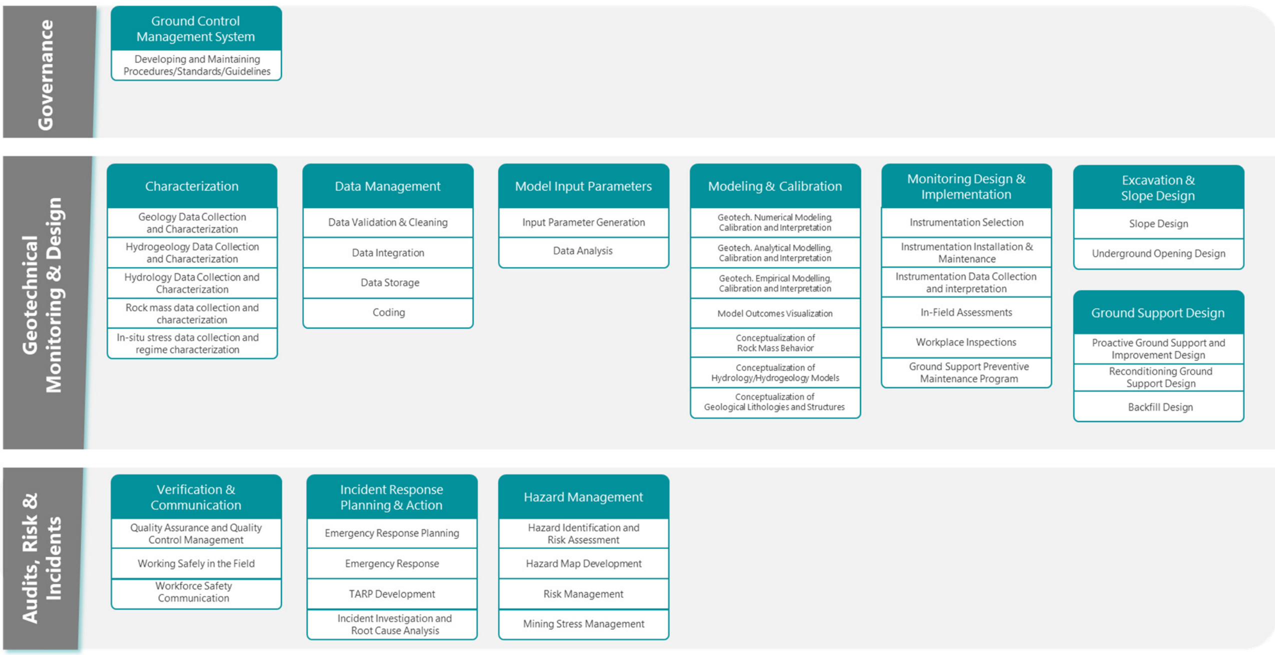


Figure 7 Geotechnical skills map for Vale Base Metals

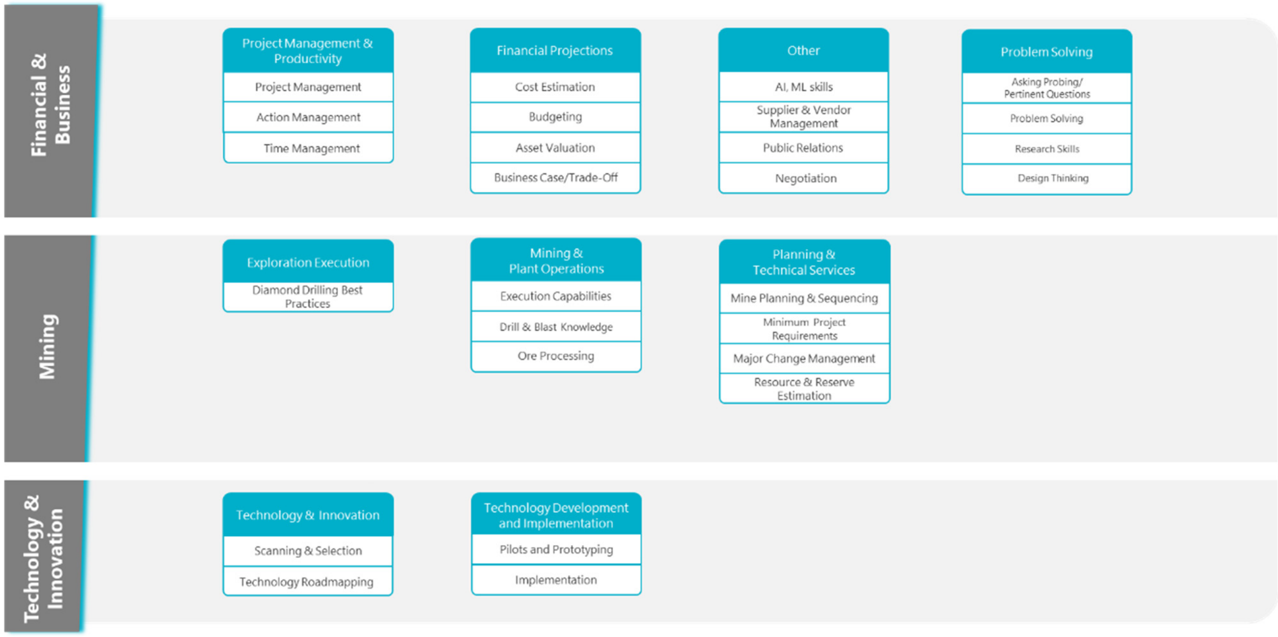


Figure 8 **Business skills map for Vale Base Metals**

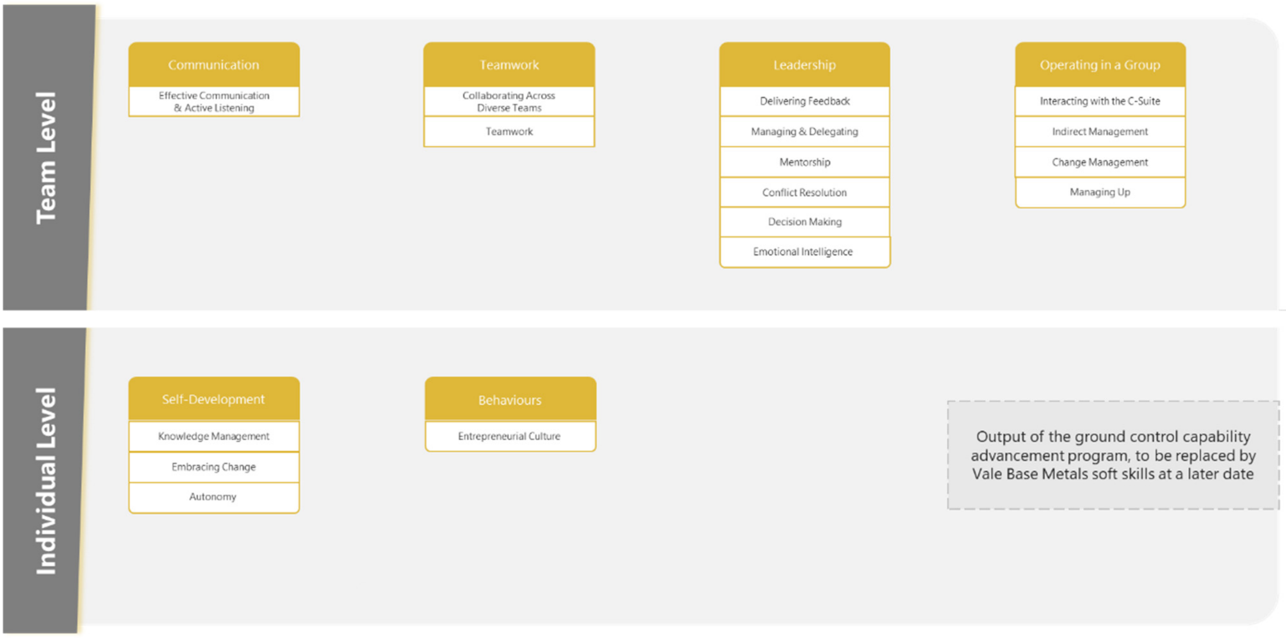


Figure 9 **Soft skills map for Vale Base Metals**

8 Role profiles

Using the results of the deliverable-based skills mapping exercise, role profiles were then defined consisting of jobs that have similar deliverables and skills. At VBM, 117 jobs were categorised into 6 role profiles including independent qualified individuals, operations (ground control management), operations (ground control), operations (hydrogeology and hydrology), operations (technologists and technicians) and capital projects (ground control).

Refer to Figures 10 to 15 for details regarding the role profiles created at VBM. It is hoped that these profiles can be used as a template for other organisations that wish to create their own role profiles.

Figure 10 Vale Base Metals independent qualified individual role profile

Figure 11 Vale Base Metals ground control management role profile

Figure 12 Vale Base Metals ground control role profile

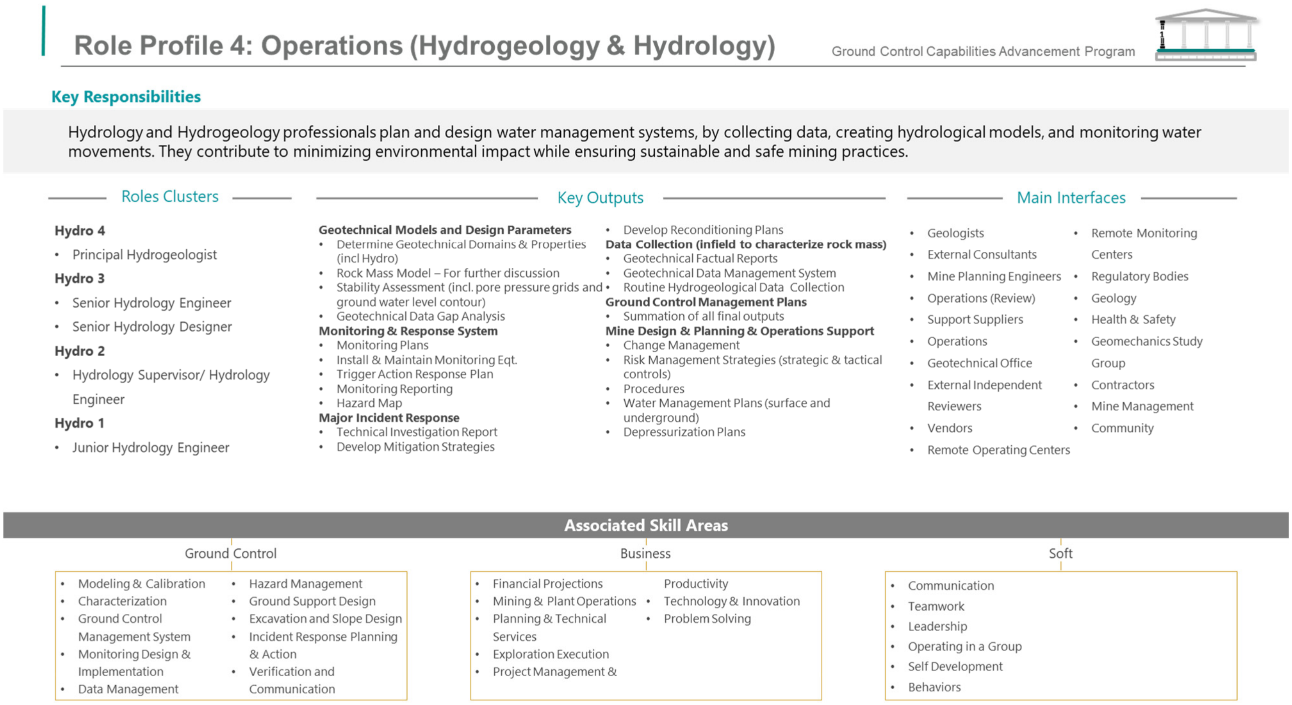


Figure 13 Vale Base Metals hydrogeology and hydrology role profile

Figure 14 Vale Base Metals technologists and technicians role profile

Figure 15 Vale Base Metals capital projects role profile

9 Skills prioritisation

Once a company-wide map of geotechnical objectives and skills was built, skills were prioritised so that proficiencies and learning modules could be developed for high priority skills in a timely manner; as well as to not overwhelm the search for solutions or the ground control community within the business.

At VBM, the process of skills prioritisation involved ranking each skill according to severity and scarcity, refer to Figures 16 and 17. Severity being the impact of the skill on the business if it were lacking, and scarcity defined as how common the skill is across the business. Each skill was then plotted on a 2 × 2 matrix to illustrate primary, secondary, and tertiary skills. To ensure priority skills were in line with the strategic needs of the business, a review by ground control leadership was carried out and adjustments made.

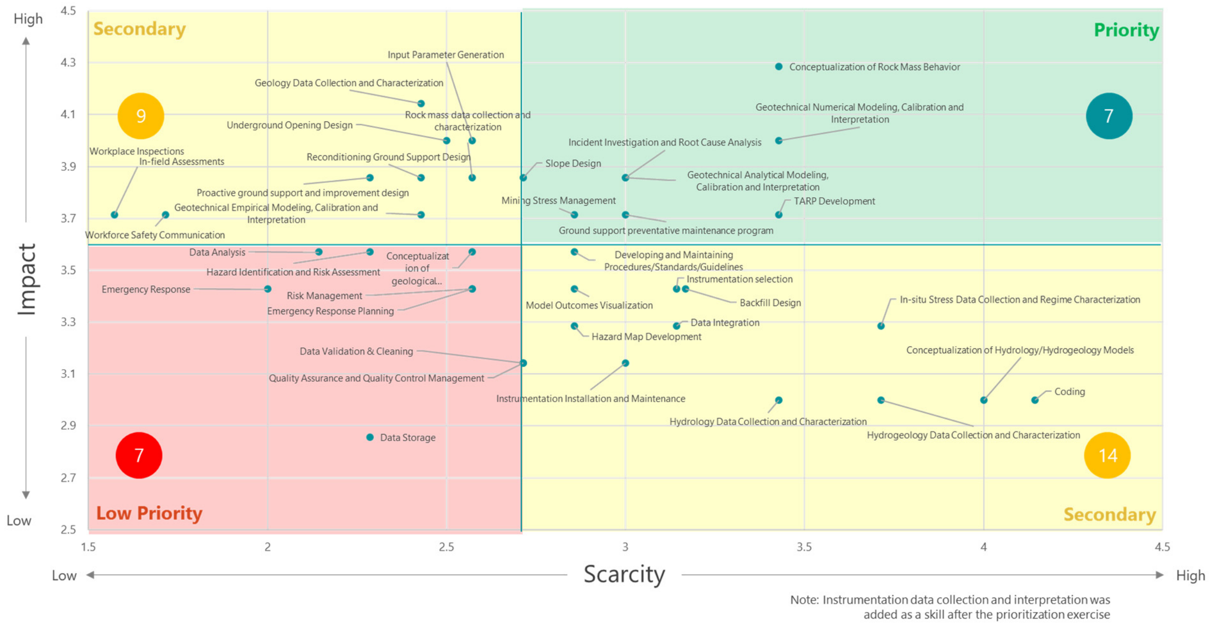


Figure 16 Results of the technical skill prioritisation exercise for Vale Base Metals

Figure 17 Results of the business skill prioritisation exercise for Vale Base Metals

10 Skill proficiency and matrix

The GCCAP for VBM introduces a multi-dimensional proficiency matrix with explicit performance bands. These performance bands were defined as the following:

- foundational: basic understanding of concepts and principles
- intermediate: ability to apply knowledge in controlled settings
- advanced: expertise in solving complex problems and innovating solutions.

Each band was associated with cognitive load thresholds, and behavioural markers, otherwise known as knowledge areas. Professionals advance through evidence-based achievement milestones. Refer to Figure 18 for an example of a skill and its associated knowledge areas defined for each proficiency.

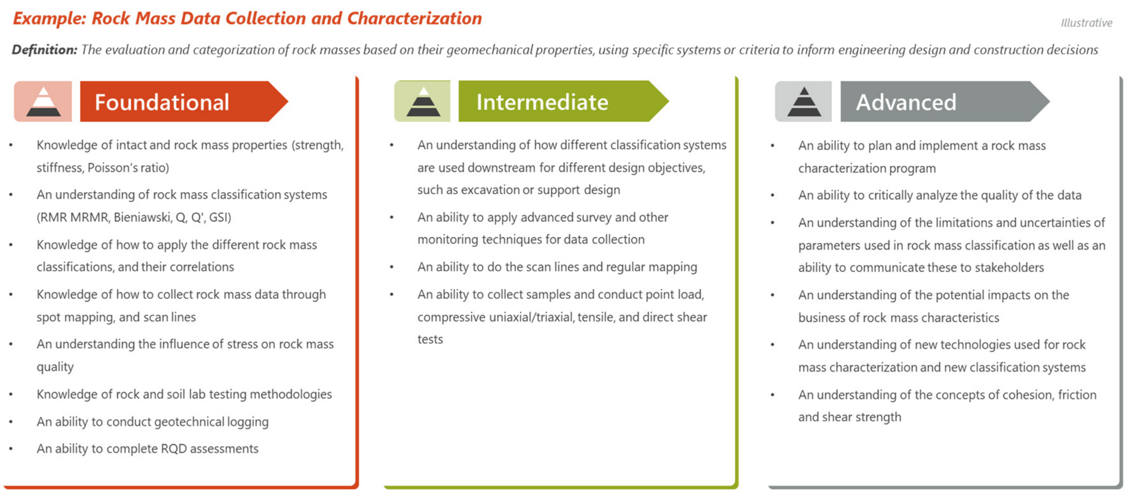


Figure 18 Example of proficiency definitions for rock mass data collection and characterisation

Once proficiencies were defined for all skills, a skills matrix which cross-references specific roles with skills and required proficiency levels was created. Unlike role profiles, which describe responsibilities, the skills matrix provides a detailed framework for identifying training needs, assessing workforce capabilities, and planning succession. Refer to Figure 19.

Ground Control Skills	Geotech Office 1	Geotech Office 2	Ground Control Ops 1	Ground Control Ops 2	Ground Control 1	Ground Control 2	Ground Control 3	Ground Control 4	Hydro 1	Hydro 2	Hydro 3	Hydro 4	Techno 1	Techno 2	Capital Project 1	Capital Project 2
Ground Control Management System																
Developing and Maintaining Procedures, Standards and Guidelines	A	A	A	A	F	F	I	A	F	F	I	A	F	F	F	I
Characterization																
Geology Data Collection and Characterization	A	I	A	I	F	I	A	A	NP	NP	NP	NP	F	I	I	A
Hydrogeology Data Collection and Characterization	A	I	I	I	F	I	I	A	F	I	A	A	F	I	I	A
Hydrology Data Collection and Characterization	A	I	I	I	F	I	I	A	F	I	A	A	F	I	I	A
Rock mass data collection and characterization	A	I	A	I	F	F	I	A	NP	NP	NP	NP	F	I	I	A
In-Situ Stress Data Collection and Regime Characterization	A	I	A	I	F	I	A	A	NP	NP	NP	NP	F	I	I	A
Data Management																
Data Validation & Cleaning	A	I	A	I	F	I	A	A	F	I	A	A	F	I	I	A
Data Integration	A	A	A	A	F	I	A	A	F	I	A	A	F	I	I	A
Data Storage	A	I	A	I	F	I	A	A	F	I	A	A	F	I	I	A
Coding	A	I	F	F	F	F	I	A	F	F	I	A	F	I	I	A
Model Input Parameters																
Input Parameter Generation	A	I	I	I	F	I	I	A	F	F	I	A	F	F	I	A
Data Analysis	A	I	I	I	F	I	I	A	F	F	I	A	F	I	I	A
Modeling & Calibration																
Geotechnical Numerical Modeling, Calibration and Interpretation	A	I	I	I	F	I	A	A	NP	NP	F	F	F	F	I	A
Geotechnical Analytical Modeling, Calibration and Interpretation	A	I	A	I	F	I	I	A	NP	NP	F	F	F	F	I	A
Geotechnical Empirical Modeling, Calibration and Interpretation	A	I	A	I	F	I	I	A	NP	NP	F	F	F	F	I	A
Model Outcomes Visualization	A	A	I	I	F	I	I	A	NP	NP	F	F	F	I	I	A
Conceptualization of Rock Mass Behavior	A	I	A	I	F	I	I	A	F	F	F	F	F	F	I	A
Conceptualization of Hydrology/Hydrogeology Models	A	I	A	I	F	F	I	I	F	I	I	A	F	F	I	A
Conceptualization of geological lithologies and structures	A	I	A	I	F	F	I	I	F	F	I	I	F	F	I	A
Monitoring Design & Implementation																
Instrumentation Selection	A	A	I	A	F	I	I	A	F	I	I	A	F	I	I	I
Instrumentation Installation and Maintenance	A	I	I	A	F	I	I	A	F	I	I	A	F	I	F	I
Instrumentation data collection and interpretation	A	I	I	A	F	I	I	A	F	I	I	A	F	F	F	I
In-field Assessments	A	A	I	A	F	I	I	A	F	I	I	A	F	I	F	1

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NP No Proficiency Required F Foundational I Intermediate A Advanced

stratalis

Figure 19 Example of a skills matrix

11 Self-assessment

Self-assessment tools enable professionals to evaluate their skill gaps and identify areas for improvement. These tools may include competency checklists, digital platforms with adaptive tests, and feedback mechanisms. By engaging in self-assessment, individuals can take ownership of their professional development and align their learning goals with their career aspirations and business requirements. A self-assessment tool was created for the VBM ground control community, to serve as a baseline and launching point for the GCCAP. Key aspects of the self-assessment survey tool include, but are not limited to:

- the gaps between current and expected proficiency level in the skills matrix are displayed
- a confidential comparison to peers within the same profile and role is displayed
- the tool can show which skills need to be developed for future roles
- the tool can also be used to facilitate the conversation between the professional and their leader, aiming at selecting which skills to focus on
- these development priorities exist for both their current role and their future aspired role.

Refer to Figure 20 for a selection of images of the self-assessment tool that was developed to support the VBM ground control community.

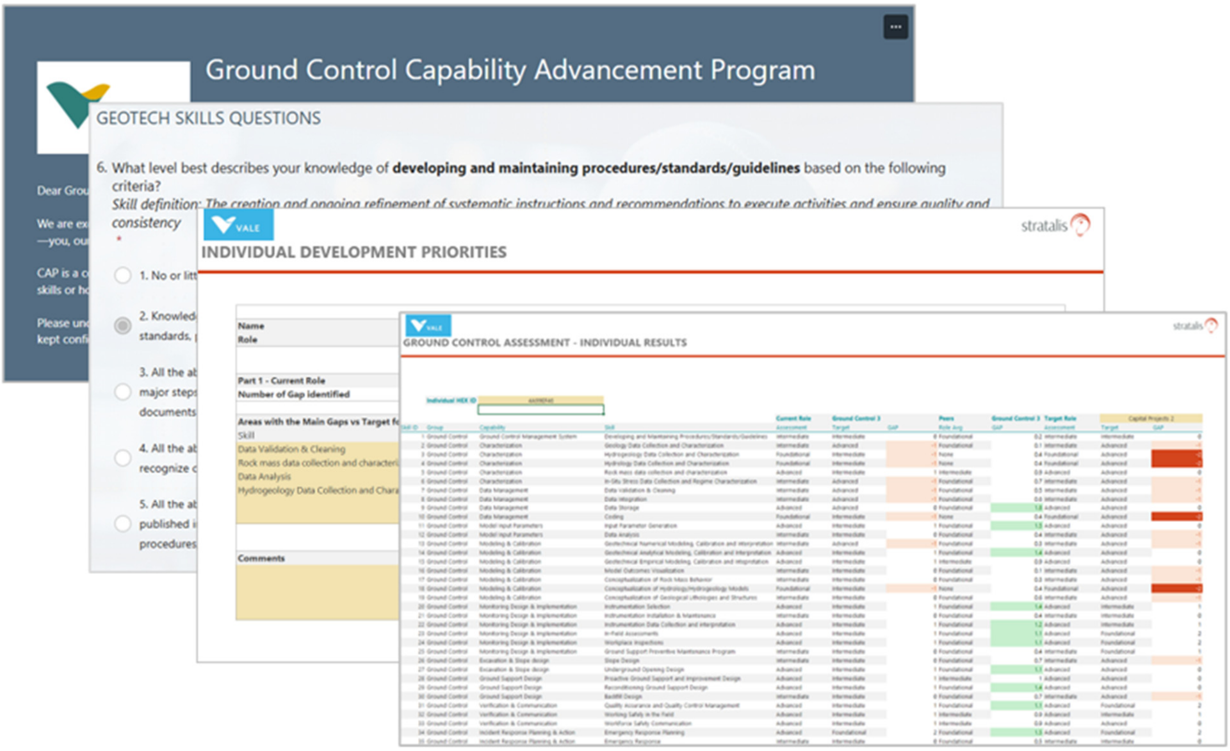

Figure 20 A selection of images of the self-assessment tool developed for the Vale Base Metals Ground Control Capabilities Advancement Program

Each member of the VBM ground control community carried out the self-assessment survey and a comprehensive analysis of the data collected was carried out, to understand broad capabilities within the organisation and to determine if preconceived hypotheses about the state of the ground control community in VBM were true.

As a result, it was discovered that most of the survey participants had an intermediate or advanced level of proficiency in safety-related skills, such as workforce safety communication, workplace inspections and working safely in the field – reflecting the company's long-term emphasis on workforce safety. Additionally, it was also discovered that many survey participants expressed gaps in 'future skills', such as coding, artificial intelligence, and machine learning, suggesting an opportunity to improve expertise required to meet the demands of emerging technologies and practices in the mining industry. Furthermore, some of the greatest opportunities for skills improvement in VBM included data collection, geotechnical numerical modelling, and rock mass behaviour conceptualisation. Finally, gaps in areas such as business case development, trade-off analysis, and cost estimation highlighted the need to develop business skills that enable community members to make better decisions; while addressing gaps in resource and reserve estimation as well as mine planning and sequencing enable community members to work more collaboratively with other disciplines.

12 Upskilling toolbox

An upskilling toolbox was then developed with customised learning approaches for all knowledge areas. Learning approaches can be categorised into passive and active learning. Passive learning methods involve structured, instructor-led or self-paced training. Examples include:

- off-the-shelf courses: pre-designed online modules, such as those offered by Coursera or the Australian Centre for Geomechanics.
- custom courses: tailored programs developed in collaboration with industry experts to address specific needs, such as slope stability analysis or seismic hazard assessment.

Active learning emphasises practical application and experiential learning. Key methods include:

- mentorship: pairing less experienced professionals with seasoned experts to facilitate knowledge transfer
- job rotation: providing exposure to diverse geotechnical scenarios to broaden skill sets
- secondment: temporary assignments to regulatory bodies or other organisations to gain insights into compliance and best practices

It can be seen from Figure 21 that knowledge areas for the primary skills were classified according to learning approach. For active learning, approaches included absorption, mentorship, tutelage, job rotation and secondment. While for passive learning, approaches included off-the-shelf courses and custom courses.

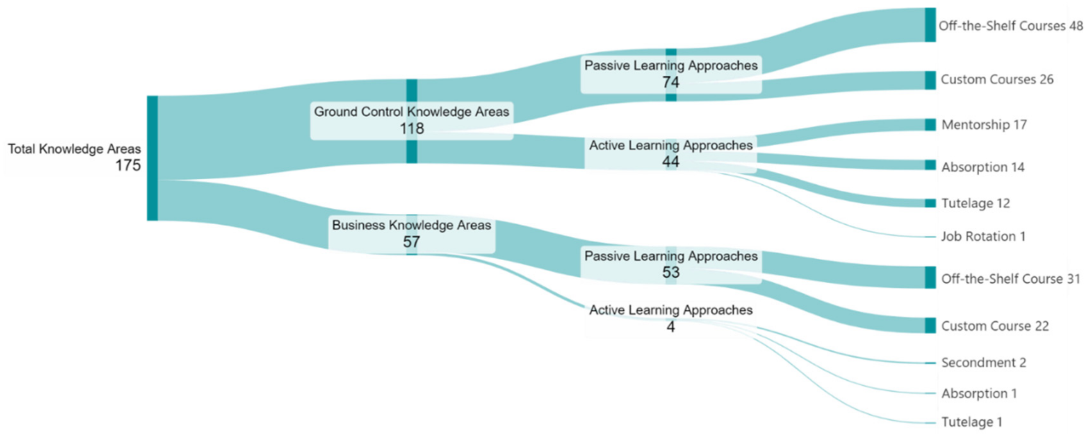

Figure 21 Breakdown of knowledge areas and associated learning approaches for the primary skills of the Vale Base Metals Ground Control Capabilities Advancement Program

13 Course catalogue

Finally, a course catalogue was also developed as part of the VBM GCCAP. The courses were sourced with subject matter experts from learning platforms, academia and vendors. Courses were organised by skill, proficiency, and knowledge area to match upskilling objectives (refer to Figure 22).

Figure 22 An example of a course 1-pager developed for the Vale Base Metals Ground Control Capabilities Advancement Program course catalogue

14 Conclusion

The development and implementation of a GCCAP at VBM has revealed several insights that may serve as valuable guidelines for others undertaking similar journeys in capability building within technical domains.

First and foremost, it is essential to begin with a clear understanding of purpose. Knowing the ‘why’ behind the program, what specific jobs are to be done and what value does the technical function delivers. This information provides a foundation for meaningful design. This clarity also ensures that the program is not merely a collection of training modules, but a strategic enabler of operational excellence and risk mitigation.

Equally important is the recognition and management of the most significant challenges, which are often both human and technical in nature. On the human side, successful implementation requires proactive engagement with non-technical stakeholders such as human resources and information technology teams. These partnerships demand clear communication, shared objectives, and mutual respect. On the technical side, the task of deconstructing geotechnical skills into their fundamental components can be daunting. It requires deep expertise and a willingness to confront the complexity of what is often tacit knowledge. Yet, through this process, it is often discovered that more insight and capability are possessed than initially realised.

Delving into the technical detail is not something to be feared. In fact, it is a necessary step in creating a program that is both rigorous and relevant. Breaking down knowledge into discrete, teachable elements demands precision and discipline, but it is this granularity that enables effective learning and skill transfer.

Prioritisation is another cornerstone of success. Without a disciplined approach to identifying and focusing on the most critical skills, there is a risk of creating an encyclopaedic repository that overwhelms rather than empowers. The goal must be to deliver targeted, high-impact learning experiences that align with operational priorities and risk profiles.

Accessibility is also paramount. Knowledge must be available at the point of need, through platforms that are intuitive, flexible, and responsive to the realities of field-based work. A well-designed learning environment supports just-in-time learning and reinforces continuous development.

Moreover, the program must be designed to create a natural pull for participation. Rather than relying on mandates or punitive measures, the most effective programs cultivate intrinsic motivation by demonstrating clear value to the learner and the organisation. This cultural shift, from compliance to curiosity, can be one of the most powerful outcomes of a well-executed development initiative.

Finally, it is important to recognise that not all content needs to be built from scratch. A wealth of digital courses, vendor modules, and academic resources already exists. The key is to curate thoughtfully, building only what is unique or critical, and integrating external resources where they meet the required standards of quality and relevance.

In summary, the journey to build geotechnical capabilities is as much about strategic alignment and cultural transformation as it is about technical instruction. By grounding the program in purpose, embracing complexity, and designing for accessibility and engagement, organisations can cultivate a geotechnical community that is not only technically proficient but also resilient, innovative, and aligned with the future of mining.

Acknowledgement

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