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REPORT ON SKILLS GAPS

Deliverable 2.1

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Executive Summary

The ‘Raw Materials sector skills, gaps and needs’ work package looks into skills that employers are looking for and are likely to be in demand in the future. Gaps are identified in professional education and training against market demands assessed through three different timeframes and corresponding methods:

- **Short-term (Horizon Europe):** Desk research;
- **Medium-term (2030):** Focus Group sessions;
- **Long-term (2050):** Delphi survey.

Such timeframes should not be understood as fixed year horizons, but rather the level of uncertainties involved when projecting different developments into the future.

Seen as one of the main risks facing the sector, the future of raw materials workforce has received growing attention in numerous publications scoping different geographies and time horizons.

Following the trends over increasing digitalisation and automation of operations, short-term skills and competencies needed are expected to shift to more complex cognitive categories with increased requirements in digital literacy. On the other hand, the growing concerns with social and environmental aspects surrounding the raw materials markets will augment the need for communication and stakeholder engagement capacities.

In essence, technological developments (e.g. increasing levels of automation, big data and internet of things) coupled with increasing social and environmental responsibility demands are behind the main expected shifts in skills needed for raw materials professionals.

Taking a systemic view on the sector, professionals will tend to be increasingly required to amplify their domains of expertise as well as having a more holistic understanding of the value chains they are part of. Employers are likely to pursue retraining and upskilling strategies as well as to seek more tech-savvy professionals also from other sectors.

It is observed all emerging trends and skills gaps must be pondered for each case and dimension of analysis. The latter includes geographic aspects, type of commodity, size of operation and technology sophistication level, lifecycle and value chain stages.

In the medium-term assessment, a group of experts was brought together from across the world for six months to assess potential developments

Highlights and key expected developments towards 2030 in the raw materials sector:

- Moving away from the “bigger is better” mentality and economies of scale – in other words, rethinking approaches to develop mineral deposits;
- Social issues will continue to increase over the next decade, continuing as one of the main challenges for the sector;

- More autonomous operations and new technologies: changing the nature of work with more flexibility and professionals working remotely from urban centres – especially in developed economies;
- Increased availability of online courses and training in raw materials – though not every skill/competence may be acquired online[1];
- Progression of integrated teams to integrated professions, where skills deployment turns more agile;
- More companies seeing themselves as 'Raw Materials companies'.

From the INTERMIN survey on skills, the following can be highlighted:

- **Technical skills:**
  - **Business Management:** improved practices in risk management accounting for sustainable and social acceptance principles. Business re-engineering for managing 'digitalization' of operations. Adapting more agile project management methodologies to increasing development and deployment of ICT solutions in the sector.
  - **Mining Equipment and Systems:** proficiency in using dedicated software packages, which may become more integrated with greater interoperability with different modules and areas.
- **Soft skills:**
  - **Sustainability:** ability to translate sustainability principles (i.e. SDGs[2]) to raw materials related activities.
  - **Social performance:** holds the strongest variety of emerging skills deemed as important in the future such as monitoring and evaluating social projects using social research tools and community engagement approaches.
- **Recycling and secondary mineral raw materials:** baseline understanding of the principles of circular economy, climate change and the recycling market, and the ability to investigate and perform R&D in the field of new materials and new processes

For the long-term assessment, a Delphi survey was conducted to support the redefinition of the boundaries of contemporary job descriptions and will identify potential challenges that will require new types of expertise. It will be used to identify key areas of future development that could require substantial adaptation of training programmes, with a view to the 2050 time horizon.

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[1] http://minetrain.eu/
[2] UNSDS (2016). Mapping Mining: to the Sustainable Development Goals: An Atlas. Link: http://unsdsn.org/resources/publications/mapping-mining-to-the-sustainable-development-goals-an-atlas/

After thorough review of reports on the future of mining the thematic clusters were defined in different categories:

- **Conventional mining approaches:** covering the extrapolation of current approaches under the ‘Mass mining’ and ‘Mineral exploration undercover’ themes.
- **Unconventional mining approaches:** spikes of interest were observed in novel mining frontiers, namely seafloor mining and mining in space. These topics were clustered under the ‘Mining in new frontiers’ theme.
- **Socio-economic trends**: sustainability is considered one of the main levers of the raw materials sector transformation. In that sense, the increasing role of the ‘Circular Economy’ in political agenda and societal values is included as one the thematic clusters.

20 statements were created based on possible states of the future for each of these topics and 69 experts from across the globe participated altogether in the two rounds of the survey, providing their judgement and beliefs in each of these topics. They were asked to provide their expertise and level of agreement on the statements, general comments and to identify emerging skills gaps.

It was identified that substantial adaptation from raw materials programmes may be required for potential emerging skills needed such as the expected level of interaction from mining engineers with automation and robotics disciplines will require strong adaptation from current programmes, nanotechnology applications for increasingly complex geomechanical problems, electro-chemical systems and biotechnology for novel mineral processing approaches, widening of economic geology disciplines i.e. EHS, community engagement and advanced data analytics (besides strong knowledge in geochemistry and geophysics), augmented emphasis on quantitative approaches integration to core geology/mineral exploration skills (maths + data science), deep water engineering knowledge for mining purposes and systems engineering.

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1. INTRODUCTION

The H2020-Project INTERMIN started in February 2018 and will last a total of 36 months. Its goal is to create a feasible, long-lasting international network of technical and vocational training centres for mineral raw materials' professionals. Specific objectives of the project are to develop common metrics and reference points for quality assurance and professional recognition of training and to create a comprehensive competency model for employment across the primary and secondary raw materials sector. INTERMIN activities include:

a) To develop an international qualification framework for technical and vocational training programs on mineral raw materials' topics, based on present and future requirements by employers.
b) To foster joint international training programs by a merger of competences and scope of existing training programmes.
c) To optimise future interaction and collaboration in Europe and internationally.

The project activities require contact with people as well the collection, analysis, treatment and storage of primary data (data collected by the Consortium involved in INTERMIN) and secondary data (data collected by others and published or publicly available). INTERMIN also includes the development of a repository, which consists of a database of documents used and generated by the project.

The 'Raw Materials sector skills, gaps and needs' work package looks into skills that employers are looking for and are likely to be in demand in the future. Gaps are identified in professional education and training against market demands assessed through three different timeframes and corresponding methods:

- Short-term (Horizon Europe): Desk research;
- Medium-term (2030): Focus Group sessions;
- Long-term (2050): Delphi survey.

The results are compared with Work Package 1 'Scoping & Mapping of educational-research programs' to build an integrated competency model for the raw materials sector. This will include the development of prospective scenarios and a roadmap of implementation.

This report is structured in three main sections according to the previously identified correspondent time frames. The first section provides an overview on existing sectoral reports that discuss skills needed in the raw materials sector and projections for the future based on relevant drivers and trends in raw materials and impacts on the related jobs and professions. The second section extrapolates these issues over the next ten to fifteen years, focusing on technological developments and sustainability-related aspects and the impacts on skills needed by employers. This assessment was done with the support of selected raw materials experts in dedicated sessions for collecting impressions, judgements and assessments in a focus group format. The last section looks beyond fifteen years with special attention to emerging skills and competencies that would require substantial adaptation from existing curricula in raw materials. A Delphi survey was designed building on previous sub-tasks where experts from across the world judged the potential states of the future regarding relevant identified areas for the time horizon of 2050, while identifying emerging skills gaps.

The results from this research are interconnected with the development of a 'Integrated Competency Model for employment across the raw materials sector' (Deliverable 2.2) and will be followed by a 'Roadmap on skills provisioning for the raw materials sector' (Deliverable 2.3). Figure 1 summarises the Work Package 2 structure, its building blocks and what is covered in each deliverable.

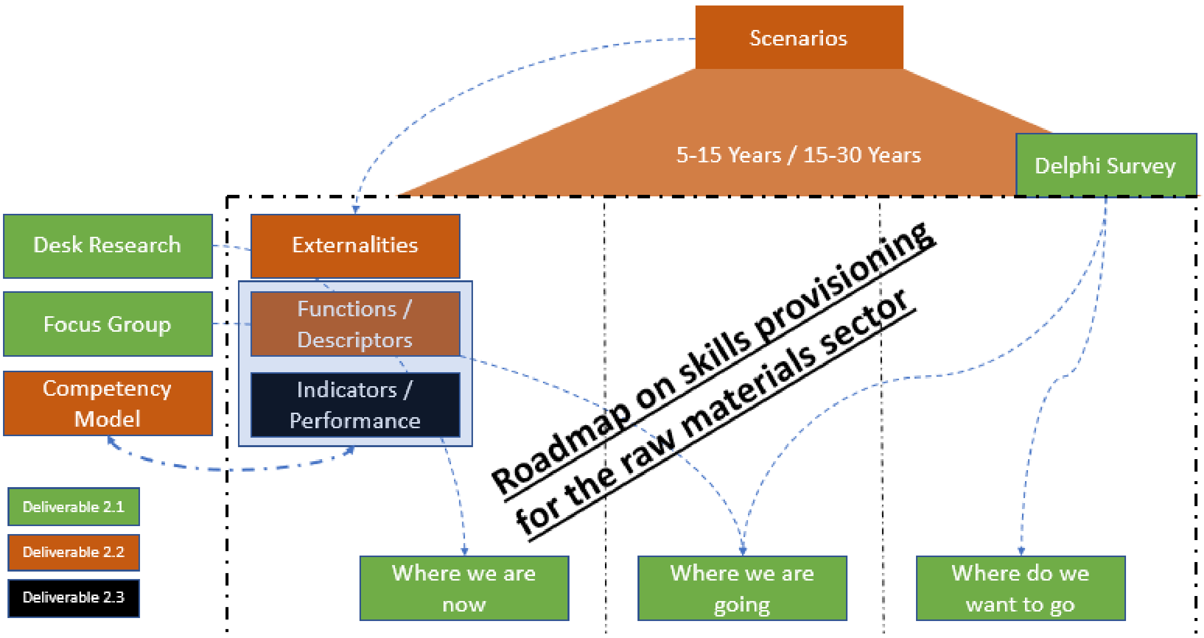

Figure 1 – INTERMIN Work Package 2 structure, building blocks and deliverables

2. ASSESSMENT OF EMPLOYERS' NEEDS

The raw materials sector faces cyclical skills shortages with different geographical impacts. This has been recognised as one of the main challenges the industry faces (WEF, 2018); (EY, 2018). Typically, there are three main factors driving skills availability in the mining industries: technological advances, market cyclicity and demographics (See Deliverable 3.1, Chapter 3). More generally, one could add globalisation and value changes as important trends shaping the future of work capturing the technological developments as well as the evolution of socio-economic systems (OECD, 2017).

It is important to stress that there are many categories of employers in the raw materials sector, with companies covering each stage of the raw materials value chain (producers), as well as service providers (METS[3]), public institutions (e.g. geological surveys), academia, among other. While each of these employers' profiles may be impacted differently, the key trends and drivers scoped are likely to affect everyone and should be contextualised for each case. This means that one might find different degrees of impact according to the different geographies and local values paired with where the jobs are located.

This review is structured under three different timeframes. For the short-term, the next five years are projected over the current baseline situation scoped through relevant reports assessing the main factors impacting workforce and skills and how this is likely to evolve over the next few years (3.1). A medium-term assessment extrapolates these trends towards 2030 with the help of a Focus Group (3.2), a group of consortium and external experts in dedicated sessions sharing impressions and judgement over a specific set of topics – scoped from the previous reviews. Finally, a longer-term assessment is undertaken to assess 'new frontiers' of raw materials jobs, skills and competencies that could emerge and are currently not acknowledged in existing training agendas and academic curricula (3.3). For that, the identification of relevant areas that are deemed impactful but uncertain are submitted to a Delphi Survey through a series of statements about the future (beyond fifteen years) to reach a convergence of judgements over potential future states of these areas and their impact on skills and competencies in the sector.

2.1 Short-term skills gaps

Immediate needs in terms of skills and competencies are expected to fit within the present-day trends in the raw materials sector. It is thus important to map and assess relevant factors that affect the need for certain skills, competencies as well as the potential emergence of new ones. Many reports in the past few years have assessed issues related with skills in the mining sector covering different geographies – from worldwide to a national scope. These reports were used to define a baseline in terms of relevant drivers and trends shaping the raw materials sector, technology development, barriers and expected impacts in the workforce and are referred to

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throughout this document. Typically, these reports refer to categories of skills and competences such as MGI (2018) and WEF (2016) (Table 1).

Table 1 - Examples of skills categories - taken from WEF (2016) and MGI (2018) reports

Skills Categories - examples	
Skills shift: Automation and the future of work (MGI, 2018)	**The Future of Jobs Report (2016)**

• Physical and manual skills
• Basic cognitive skills
• Higher cognitive skills
• Social and emotional skills
• Technological skills
	• Abilities
	  ○ Cognitive abilities
	  ○ Physical abilities
	• Basic Skills
	  ○ Content skills
	  ○ Process skills
	• Cross-functional Skills
	  ○ Social skills
	  ○ Systems skills
	  ○ Complex problem-solving skills
	  ○ Resource management skills
	  ○ Technical skills

Such categories are used to identify across different occupations where positive and negative changes are expected to occur and relate to the observed drivers for specific industry, geographies etc. The research done by the MGI (2018) in the Energy and Mining sector shows an expected increase in demand for higher cognitive skills, social and emotional and technological skills expected for the next 5 years. In other words, skills related to quantitative and statistical abilities, critical thinking, complex problem-solving and creativity are expected to increase in demand, while basic cognitive skills such as basic data input and processing are likely to decrease due to increase in automation. The 'Mining & Metals Industry profile' by WEF (2018) projects on the short term, based on companies surveyed, a move towards augmented machine-based share of job tasks in relation to humans (10-30% of share of task hours). The survey also projects the emergence of roles such as 'new technology specialists', 'data analysts and scientists', 'big data specialists', 'AI and Machine Learning specialists' and 'systems engineers', among other. On the other hand, roles such as 'plant operators', 'management and organisation analysts' and 'extraction workers' are expected to decline by 2022. The OECD (2017) also highlights that future of work will be marked by a decrease in routine tasks with growing emphasis on skills that cannot be automated. In that sense, 'soft skills' can gain in prominence, such as the ability to communicate in diverse settings, work in teams, and solve complex problems. This, however, does not preclude a rapid rise in demand for ICT (Information and Communications Technology) specialist skills, which in turn points to an increased potential risk of skills mismatch. Such gap may be more acute in emerging economies (WEF, 2017).

2.1.1 Employers strategies

According to the WEF (2016) report, typical responses from companies across industries are: investing in reskilling of current employees, support mobility and job rotation, increase collaboration, target and attract female and foreign talent, among other. The following WEF (2018) Mining & Metals Industry analysis points the main strategies mining & metals companies need to tap into:

- **Retrain and upskill:** imperative for companies to compare their current skills base against the skillsets they anticipate needing in the future;
- **Adopt new retention and attraction strategies:** under scarcity and high competition for tech-savvy professionals;
- **Source and integrate talent across networks:** attracting talents from other sectors and industries;
- **Redesign work for technology and learning**: identify areas where digital technology can augment worker performance;
- **Create a new social contract with communities and governments:** mitigate new labour dynamics in relation to local communities

Further desk research shows many indications of how raw materials companies in general project their strategy against skills requirements, for instance:

- Many mining companies are pushing forward up- and re-skilling (e.g. online campuses). For instance, Rio Tinto recently partnered with the Western Australia Government and TAFE Australia[4] to provide vocational training in robotics for mining workers.
- BHP already stated[5] that by 2030 half of the future workforce will need high-level programming, coding and software skills.
- The Head of Digital Planning from Barrick Gold – a gold mining company - stated that "As we move forward as a business, I would love to be seen as a place where we actually give people those skills" (McCrae, 2016). This suggests another approach to skills shortage, where employers might also position themselves strategically as skills and career development providers to attract more talents.

[4] URL: https://thewest.com.au/business/mining/tafe-levels-up-with-first-qualification-in-automation-to-meet-mine-skills-demand-ng-b881227303z (accessed 01.07.2019)
[5] URL: https://www.bhp.com/media-and-insights/reports-and-presentations/2017/10/creating-the-future-of-mining-integration-and-automation (accessed 01.07.2019)

- It is expected that a big share of the workforce will follow operational and service streams, where professionals will interact with more diverse backgrounds, skills and culture – with more outsourcing.

The so-called 'Digital Transformation' (i.e. increase in pervasive digital solutions in raw materials operations and enterprises) under the 'Industry 4.0' paradigm, is likely to increase competition for tech savvy professionals forcing raw materials companies to compete with other sectors for highly qualified professionals. This trend is reinforced by the increase in 'remote operating centres' where operations might happen in remote locations, while a big share of the workforce will be based in urban centres.

Another important issue regarding local factors is the age generation gaps frequently observed by the cyclicity of the raw materials markets. This can create a shortage in mentorship and appropriate training of professionals at local/regional level to develop skills not taught in tertiary programmes. This has been observed as an issue causing 'lack of confidence and technical effectiveness' in the MinSoc project report (2014), on geotechnical engineering skills gaps, commissioned by the Australasian Institute for Mining and Metallurgy.

2.1.2 Key drivers and trends

Trends are broadly understood as gradual forces, factors and patterns that are observed to be causing widespread change in society generally. Drivers on the other hand typically refer to major influences on a phenomenon, especially major forces that underpin trends (Miles et al. 2016).

The World Economic Forum has recently defined seven trends[6] that are expected to shape the future of mining:

1. **Transition to a low-carbon economy:** on the energy transition to renewables – sourcing different sets of raw materials and pushing the industry to reduce emissions.
2. **Access to resources:** lower quality and grades of deposits pushing for 'new frontiers'.
3. **New ways to finance mining:** e.g. royalty and metal stream agreements.
4. **A social contract for mining:** social responsibility and local community acceptance.
5. **Big data and mining:** improving efficiency of operations and transparency of value chains.
6. **The geopolitics of mining:** dynamics of geopolitical risks and economic protectionism.

[6] Source: https://www.weforum.org/agenda/2019/03/seven-trends-shaping-the-future-of-the-mining-and-metals-sector/ (accessed 01.07.2019)

7. **Modern mining workforce:** evolving technologies will require employees to develop new skills. Competition with IT sector to attract talents, partnership with Governments for up-skilling, re-training and transitioning workforce to a more 'automated' mining sector.

On the workforce trend, the report suggests that the speed at which mining companies will be able to rollout new technologies will depend on the local host government's and labour union's acceptance of reduced employment and procurement opportunities. In another recent publication, the WEF (2018) listed 10 trends shaping industry growth:

1. Increasing adoption of new technology
2. Advances in devices bridging the human-machine divide
3. Advances in new energy supplies and technologies
4. Advances in Artificial Intelligence
5. Shifts in national economic growth
6. Expansion of education
7. Expansion of gender parity
8. Increasing availability of big data
9. Shifts in global macroeconomic growth
10. Advances in cloud technology

These trends can be expected to generate impacts in the workforce, skills and competencies needed to successfully advance industry growth. The WEF report also surveyed companies, listing skills gaps in local labour market and in leadership among the main barriers for technological adoption in the industry (more than half of respondents).

In the European Union, according to EUROSTAT (2017)[7], approximately 31% of EU workers only have above basic levels of digital skills. The mining (extraction and processing) sector alone in the EU for metals and non-metallics employs at least 2 million workers (EC, 2018). The manufacturing sector, for instance, has been the host of strong digitalisation, where many European companies are now in the forefront of new generation technologies such as IIoT, cloud computing, big data, AI/ML and data analytics, robotics and additive manufacturing. The recently created European Commission 'Digital Europe Programme' (2021-2027) is expected to shape and support the digital transformation in Europe, boosting investments among other in advanced digital skills. This will offer current and future students as well as technology experts opportunities to pursue training and career in advanced digital technologies (Figure 2).

[7] http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

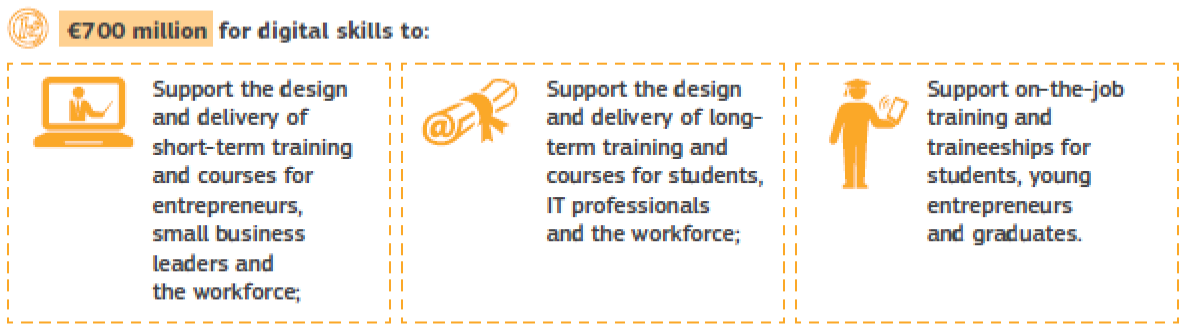

Figure 2 - Initiatives under the Digital Europe programme - advanced digital skills pillar (EC, 2019)

As mentioned in the beginning of the chapter, there are a multitude of employers' profiles in the raw materials sector. Many of them fall under the so-called METS[8] sector. The Australian CSIRO (2017) introduced the concept of 'Global Mining Megatrends' for the Australian METS companies. Megatrends occur in the intersection of many trends, being able to reshape the way an industry operates (Table 2). This in turn can strongly require adaptation of companies with new operation and business models, thereby affecting work expectations on raw materials professions and graduates. Such consequences are captured by Yeates (2018) and summarised in Table 3.

Table 2 - Global Mining Megatrends (CSIRO, 2017)

Megatrends	**Description**
The Innovation Imperative	After the previous mining boom marked by strong demand mainly from China and a rise in commodities prices, companies refocused attention to operational efficiency and productivity. This will require a new mindset for long-term realisation. Where innovation is combined with organisational and structural changes will require closer collaboration and holistic value chain assessments.
Plugged in, switched on	Future mining will be underpinned by smarter and more automated equipment, processes and infrastructure. This may reduce the requirements for local and FIFO (fly-in fly-out) on-site workers – switching to a LILO model (Log-in Log-out)
The era of accountability	Mining companies will need to exceed environmental expectations, strengthening community engagement and guaranteeing a social license to operate. Strategies will deal with whole life cycle sustainability, with solid management practices for water, biodiversity, remediation and climate. In essence, mining companies will need to be more transparent, propagating this accountability to secondary and tertiary industry providers.
New supply, new demand	New consumer technologies such as modern electronics and renewable energy technologies are shifting demands for high-value, low volume raw materials while at the same time demographic changes especially in developing countries will continue to demand many types of mineral commodities.
The knowledge economy	In advanced economies, increased adoption of specialised digital technologies are increasing the need for more collaboration resulting in new business models and strong competition for

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	talent. The expected increase in automation, digitalisation and data analytics is likely to require skills from outside the mining industry.
Rethinking our reserves	High-grade and high-volume deposits are becoming scarce – by decreasing rates of discovery and exhaustion of current operations. In many mining areas, this is forcing a need to go deeper to access reserves. In essence, new technologies are expected to increase the life of the mines and optimise recovery while also social expectation will drive attention to recycling, re-use and urban mining.

Table 3 - Changing nature of work in mining (adapted from Yeates, 2018)

Drivers for new operating models	Impact on graduates
Data rich collaboration platforms	• Increasing employment by METS companies; • Commitment to a life-long process of learning and re-learning • Increasingly specialised with wider general context; • Increasingly digital and more numerically and statistically capable • Need a strong grounding in the fundamental sciences and scientific method • Work collaboratively in teams • Deal constructively with failure • Capability to unlearn
The global connectedness with VR/AR	
The millennial generation	
The rise of the gig economy	
An agile approach to all aspects of work	
More nuanced metrics	

A recent report by Deloitte and Norcat (2018) on the future of mining workforce outline three main drivers of change:

- **A technology shift:** pointing to the gap in generic training and development programmes providing fundamental knowledge of how the emerging technologies work, skills to operate equipment, troubleshooting and installing equipment in an underground environment do not exist;
- **A generation shift**: the combination of an ageing workforce, pending labour shortages and significant investments in emerging and innovative technologies is driving the need for new and innovative training programmes;
- **A career shift**: where the main challenge for mining companies will be to help employees to shift their own careers, embracing up-skilling, and to find a balance between managing their resources internally as well as closing the skills gaps through outsourcing;

The report also features industry perspectives, where leaders shared comments and concerns regarding the future of work in mining. Consistency was observed in issues including safety, efficiency and engagement of workers as a top priority. Also recurrent was the challenge of needing fewer workers on-site, but then needing to compete for talent living in large urban centres. Divergence was observed regarding the organisational structures and cultures required for success in any change process and to which extent existing professionals could be upskilled for job profiles of the future. All these challenges can vary further depending on situation, geography and the overall regulatory and competitive environment.

According to a research from EY commissioned by MCA (Minerals Council of Australia), over the next five years three quarters of jobs in Australia's mining industry will be enhanced or redesigned by technology. The study finds that the Australian education and training systems need to be modernised to deliver high certification and fit-for-purpose degrees. The study selected 4 dominant drivers shaping the future of work:

- **Shifting workforce expectations:** more flexible working options, purpose-driven workplaces and corporate cultures that align with culture of lifelong learning;
- **Convergence of technology, robotics and artificial intelligence:** driving human work towards higher cognitive tasks.
- **Social and demographic factors:** increasing global competition for talent, migration, and workforces increasingly marked by multi-generational, multi-skilled and diverse individuals.
- **The known unknowns:** with increasing technological innovations, more unexpected disruptors are likely to hit the industry more frequently – this in turn requires capacities to respond to constant change and also pivoting strategies when necessary.

A Deloitte (2018) report suggests that the convergence of IT and OT will require back office mining professionals to combine traditional mining skills with advanced technology skills – highlighting a need to be digitally literate, to have strong problem-solving skills and the ability to think creatively.

2.1.3 Expected impacts on workforce

Much of the expected impacts on the workforce are coming from technological adoption in the mining sector. Increasing mechanisation in mining is not new, however the rate of technological development and digital innovations currently seen are expected to have profound impact on a sectoral level and across value chains.

EY (2019) research in Australia, summarises expected impacts from digital and technological innovations in three aspects:

1. **Capability:** reduction in traditional operators and increase in demand for technologically savvy professionals. Core functional support will be provided by professionals who can combine technical mining skills with digital technologies competencies.
2. **Location:** Increase in remote operations shifting site-based workforce to remote operating centres in urban centres.
3. **Number:** a transition and re-definition of roles, as certain traditional ones will be reduced while new ones will be created.

The Autonomous Mining Working Group (GMSG, 2017) suggests that in 15 years' time more than 60% of sites will be fully autonomous (Figure 3). Respondents of the survey also listed workforce/training/skills as one of the main challenges for implementing more and fully autonomous operations.

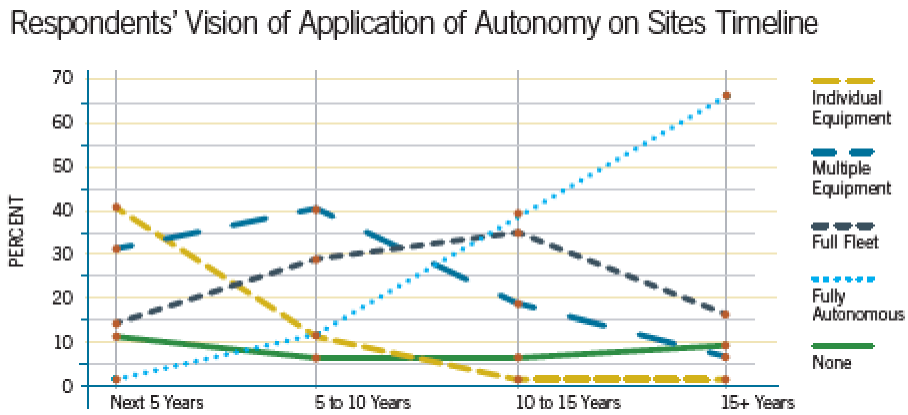


Figure 3 - GMSG (2017) Survey on the future levels of autonomy in mining operations

The pathway to more autonomous mining is also likely to surface different skill sets. As observed by Buckingham & Sainsbury (2017) different types of resource endowments determine capabilities and types of work in the raw materials sector. In Australia this has meant a technological intensification in urban areas (remote operating centres) removing and centralising mine control activities away from the site, whilst cases in Sweden feature technological intensification in the mine, with strong on-site experimentation with different configurations of autonomous technology (Cooney & Lansbury, 2018).

The report identified a major skills gap in the Australian case from the lack of skills in tele-remote communication and lack of high-order computer skills. It was pointed that this was due to inadequate coverage at university level of areas such as computer modelling, software engineering, problem solving, data analysis and tele-remote communications. In the Swedish case, skill gaps mainly arose from the low level of general and vocational education before entering mining.

New job titles are starting to emerge as an outcome of current employers' needs – "Mine automation and technology engineer", "production development specialist" "Geology data administrator" among other.

The WEF (2018) survey 'Future of Jobs' surveyed companies in terms of technology adoption and expected impact on workforce (Table 4 and Table 5).

Table 4 - Technology adoption survey (WEF, 2018)

Technology adoption in industry (% of companies surveyed)	
• Machine Learning (69%) • User and entity big data analytics (62%) • New materials (62%)	• 3D printing (50%) • Biotechnology (44%) • Stationary robots (38%)

• Cloud computing (62%) • Augmented and virtual reality (62%) • Internet of things (50%) • Digital trade (50%) • Autonomous Transport (50%) • App and web-enabled markets (50%)	• Distributed ledger (blockchain) (38%) • Non-humanoid land robots (25%) • Humanoid robots (25%) • Encryption (25%) • Aerial and underwater robots (25%) • Quantum computing (19%)

Table 5 - Expected impact on workforce (WEF, 2018)

Expected impact on workforce (% of companies surveyed) – Mining & Metals	**Expected impact on workforce (% of companies surveyed) – Overall average**
• Reduce workforce due to automation (72%) • Expand task-specialised contractors (56%) • Modify value-chain (44%) • Modify location of operations (44%) • Expand workforce due to automation (33%) • Expand the workforce (22%) • Bring financing on-board for transition (22%)	• Reduce workforce due to automation (50%) • Expand task-specialised contractors (48%) • Modify value-chain (59%) • Modify location of operations (48%) • Expand workforce due to automation (28%) • Expand the workforce (38%) • Bring financing on-board for transition (36%)

The report also identified emerging roles in the upcoming years (2018-2022). Many of which are related to 'Data Science' jobs e.g. 'Data Analysts and scientists', 'Big data specialists', 'AI and Machine Learning specialists. Others reflect the increasing complexity of operations as level of automation increases e.g. 'New technology specialists' 'Process Automation specialists', 'Systems Engineers'.

Another large-scale survey was carried out by the 'Mining Journal Intelligence' (2016), where the research surveyed 200 miners over the future of mining. When questioned over which technologies will impact the most, and when, respondents agreed (>90%) on 'high-power computing/cloud', 'Big Data/predictive analytics' and 'HP Satellite/drones/laser survey/imaging'- whereas no such level of consensus was reached for the present timeframe.

Table 6 - 'Mining Journal Intelligence' survey (2016) - future mining technologies (adapted)

Which technologies will impact the most, and when? (≥ 50% of respondents)		
Technology	**Within 1 year**	**5-10yr horizon**
Remote/ teleremote control	28.4%	**50%**
High precision guidance and control	14.6%	**53.4%**
High-power computing/ cloud	**52.6%**	**92.2%**
Big Data/predictive analytics	40.5%	**97.4%**

OT-IT integration	19.8%	**53.4%**
High precision satellite/drones/laser survey/imaging	19.8%	**97.4%**

A report from Deloitte (2018) underlines four key implications across the demand of work, workers and the workplace:

- Technological proficiency will be preferred over transactional work;
- Increase access and competition for talents;
- Diversity will spread to all organisation levels;
- Workplace as an increasingly fluid concept – with tasks or the entire job performed virtually.

More recently, a report commissioned by the Minerals Council of Australia (MCA) and EY (2019) suggests that technological innovations will impact work in the whole value chain – from exploration to trading (Table 7).

Table 7 - Digital impact on mining value chain workforce and skills requirements (based on EY, 2019)

Mining value chain stage	Workforce impacts and skills required
Exploration	• Reduction in drilling operators due to automation • Increased demand on advanced analytics and modelling skills • Increasing share of remote work
Mining Operations	• Reduction in drilling operators due to automation • Key skills shift from technical execution to decision support focus • Emerging roles: ‘systems engineering’ and ‘data scientists’ • Increasing share of remote work • More complex problem-solving thinking ability to anticipate and plan activities • Managing human-to-machine interfaces • Advanced systems development and integration
Processing	• Increase in advanced analytics and ‘big data’ applications – i.e. ‘data scientists’
Transport	• Upskilling of operators to manage human-to-machine interfaces • Advanced systems development and integration – management of autonomous systems and shipping platforms
Trading	• Shift on operating model from mining based on volumes to quality and customer requirement focus.
End-to-end	• Dealing with increased complexity of planning, scheduling and advanced decision-making – complex systems management for end-to-end optimisation • Technical modelling and advanced geological and geo-spatial capabilities.

Whilst the report emphasises the benefits of these improvements, it also highlights potential barriers that should not be neglected. Namely, the Social License to Operate, where changes in operational and workforce associated with new technologies must be aligned with social and political perceptions.

2.2 Medium-term skills gaps

The aim of the Medium-term assessment was to bring together experts from across the world for six months to assess potential developments in the raw materials sector and implications in terms of skills demand towards 2030. A Focus Group format was chosen as an effective way of collecting qualitative judgement on a specific set of topics. The work was carried out online to facilitate the meetings of a geographically diverse group of experts and it was finalised with a face to face session during the INTERMIN Consortium Meeting held in Madrid in January 30-31, 2019. More details on participation and the Focus Group Manifesto can be found in Annex 1.

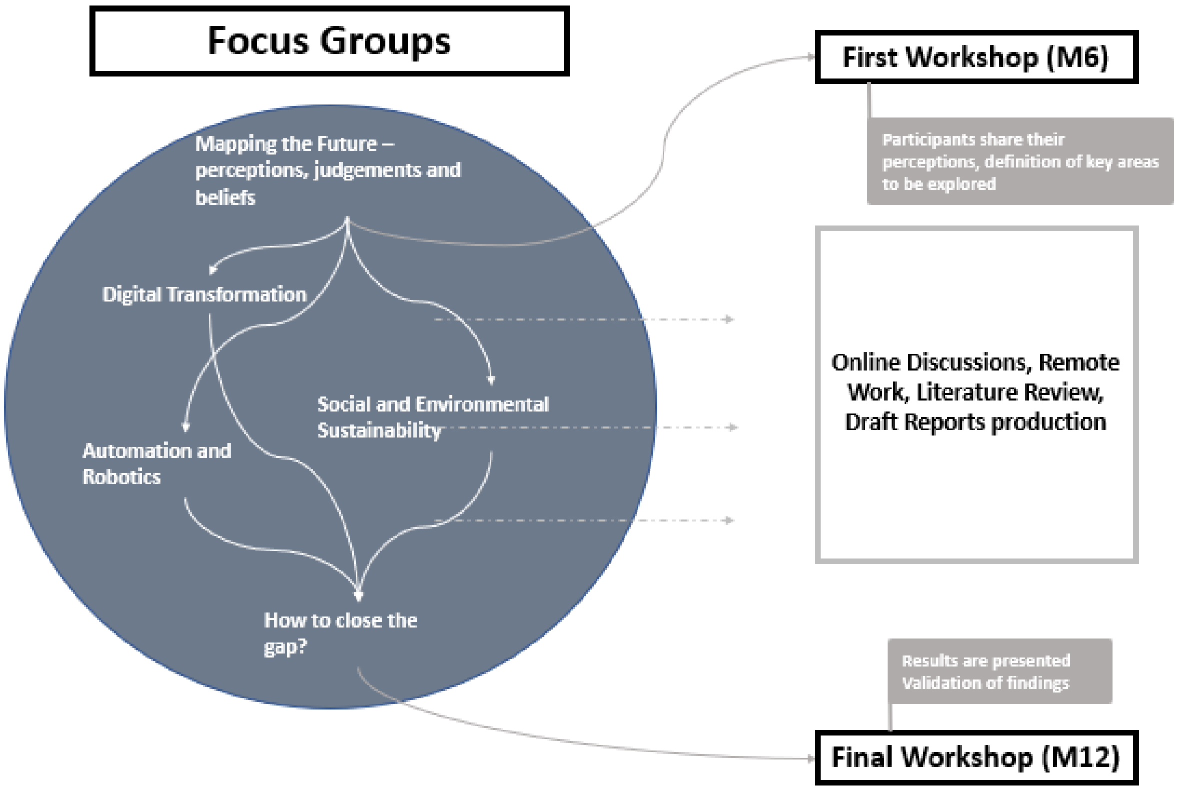


Figure 4 - Focus Group structure and workflow

2.2.1 Overview, Focus Group definition and main thematic clusters

The WP2 kick-off meeting allowed for an initial collection of perceptions and judgements over preselected and broad issues that were further explored during the next six months. For that, a group of 10 participants composed by consortium members and external experts actively engaged in sharing their views and opinions.

The subjects brought up in the exercise were aggregated by topic. The summary below aims to reflect the perception and judgements of participants over challenges, uncertainties and trends during exercise as well as the discussion that followed.

2.2.2 Market strategies

A noted uncertainty was the development of the raw material/mining companies in adopting horizontalization strategies as opposed to verticalization of their businesses. The impact on skill demand also depends of which path the sector takes. Typically, the upstream side of chain is seen as a cost centre and much investment is going towards offsetting labour e.g. Watson for Natural Resources.

Also mentioned was a need for the mining industry to recruit investors that can think in the long term. The long-term nature of the sector as well as the long time spans required for training to generate results clash against short term orientation frequently observed in investors seeking financial returns as soon as possible.

2.2.3 Raw Materials professions

Traditional professionals like ‘Mining Engineer’ will most likely be very different in 10-15 years or likely to be picked apart – that is, becoming a sub-specialisation of other engineering disciplines.

2.2.4 Interrelationship between different disciplines

The interaction between socio-environmental and technical aspects is a trending topic of discussion. Ongoing initiatives such as the ‘Complex Orebodies 2018’ conference explicitly seeks to better understand this. Professionals need to handle social awareness aspects of operations from early on in the process. Important initiatives such as the ICMM also cover the relationship between mining and development in the context of SDGs – and the translation to the technical side of the industry. In terms of translation to skills required, the extractives sector was said to be shifting focus for “where the disciplines meet, rather than focus on the center of the disciplines.” For instance, better understanding as to where does mining skills interface with recycling, rather than assessing them separately. Discussions followed over how the communication and social skillset is demanded – whether at mineral development area or at a corporate level. For example, in Australia investor and government relation typically sit on corporate head offices, whereas issues around social impacts sit at a site level, from exploration along the value chain. Adding to communication aspects, there is also a need for social investments and community engagements – this is managed by a community relations or social performance team. Some mine managers may report more than 50% of their time being directed to the social community affairs, especially in more challenging sites.

2.2.5 Systems thinking

From the previous topic the concept of 'Systems thinking' emerged recurrently. An identified development is the view to optimise whole value chain as opposed to individual process therein, this in turn will impact the skillset and training required to enable such capacity. This can thus blur the lines in more technical areas with emerging new occupational categories. As an example, McCuaig et al. (2014) develops the concept of 'Boundary Spanners' for mineral projects development – people who can effectively recognize systemic linkages between silos and work with different 'mental models' – exposing two different mindsets: mineral exploration (geoscientific, risk explorer) and project development (non-geoscientific, risk averse). This 'boundary' should be crossed by 'outside insiders' (e.g. geologists able to bring ideas from different fields) and 'inside-outsiders' (e.g. professionals from other field, who can successfully bring in new ideas).

2.2.6 Technological developments

Emerging Industry 4.0 concepts in mining is an important aspect for modernising the industry while at the same time helping to improve its perception in environmental and sustainability point of view – communication skills are then also greatly required. Specifically mentioned was the thinking paradigm where industry is more open to new technologies – and also improving its capacity to identify – maintaining a sense of 'broader picture'

2.2.7 Training aspects

Companies show signs of shifting of professional requirements to the higher cognitive spectrum of skills – preparing workers to deal with harder or more complex problems. Previous experience shows that it typically takes a rather long time for international knowledge transfer programs to generate solid results for a variety of reasons. In the experience of BGS, knowledge transfer programmes require some source of public funding (e.g. EU Sysmin, World Bank, DFID, USAID or national taxpayers) and are unlikely to be commercially viable. Time horizons for a 'return on investment' in that sense can be as long as 15-20 years, which is hardly tolerated from a private sector and/or short-term perspective. Also, trained staff can end up moving to 'richer' mining areas, which is good for the recipient region/country but maybe not for the original sponsor.

Skills provided on the job vs. formal training centres – an important point for INTERMIN is to understand how and where certain skills can be acquired. Discussion highlighted a need of consensus over what can be learned online, in training centres and what should be skills developed 'on the job'.

Potential trends/future developments identified:

- Moving away from getting bigger and bigger or "bigger is better" and economies of scale - in other words, rethinking approaches to develop mineral deposits.
- Social issues are becoming the main challenge for the next 10-15 years.

- Increasing online courses and training in raw materials – though not every skill/competence may be acquired online.
- Progression of integrated teams to integrated professions, where skills deployment turns more agile.
- More companies seeing themselves as 'Raw Materials companies' – in response to ongoing sectoral dialogues and programmes e.g. ICMM, H2020.

Following the review of drivers and trends (Section 2.1), two domains were identified for the forthcoming dedicated Focus Group sessions. The first meeting would then cover Technological Developments and topics such as 'Industry 4.0' and the 'Digital Transformation, and the second meeting covered social and environmental aspects related to sustainability challenges e.g. Circular Economy, Climate change, Social License to Operate.

2.2.8 First Focus Group session - Industry 4.0

Industry 4.0 is broadly understood as the result of coupling smart digital technologies with advanced production and operations techniques, allowing for enterprises to become more interconnected, autonomous and able to analyse and use big data to drive further intelligent decisions to the physical operations. Many underlying technologies are expected to support this such as robotics, Artificial Intelligence, quantum computing, wearables, Internet of Things, and additive manufacturing among other. Its impacts may change how products are designed and maintained, how companies operate (business models) and ultimately the nature of work. Skills required, tasks and roles that will exist in the future are still somewhat uncertain.

In the mining sector Industry 4.0 became an umbrella for buzzwords such as 'Digital transformation' and the 'Digital mines of the future'.

A report from the WEF (2017) scopes digital innovations that have the greatest potential to create value for the mineral raw materials sector by 2025. Such innovations are structure under four themes and ten initiatives, summarised in Table 7.

Table 8 - Digital themes and initiatives in Mining and Metals (WEF, 2017)

Themes	Initiatives
Automation, Robotics and Operational Hardware	Autonomous Operations and Robotics
	3D printing
	Smart sensors
Digitally Enabled Workforce	Connected worker
	Remote Operations Centre
Integrated Enterprise, Platforms and Ecosystems	IT/OT Convergence
	Asset Cybersecurity
	Integrated sourcing, Data Exchange and Commerce
	Advanced Analytics and Simulation Modelling

Next-generation Analytics and Decision Support	Artificial Intelligence

It can be expected that as manual jobs become more automated, new opportunities will emerge. However, current practices in mining operations and the relationship with local communities – also as a source of the workforce – are likely to be impacted. Another tendency is the increasing share of the workforce that will be based in 'service centres' more likely to be located in urban centres as many services and tasks can be performed, at least in part, remotely.

Automation is reported to reach its peak of deployment in the next 10-15 years' time. This will impact how mining is done in many of its core processes, such as:

- Automation of physical operations;
- Data-driven planning, control and decision-making;
- Integrated and automated support processes.

Such changes are bound to affect the set of skills and competencies that employers will need in such environment. In fact, skills gaps, local labour market and leadership are main barriers to adoption of new technologies in the mining & metals industries.

In this second Focus Group meeting, participants shared their impressions, opinions and beliefs regarding the impacts that such developments will have for employers and their skills needs. More broadly, the ecosystem of stakeholders and their role in that sense was also explored.

After a thorough review of relevant reports, critical uncertainties were identified and framed as questions for the online meeting. Questions were posed to participants to trigger reactions and discussions. Such questions and topics were aggregated under four pillars:

- Technological developments;
- Integrated businesses, professions and disciplines;
- Market strategies;
- Training & Generational aspects.

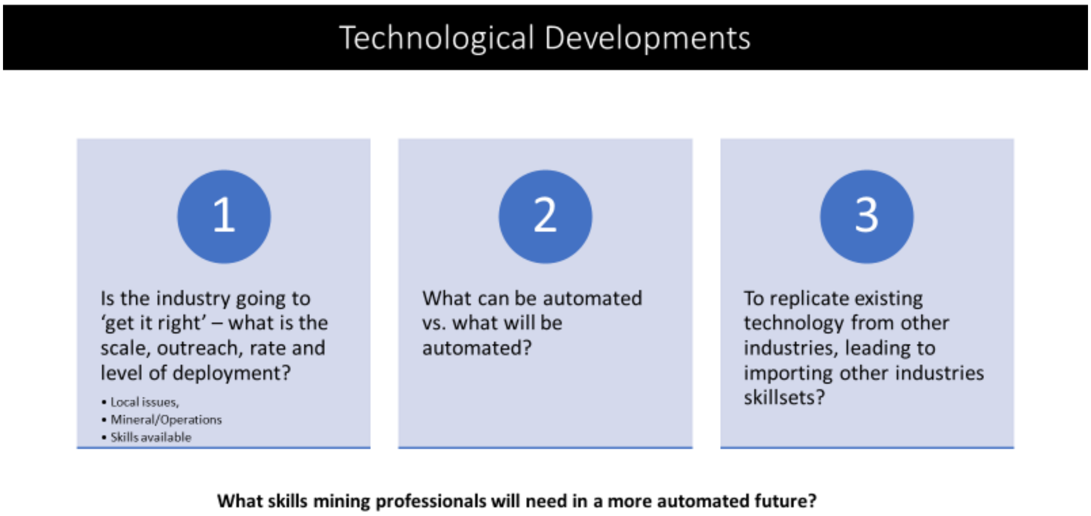


Figure 5 - Focus Group - Technological developments question 1 slide

There is a great heterogeneity in the so-called 'mining industry'. There is a wide distance between major players and small-scale employers, where other dimensions such as local (geographical) issues, type of product and skills available play a role. Given such diversity there is not a one-size-fits-all solution. For instance, in Australia although there is a big push in Automation in some locations, in others it tends to be slowed down with concerns over impacts on workforce. More automation also means the focus is shifting to (complex) problem-solving rather than just "mechanically" moving things forward.

Another important point in organisations is the cultural aspect. Companies changing personnel will not necessarily change the thinking processes. Such aspect is consequential when 'digital thinking' is emerging as an important skill and capacity to successfully bring about the changes championed by the industry 4.0.

In the next 15 years it must be considered that an evolution may come in the form of 'replacement' of companies – some will go away, and new players will come in.

One can expect greater presence of equipment manufacturers and service providers as workforce providers as they are strongly engaged in the process of deploying the 'industry 4.0' in the mining sector.

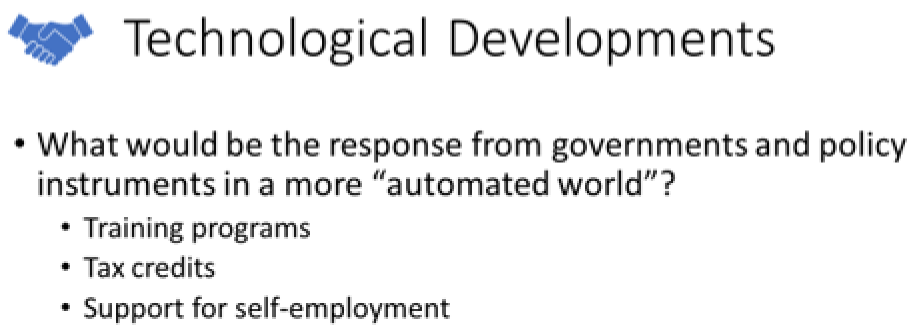


Figure 6 - Focus Group - Technological developments question 2 slide

A report[9] on the impact of automation on mine economics and government tax regimes shows that the introduction of automation can largely affect countries with large scale operating mines. The authors also underline the fact that even when there is no net impact on employment, the changes in how they operate mean at least changes in the skill sets involved. Moreover, the report emphasises that workers with specialised skills in remotely controlled and automated systems will be in demand as automation increases, while current employees will need retraining and re-skilling. Such skills will greatly rely on knowledge of mathematics and science and ability to use information technologies.

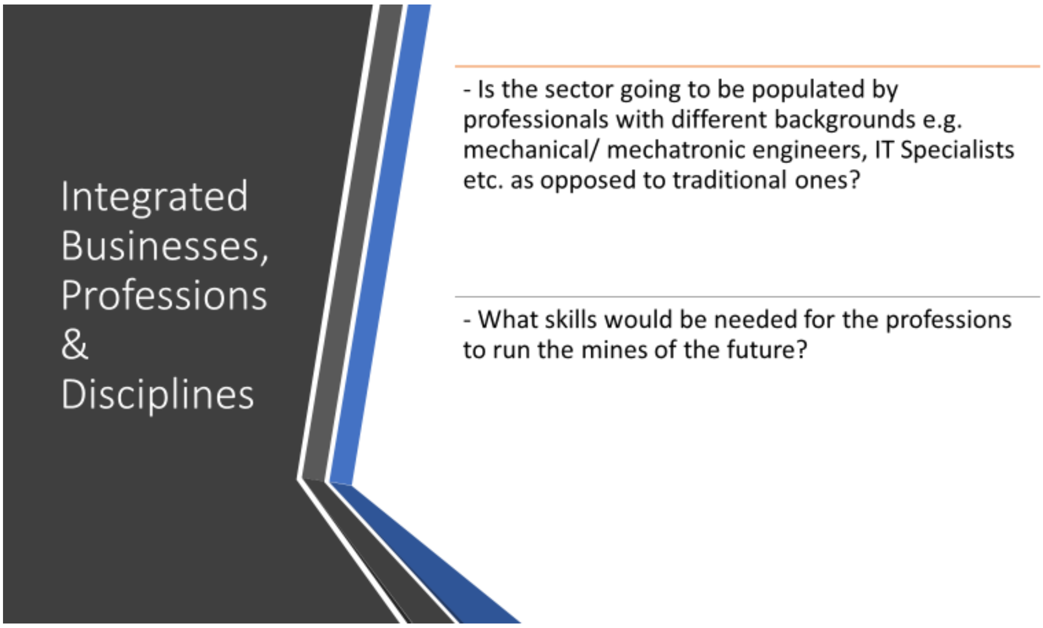


Figure 7 Focus Group - Integrated businesses, professions & disciplines question 1 slide

[9] "Mining a mirage? Reassessing the shared-value paradigm in light of the technological advances in the mining sector" (IISD, 2016)

Other fields of study have been present around mine sites and some increasingly are – such as mechatronic/automation engineers, who are currently being drafted by companies.
One approach to professions could be a "T-shaped" career progress (Deliverable 1.1, Chapter 3) where professionals specialise quite deeply in a specific area and the move 'laterally' broadening their skills spectrum. This would facilitate dealing with high order complexity problems, while also engaging in integrated platforms, businesses and sectors.
'Engineer'-minded professionals might not cover what it takes to run a raw materials company and/or operation. Important skills come then from successfully putting together a diverse team with complementary skill sets.
One aspect that is already seen organically and can trend up for the next 15 years is the conversion of different backgrounds to particular, domain-specific areas of the raw materials value chain e.g. chemical process engineer turning into a mineral processing engineer. The new developments and challenges employers are facing must be contrasted with the profile of graduates coming out of universities. If more traditional backgrounds are not coping with the level of skills required, naturally one would see such outcomes of professional 'conversions'. Other example could be that if we are moving to more math-heavy complex problem solving or programming/data analytics, disciplines such as electrical engineering and computer sciences could naturally become more welcomed by raw materials companies.
Additionally, in terms of secondary raw materials, the circular economy can push for better economics on recycling processes and re-use of materials. Certain applications of chemical processing techniques can also be transported to the secondary resources – it certainly constitutes a gap towards the end of the value chain in filling companies with such skills. This particular area tends to be heavily regulated by governments, so approaches stemming solely from 'free market' responses would not cover.

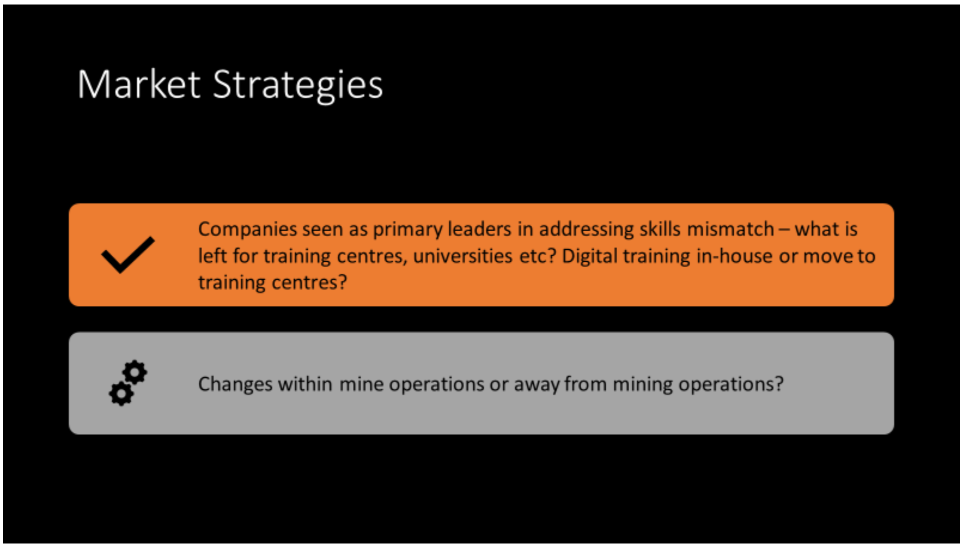


Figure 8 - Focus Group - Market strategies question 1 slide

There is an obvious contrast between companies that are big enough to develop their own training centres in-house and smaller companies who would never have such capacity and will

rely at best on external sources of training. The trend of moving skills requirement to higher orders of cognition might mean more complex and expensive training as well, which could exacerbate this aspect.
On the other hand, in-house solutions are not universal. Many employers frequently come to universities as first option for contracting professional development programmes and courses of the like.

Figure 9 - Focus Group - Training and generational aspects question 1 slide

The implementation of novel concepts such as Machine Learning and advanced data analytics might expose a generational issue for successfully implementing it. Younger generations are more accustomed to handle ‘digital things’ in comparison with older generations. However, this is not to be confused with an inability of the latter to be ‘plugged in & switched on’. In fact, many senior professionals in the sector are having a key role in helping and engaging the industry in going through this transition. The complementary nature of skill sets should be leveraged – for instance, more advanced digital tools able to generate larger and better data sets can be better interpreted by senior professionals. The ability to work well in such domains of contrast of generations can generate successful outcomes for companies and could be seen as an important skill for professionals over the next 10-15 years in the backdrop of a digital transformation.

2.2.9 Second Focus Group session - Socio & environmental and sustainability aspects

Social aspects in raw materials businesses have been consistently referenced as one of the main risks facing companies operating in the sector. Increasing social pressures over mining social, environmental and economic impacts demand companies to enhance their capability of maintaining a ‘Social License to Operate’. Compounded effects with technological developments taking place are likely to increase the level of complexity in this regard. Such changes are bound to affect the set of skills and competencies that employers will need in such environment.

In the third Focus Group meeting, participants shared their impressions, opinions and beliefs regarding the impacts that such developments will have for employers and their skills needs.

After a thorough review of relevant reports, critical uncertainties were identified and framed as questions for the online meeting. Questions were posed to participants to trigger reactions and discussions.

The summary below aims to reflect the perception and judgements of participants over such topics during the session.

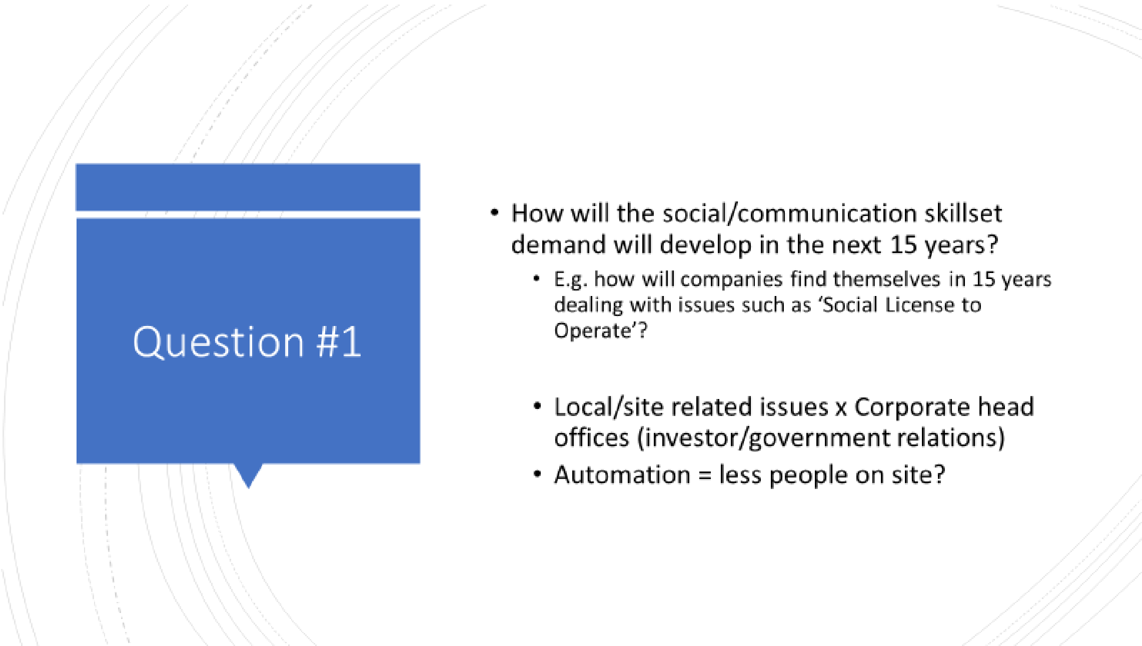


Figure 10 - Focus Group - socio-environmental factors question 1 slide

Discussions started acknowledging that the focus in issues related to 'Social License to Operate' are likely to increase in the future. Also, an emphasis is to be put on the timing of engagement with local communities in terms of project stage. Typically, exploration professionals (geoscientists) are the first one to arrive at site, becoming the first impression for local stakeholders.

There is a dynamic balance between 'Local economic benefit' and 'awareness of local impacts'. The trend of automatization might decrease economic support of local communities, while suffering less from concerns over local impacts. Companies might find themselves rethinking the concept of benefaction to local communities across different geographies. This is also a function of macro-politics of each country and the set of incentives under which governments act from local, through regional and national levels. Dealing with these aspects can be particularly challenging for mid- or small-size companies – requiring a different approach in comparison with major companies.

"To which degree classical roles (geologists, engineers) may dedicate work hours to social community affairs?"

Including social/community affairs as a topic on curricula for raw materials professions might evolve in a similar fashion as observed in the past with health, safety and environmental (HSE) topics, which were commonly neglected until a few decades ago.

'Off-the-shelf'' responses might be in the form of more training at graduate level, certification and mentoring. The latter can be particularly successful if implemented at a local level, considering social issues tend to be very site-specific.

An interesting reference based on a series of case studies was produced by the University of Dundee for the World Bank entitled "Good practices on Community Development Agreements" (2011). Such reference can provide an important picture of the many dimensions and particularities that community affairs might entail (see question 3).

Social Performance is ideally a profession on its own right. At a company level its important to understand what related skills are needed and to which extent engineers and geologists should/will develop these competences for their jobs. That does not preclude the possibility of professionals in those disciplines turning into full-time workers on social/community.

In North America some companies signal an increasing interest for "broad" scientists across a range of relevant topics, as opposed to looking into specific specialists – e.g. geophysicist + geochemist etc.

Question 2: ***"How does social/communication skills requirements change in function of different dimensions?"***

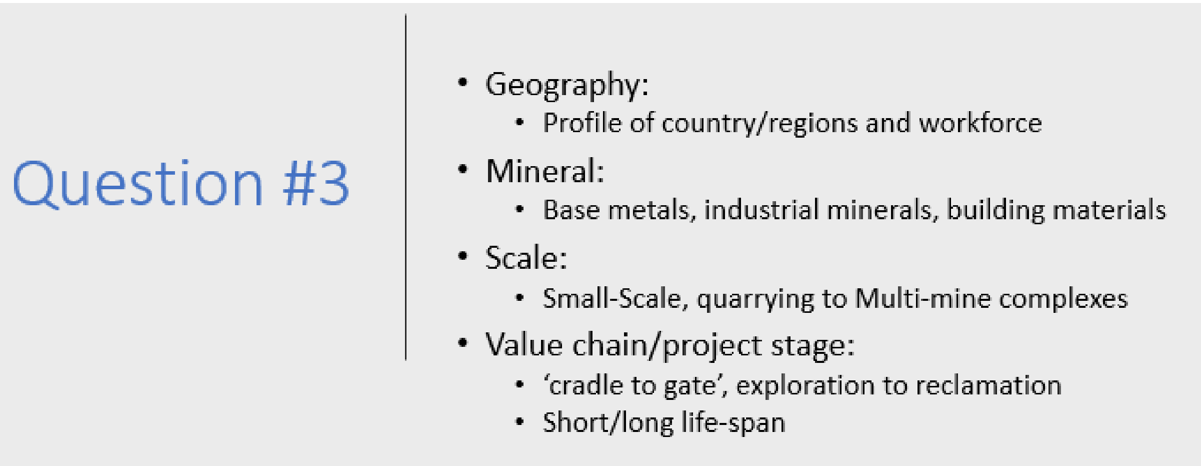


Figure 11 - Focus Group - socio-environmental factors question 1 slide

With regards to geography and type of commodity, one important differentiation is the local usefulness of the materials produced. Where at one end you have no application of the raw material at regional level and/or no further added value. On the other end you have, for instance, building materials responding a very local demand. Also, mine closure emerges as an important social issue. In general, one can highlight ‘opposing forces’ on skills demands for traditional professions in the raw materials sector: more technical, quantitative and IT literate jobs, while at the same time an increasing need of improving skills for dealing with social communication. For training providers this can be particularly challenging under different constraints of accreditation requirements and courses workload.

2.3 Long-term skills gaps – new frontiers of raw materials

This sub-task supported a redefinition of the boundaries of contemporary job descriptions and will identify potential challenges that will require new types of expertise. It will be used to identify key areas of future development that could require substantial adaptation of training programmes, with a view to the 2050 time horizon.

2.3.1 Delphi survey methodology and definition of themes

At its core, a Delphi survey makes use of information from the experience and knowledge of participants, who are mainly experts in the topics covered[10]. It stands out as a reliable method in situations where individual judgements must be collected and combined to address an incomplete state of knowledge and is frequently use for assessing long-term issues related to society, policymaking, science and technology. Delphi is based on anonymous opinions of experts who are fed back the results of a round-based survey, allowing these experts to rethink their judgement and converge – or not - to consensus over key identified topics after each round.

Participants were identified according to their expertise – in line with the topics covered in the survey. Some participants were part of the consortium while most of them were external experts identified from relevant publications and internal desk research.

The survey ran online between April and May 2019 (Google Forms), where participants were able to go through all statements in all areas sequentially or choose individual thematic clusters. Each page contained a statement about the future in one related to one of the thematic clusters and participants were asked to comment and judge the statements while also noting their expertise on the topic and level of agreement (Figure 12). Finally, in the same page participants were invited to identifying emerging skill gaps stemming from the statement’s purview towards 2050.

[10] European Foresight Platform, URL: http://www.foresight-platform.eu/community/forlearn/how-to-do-foresight/methods/classical-delphi/

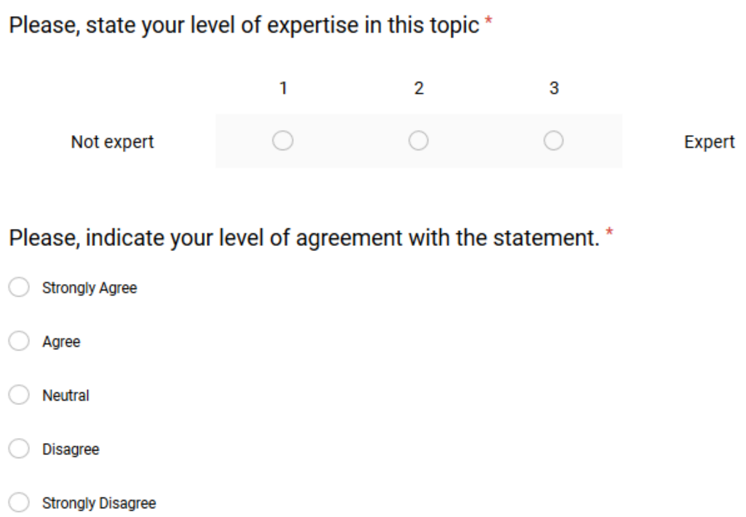


Figure 12 - Sample of information asked from participants on each statement of the survey

The INTERMIN Delphi survey had collectively 69 participants from 20 different countries.

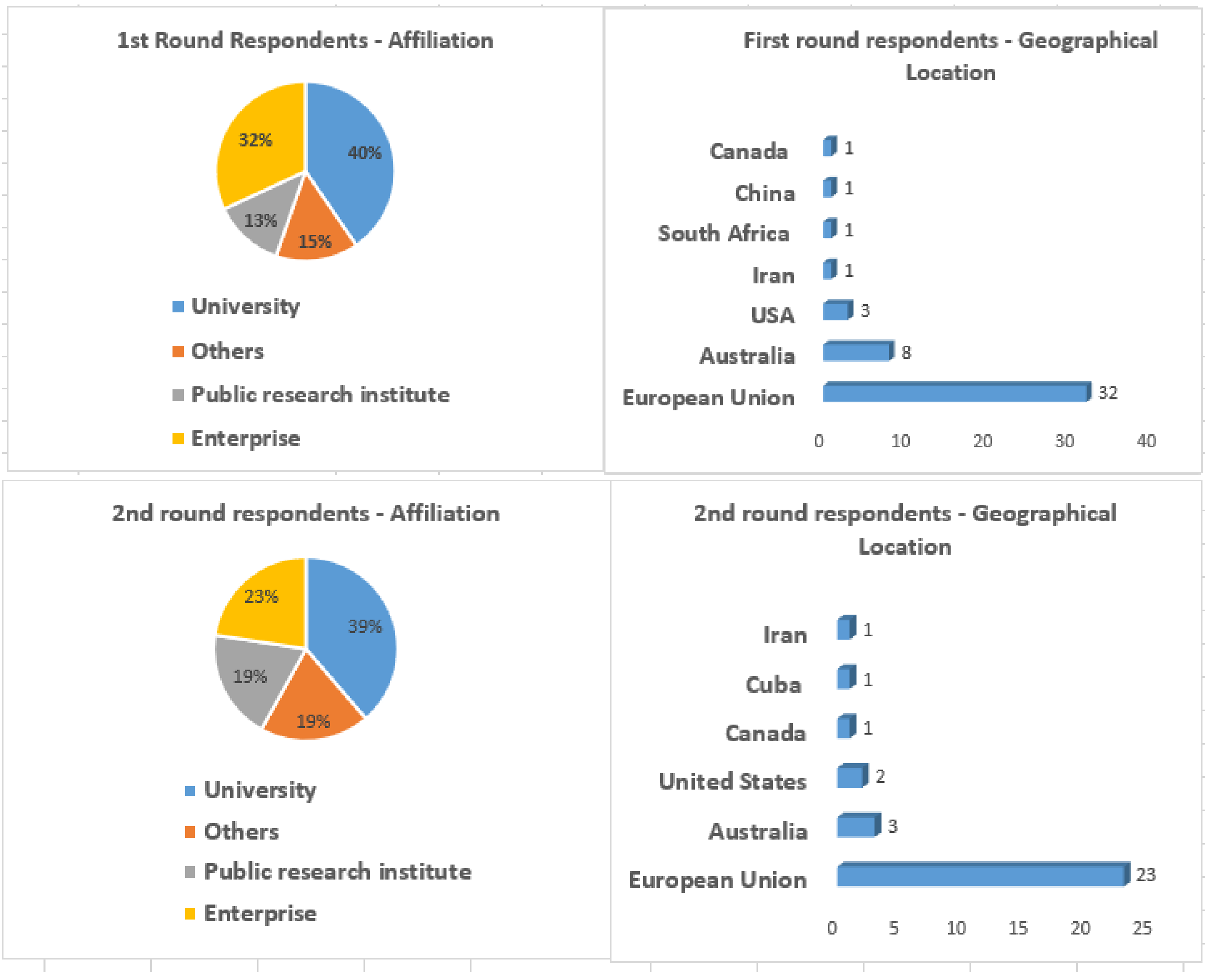


Figure 13 - Affiliation and Geographical Location of ITNERMIN Delphi Survey participants - first round (above) and second round (below)

The first phase of this activity was to identify the main thematic clusters of interest for developing statements about the long-term future of such themes. Many topics were scoped and were screened as to their relevance and level of uncertainty. As the Delphi method proposes, it brings experts judgements on the future of highly important and very uncertain areas, where prediction models or extrapolations are either impossible or undesirable.

After thorough review of reports on the future of mining the thematic clusters were defined in the following categories:

- **Conventional mining approaches:** following the expected evolution of traditional raw materials exploration and extraction approaches, topics covered were clustered under 'Mass mining' and 'Mineral exploration undercover' themes.
- **Unconventional mining approaches:** spikes of interest were observed in novel mining frontiers, namely seafloor mining and mining in space. These topics were clusters under the 'Mining in new frontiers' theme.
- **Socio-economic trends**: sustainability is considered one of the main levers of the raw materials sector transformation. In that sense, the increasing role of the 'Circular Economy' in political agenda and societal values is included as one the thematic clusters.

Table 9 summarises the areas covered in the INTERMIN Delphi survey.

Table 9 - Main themes covered on the INTERMIN Delphi survey

New Frontiers - Core Topics	Mining 2030-2050
Mass Mining	Ultra-deep pits, 'supercaves', 'in-place' recovery – 'conventional' mining is expected to evolve in face of various challenges and technological developments. This will also result in adaptation and new professional requirements in order to operate effectively in conditions of e.g. larger and deeper open-pits, ultra-depths of underground operations and highly selective extraction, materials handling and processing.
Mineral Exploration Undercover	Current trends are pointing out to mineral exploration going undercover – not necessarily at depth, but away from the 'known'. It is likely that this will be enabled by leveraging new and adapted techniques and technologies.
Seafloor Mining & Space Mining	While these are mining 'new frontiers' and considering the hardship of predicting when and if each would come to fruition, the set of technical, regulatory and environmental aspects are likely to require new professional roles, competencies and training programmes.

Raw Materials in the 'Circular Economy'	While mining won't disappear, a strong move towards recycling and circularity is likely. Changes in the raw materials value chains and consumer preferences coupled with technological advances will drive changes in skills and competences required.

The survey was designed for two rounds of collection of judgements, where participants had access in the second round to an overview of first round results. Results of the first round were also used to refine second round statements (statements were not added or suppressed in the second stage).

Table 10 lists all the statements generated. Codes are attributed for facilitating post references in the document.

Table 10 - INTERMIN Delphi statements

Thematic Cluster	INTERMIN Delphi Statement
Mass mining	1. "Primary production of raw materials will mostly come from the evolution of conventional mining – deeper and larger open-pits and ultra-deep underground operations ('supercaves') marked by one order of magnitude higher production rates."
	2. "Advanced mineral extraction techniques such as in-situ mineral recovery (ISR) will render traditional mineral processing in general and flotation in particular obsolete"
	3. "By 2050, the majority of mine sites will be fully autonomous operations"
	4. "Virtual Reality technology will be used to link all raw materials production functions underpinned by Cyber-Physical Systems (CPS)/Industrial Internet of Things (IIoT)."
	5. "Biotechnology will see a huge increase in research and development for extracting metals through biological processes."
	6. "Phyto-mining will become a relevant source of raw materials."
Mineral Exploration Undercover	7. "Improvements to professional competences will come about much more on improving 'exploration thinking' rather than data processing – a computer is not the solution to discovering ore."
	8. "Professionals will have to effectively operate in predictive exploration platforms that use analytics, modelling and simulation to identify targets in largely unexplored global regions with minimal (or no) drilling."

	9. "Geophysical and geochemical knowledge in parallel with data sciences, modelling and geographic information system (GIS) skills will be a requirement for geologists working in mining."
Raw Materials in the Circular Economy	10. "New and improved techniques for waste retreatment and processing will be developed for multiple commodities with multiple applications – dedicated, competent professions will deal exclusively with tailings re-use as well as working together with downstream users for identification of new products and applications."
	11. "Sustainability professional roles will be consolidated including competences in social and environmental performance, Corporate Social Responsibility and post-mine rehabilitation and restoration."
	12. "Between 2030 and 2050, social acceptance and community relationship will still be important issues requiring continuous improving and adaptation from raw materials companies."
	13. "Millenials will be the decision-makers in the mining investors room, representing a huge shift in how investment in the metals and mining sector is approached."
Mining in new frontiers	14. "New tailored deep-sea mining training programmes/ specialisation will be needed, covering the following modules: • Exploration and Resource Estimation • Technology Development (Mining & Metallurgical processing) • Environmental Studies • Impact assessment and monitoring – Environmental Management Plan • Project Execution – Techno-economic Assessment + Legal Framework."
	15. "Deep-sea mining has evolved in close synergy with mining, oil & gas and space research."
	16. "Main adaptation for a space mining training program will be courses on 'Systems Engineering' focusing on In Situ Resources Utilization (ISRU) and interplanetary geology. Much in line with what is already being proposed by the Colorado School of Mines."
Future of Education	17. "Education system will be revolutionized, moving from certification and general preparation to a flexible needs-based education – professionals won't have professions, but a portfolio of abilities and skills."
	18. "Professionals will be more demanded in scientific education (physics, math and chemistry) as well as higher cognitive skills such as creativity and critical thinking than technological skills."

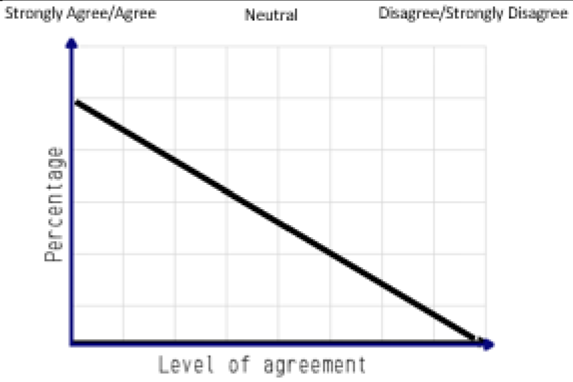
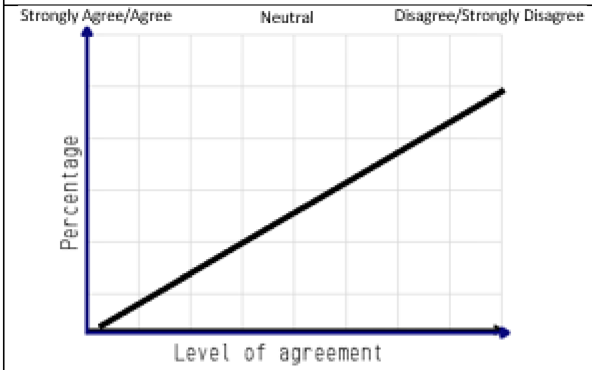
	19. “Employers will need multi-skilled workers who can operate in several areas and functions within the company.”
	20. “Raw materials jobs will be decoupled from specific geographical locations.”

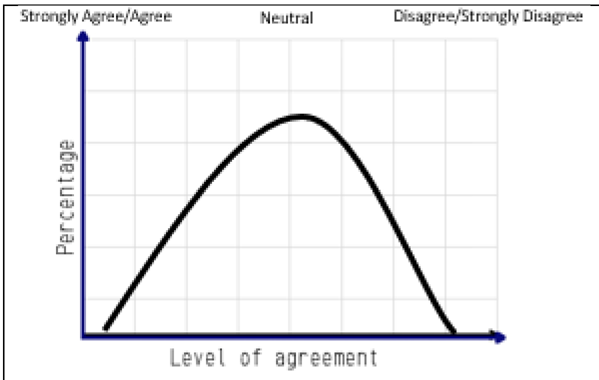
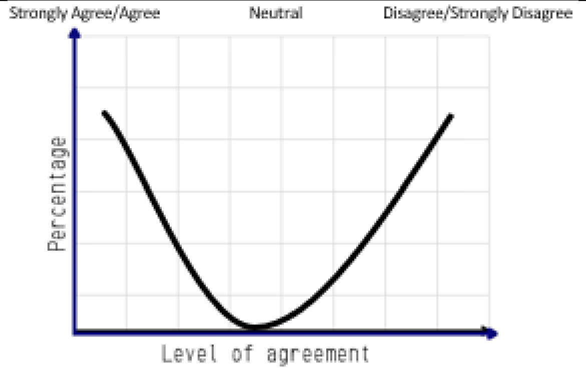
The next section summarises the findings of the survey. Annex 2 contains links to the complete database of entries as well as a more detailed overview on the results of individual statements.

2.3.2 Delphi survey results

First round results were collected in Excel and assessed for each thematic cluster, where interpretation and basic statistics were carried out for presenting these results in the second round. Levels of agreement were observed as varying over converging to agreement, disagreement and neutral views, or diverging between agreement and disagreement (See Table 11). See Annex 2 for a complete overview on the responses.

Table 11 - Delphi statements levels of agreement - generic shape of responses

Generic shape of responses	**Description**
	➢ Consensus over agreement ➢ Statements (sample): S9: “Geophysical and geochemical knowledge in parallel with data sciences, modelling and geographic information system (GIS) skills will be a requirement for geologists working in mining.” S11: “Sustainability professional roles will be consolidated including competences in social and environmental performance, Corporate Social Responsibility and post-mine rehabilitation and restoration.”
	➢ Consensus over disagreement ➢ No case was observed.

	➢ Higher level of neutral views ➢ Statements (sample): S2: "Advanced mineral extraction techniques such as in-situ mineral recovery (ISR) will render traditional mineral processing in general and flotation in particular obsolete" S6: "Phyto-mining will become a relevant source of raw materials."
	➢ Divergence of views – levels of agreement and disagreement above neutral views. ➢ Statements (sample): S17: "Education system will be revolutionized, moving from certification and general preparation to a flexible needs-based education – professionals won't have professions, but a portfolio of abilities and skills." S18: "Professionals will be more demanded in scientific education (physics, math and chemistry) as well as higher cognitive skills such as creativity and critical thinking than technological skills."

2.3.2.1 Mass Mining

Statement #1 (Round 1): "Primary production of raw materials will mostly come from the evolution of conventional mining – deeper and larger open-pits and ultra-deep underground operations ('supercaves') marked by one order of magnitude higher production rates."
Statement #1 (Round 2): "While conventional mining will evolve to deeper and larger open-pits and ultra-deep underground operations ('supercaves'), it will co-exist with novel, not yet developed mining methods."

Around 51% of respondents agreed with the statement and 11% strongly agreed. Remarks were made regarding the role that unconventional or new mining methods might play in such timeframe (2050), especially under social acceptance conflicts of large footprint operations. This is captured in the new statement (round 2) of the survey, where 60% of respondents agreed and 28% strongly agreed. Some of the emerging skills gaps remarked were: high level of integration between mining engineering, mineral processing and robotics, new environment in deeper conditions may require new geotechnical thinking and skills, extended to hydrogeology. Logistics and operations management were noted as becoming more challenging for mining engineers to deal with in such future state.

Statement #2 (Round 1) "Advanced mineral extraction techniques such as in-situ mineral recovery (ISR) will render traditional mineral processing in general and flotation in particular obsolete"
Statement #2 (Round 2) "Advanced mineral extraction techniques such as In-situ Mineral Recovery (ISR) will evolve, increasing its application share (in production volume) for a specific set of mineral raw materials/mineral deposit types."

Respondents were somewhat divided as the majority stayed neutral to the first round statement – with similar numbers agreeing/disagreeing. Agreement was observed as with relation to the positive outlook the method produces when it comes to social and environmental factors (energy, social acceptance etc,). However, it was remarked that it is not easy to rule out traditional processing methods completely, which was the primary reason for disagreement together with the fact that the sort of technique posed in the statement is bounded in applicability to a few types of deposits. The new statement of the second round attempting to resolve this issue. Although the level of 'neutral' responses remained the same (around 37%), the rest of the responses strongly leaned towards agreement 56% combined. Some of the emerging skills noted were: besides improved understanding of geomechanical properties in such environments, fluid dynamics, nanotechnology were mentioned together with broader mentions to increasing collaboration with biotechnology, electro-mechanical systems and rock fragmentation at depth.

Statement #3 (Round 1 and 2): "By 2050, the majority of mine sites will be fully autonomous operations"

While most respondents were on the agreement side in the first round, some scepticism was observed regarding the 'fully autonomous' expectation. The consensus was observed strongly with regards to the continuous increase on automation in mine operations, with constraining factors such as time horizon proposed, need for human grade control interaction etc. Second round presented similar views, underlining expectations for fully autonomous systems especially for routine processes (trucks, shovels, drilling etc.). Emerging skills gap were repeatedly related to an 'advanced digital literacy' for professionals including programming, mechatronics and AI skills.

Statement #4 (Round 1 and 2): "Virtual Reality technology will be used to link all raw materials production functions underpinned by Cyber-Physical Systems (CPS)/Industrial Internet of Things (IIoT)."
In both rounds this statement presented similar levels of agreement (more than 50% agreed and strongly agreed), with low levels of disagreement. Some uncertainties were repeatedly noted as to which extent VR will be developed in the mining sector. Remark was made as to expectance over VR and IIoT will go beyond as these are currently understood: a fully

simulatable physical model-based digital representation of the operations. Some of the emerging skills gap noted were: increased levels of combination of core mining skills with programming/data science.

Statement #5 (Round 1 and 2): "Biotechnology will see a huge increase in research and development for extracting metals through biological processes."

Majority of respondents on the agreement side (more than 60% combined) in the first round and 60% in the second round. Main concern is regarding how big biotechnology will be in that sense, with economic and technical constraints, such as the limitation of mineralisation types suitable for this type of agent. Based on past and current cases, biotechnology can increase in importance also for secondary raw materials (recovery from scrap). Emerging skills gaps noted were: lack of industrial biotechnology specialists in the minerals industry and greater understanding of bio-oxidation and chemical processes for geologists and mining engineers.

Statement #6 (Round 1 and 2): "Phyto-mining will become a relevant source of raw materials."

Responses were symmetrically distributed along 'neutral' opinions in the first round (47% in the first round, 83% in the second round stated 'netural'). Lack of expertise among respondents (as per self-assessment) indicates that such area is still hard to classify in terms of potential importance. What repeatedly was observed is the judgement that potential amount of metals obtained from such sources is unlikely to be relevant and may play a minor role in specific raw materials value chains, without excluding risks such as competing land-uses. Emerging skills identified were: basic knowledge in areas such as microbiology, botany and biochemical currently apart from any raw materials related degrees

2.3.2.2 Mineral Exploration Undercover

Statement #1 (Round 1 and 2): "Improvements to professional competences will come about much more on improving 'exploration thinking' rather than data processing – a computer is not the solution to discovering ore."

Both rounds saw similar levels of agreement - 40% of respondents strongly agreed with the statement and only around one fifth on the disagreement side. In general, agreements were emphasising the importance of (human) exploration thinking that will still need to be combined with advanced computational resources to generate better discoveries in the future. By the second round, it became clear that disagreements were more on the lines of not demeaning the potential that data processing tools can have in exploration geology. Main skills gaps identified were: improved coding and data analysis with strong integration to systems thinking, but also the risk of over reliance in computer-based methods may decrease necessary knowledge in classical methods of geological work – field observation, mapping and microscopy.

Statement #2 (Round 1 and 2): "Professionals will have to effectively operate in predictive exploration platforms that use analytics, modelling and simulation to identify targets in largely unexplored global regions with minimal (or no) drilling."
Most of the respondents in both rounds were on the agreement side (more than 66% combined and 55% combined, in the first and second round respectively). Main restraint was potentially not needing drilling although it was recognised that many of these tools – advanced modelling and simulation – can strongly contribute to better locate drillholes and thereby reducing the amount of drilling. Emerging skills gaps identified: the ability to model and interpret big data in synergy with improved understanding of orebody formations and geological processes.

Statement #3 (Round 1 and 2): "Geophysical and geochemical knowledge in parallel with data sciences, modelling and geographic information system (GIS) skills will be a requirement for geologists working in mining."
This statement generated greater levels of agreement in both rounds (more than 80% combined). Some remarks were made concerning that collaboration of a team of specialists can produce the necessary knowledge to deploy the best techniques available, shifting the emphasis to better communication among disciplines and improved creative thinking. Emerging skills gaps: teamwork in large projects with diverse expertise,

2.3.2.3 Raw Materials in the Circular Economy

Statement #1 (Round 1 and 2): "New and improved techniques for waste retreatment and processing will be developed for multiple commodities with multiple applications – dedicated, competent professions will deal exclusively with tailings re-use as well as working together with downstream users for identification of new products and applications."
Both rounds had similar levels of agreement (app. 85% of respondents). Some comments acknowledge this statement as an already ongoing process, strongly framed by legislation in many cases, but an inevitable development nonetheless. Emerging skills gaps: waste management and legislation, mineralogy/geochemistry applied to waste/tailings.

Statement #2 (Round 1 and 2): "**Sustainability professional roles will be consolidated including competences in social and environmental performance, Corporate Social Responsibility and post-mine rehabilitation and restoration."**
This statement also had high levels of agreement in both rounds (more than 80% combined). Remarks were made over the need of a team of professionals working together to deploy the necessary skillsets – for both social and environmental aspects. In other words, not necessarily a single professional with strong Public Relations expertise and also strong scientific/ engineering background. Emerging skills gaps: social sciences knowledge for engineers and geoscientists.

Statement #3 (Round 1 and 2): "Between 2030 and 2050, social acceptance and community relationship will still be important issues requiring continuous improving and adaptation from raw materials companies."
This statement reached more than 90% of responses in the agreement level, with a strong emphasis on how important Social License to Operate is and is expected to be into the long-term future of raw materials production. In an ever more 'connected' world, poor social, environmental and community performance will not be tolerated. Emerging skills gaps: same as above.

Statement #4 (Round 1) "Millenials will be the decision-makers in the mining investors room, representing a huge shift in how investment in the metals and mining sector is approached."
Statement #4 (Round 2) "Future leaders in mining will have greater socio-environmental awareness and will objectively influence how value is perceived in mining."
Agreement in the first round was mostly 'neutral' (37%), while the rest pended more towards agreement with the statement (25% 'strongly agree' and 21% 'agree). Some scepticism was noted as to whether new generation of professionals will think so differently by 2050 – that is, investing is and will be in the end about the bottom line: However, respondents agreed that some change on how value is perceived may change to some extent. This is explicated in the second round statement, where level of agreement remained similar as well as comments.

2.3.2.4 Mining in New Frontiers

Statement #1 (Round 1 and 2): "New tailored deep-sea mining training programmes/ specialisation will be needed, covering the following modules: • Exploration and Resource Estimation • Technology Development (Mining & Metallurgical processing) • Environmental Studies • Impact assessment and monitoring – Environmental Management Plan • Project Execution – Techno-economic Assessment + Legal Framework."
The majority of the respondents either agreed or strongly agreed with the statement in the first round (70% combined). Remarks were made over many specific challenges deep-sea mining would present such as new environmental impacts, legal aspects and deep oceanic environments, which in turn would have to bring in disciplines together (e.g. marine sciences, geology, robotics) while also considering off-shore operations analogues. Second round presented slightly more 'neutral' views, but with the majority still agreeing with the statement and repeated scepticism over the actual fruition of such new frontier for raw materials sourcing. Emerging skill gaps: skills related to remote under (deep)waters operations.

Statement #2 (Round 1): "Deep-sea mining has evolved in close synergy with mining, oil & gas and space research."
Statement #2 (Round 2): "By 2050, Deep-sea mining has evolved in close synergy with mining, oil & gas and space research."
In the first round half of respondents were on the side of agreement while 25% gave 'neutral' responses. Disagreements were mostly stating that offshore Oil & Gas projects are completely different and should not be considered. In the second round the statement was updated to emphasise the plausibility of a 2050 scenario were deep-sea mining exists and evolved in synergy with the above-mentioned areas. Individually, most of the responses were 'neutral' (38%) with 45% on the agreement side (combined).

Statement #3 (Round 1 and 2): "Main adaptation for a space mining training program will be courses on 'Systems Engineering' focusing on In Situ Resources Utilization (ISRU) and interplanetary geology. Much in line with what is already being proposed by the Colorado School of Mines."
In the first round, the majority of responses were 'neutral' (49%), while in the second round distribution of agreement levels remained very similar. Most concerns were related with the uncertainty of the time horizon considered (2050), whether that will be enough to see important developments. Emerging skills gaps: systems engineering, planetary geology for raw materials.

2.3.2.5 Future of Education

Statement #1 (Round 1): "Education system will be revolutionized, moving from certification and general preparation to a flexible needs-based education – professionals won't have professions, but a portfolio of abilities and skills."
Statement #1 (Round 2): "Education system will be revolutionized, moving from certification and general preparation to a flexible needs-based education – professionals won't have fixed professions, but lifelong learning, developing a dynamic portfolio of abilities and skills."
In the first round responses were well divided – 58% on the agreement side and 32% on the disagreement side. Overall, respondents agree that there is a set of foundational competencies that are pivotal to which advanced abilities can be developed. In the second round, the statement was updated so as to better reflect the potential professional dynamics considered. Most of participants were on the agreement side (more than 70%). Remarks were made such as that certifications will still be needed and that much of this flexibility is dependent on the speed of change (technological, labour market etc.).

Statement #2 (Round 1 and 2): "Professionals will be more demanded in scientific education (physics, math and chemistry) as well as higher cognitive skills such as creativity and critical thinking than technological skills."
Most of respondents were on the agreement side (57% in the first round, and more than 60%

in the second round). Although the high levels of agreement, repeated remarks were made over that the optimum would be combination of all these skills – as some level of technological skills will be required.

Statement #3 (Round 1 and 2): "Employers will need multi-skilled workers who can operate in several areas and functions within the company."

Most of participants agreed with the statement in both rounds (67% and 80%, respectively). Comments where underpinning that this is true and has been for some time to some extent. However, more sceptical comments remarked that companies might increase outsourcing of specialised skills not necessarily pushing for internal multi-skilled professionals career development.

Statement #4 (Round 1): "Raw materials jobs will be decoupled from specific geographical locations."

Statement #4 (Round 2) "Raw materials jobs will be decoupled from operation sites."

In the first round, most of individual responses were neutral (35%) with more respondents on the agreement side (42% combined). Some struggle was noted as to the meaning of the statement, which was to emphasize the role that remote work will have in the raw materials sector. The updated statement of the second round attempted to overcome this. Remarks were made that in some areas there should always be a need for local work keeping geologists and engineers locally required. However, that does not preclude the trend that more professional roles are expected to be able to be entirely away from mine sites.

3. CONCLUSIONS

Sectoral reports showed the main drivers and trends shaping the future of the sector and its impacts on the workforce and skills needed. Currently, greater focus is being put on themes related to the implementation of digital technologies and increased automation and its impact in the raw materials workforce. Furthermore, sustainability related factors (social, environmental and political aspects) are expected to change the way raw materials companies operate on one hand and the set of values that professionals might bring into the organisation. The future will ultimately stem from the interrelations between the broad scope of stakeholders and technological evolution. INTERMIN Focus Group explored more in detail these issues highlighting the interlinkages between technological evolution, societal demands and employers' evolving needs. This is compounded with a survey confirming that over the next decade trending skills and competencies will be heavily related to new mining equipment and systems and secondary production as well as 'softer skills' related to sustainability performance (and all the social, environmental and economic aspects therein).

It is well established that employers focus on different professional development approaches for closing skills gaps. Namely, through re-skilling, up-skilling, mentoring, partnerships with universities and training centres mainly. However, it must be noted that the degree of impact current trends might have in the future of raw materials companies can also give rise to new operating and business models. Therefore, ongoing feedback of emerging needs in the sector and raw materials employers at large is key for training centres and universities to strategically adapt and timely respond to these needs by adjusting curricula.

Foresight studies are methodologically consistent in providing not only predictions but better anticipatory capabilities by increasing collective intelligence on relevant issues and by generating insights otherwise not identified. As a participatory process, it leveraged a wide community of participants – INTERMIN partners and external experts in raw materials from across the world. The longer time frames considered in this deliverable show that the power of anticipation will be crucial for the ongoing and upcoming changes in the raw materials sector. This will impact stakeholders differently, but all traditional raw materials jobs and professions are likely to be impacted or even completely changed, nonetheless.

The INTERMIN Delphi survey helped to identify – and clarify – expectations regarding a set of long-term future issues that can impact skills and competencies needed from professionals. An overarching aspect is that of the importance of conveying multiple images of the future of raw materials production for better anticipation and generation of insights – in essence, future mining can be expected to be a product of the co-existence of the many building block composing current images scoped throughout this forward-looking assessment.

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ANNEX 1 – FOCUS GROUP

PARTICIPATION

Focus Group Core Participants	
Christopher Keane	**American Geosciences Institute**
Marco K. Martins	**La Palma Research Centre**
Robin Evans	**University of Queensland**
Luis Jorda	**IGME**
David Ovadia	**IAPG/External Experts**

MANIFESTO

Focus Group and Manifesto

INTERMIN FOCUS GROUP POSITIONING

The mining extractive sector is globally interconnected and increasingly inter-dependent. It spans from the policies to environmental regulation, ethical aspects and community relations up until access to finance and technical challenges related to locating, measuring and exploiting mineral resources in profitable ways, while minimizing risks. This in turn requires a multitude of skills and competencies to be deployed throughout the mining sector – and mining stages - in order to provide the mineral raw materials needed for societies across the globe. Understanding these dynamics coupled with the expected developments in the next fifteen years is important in order to better prepare professionals to lead and solve future challenges successfully.

Mining 4.0

Ongoing trends such as the ‘Industry 4.0’ are asking from engineering professionals greater skills in IT and advanced digital tools - namely advanced data analysis, predictive analytics, simulation/ optimisation and application of advanced data processing and programming tools, e.g. Deep Learning and Machine Learning. This is in line with the shift to do 'higher-cognitive, complex problem-solving', by improving capacities on critical thinking, decision making, creativity The next 15 years will see employment trends in developing initiatives for re-skilling and up-skilling employees, reviewing strategies for mobility and job rotation and, increase in collaboration programmes – with local governments, training centres/universities and the suppliers of technology and specialised services. This will help to meet the needs of companies to move from a 'siloed' mentality to more integrated business approaches, requiring professionals able to understand the 'whole-of-systems' rather than staying entrenched in their operational units. Consequently, future raw materials professionals will come from a more diverse – or even generic – engineering backgrounds with mining-related specializations sitting across the top. By extent, training centres will have to be prepared to educate professionals with such diverse background, rather than just focus on classical dedicated professions such as 'Mining Engineers'. This diversity of the workplace can be expanded to being able to work well with different cultures and generations, contributing to a synergetic workplace.

With regards to Geoscientists, experience shows that companies may re-orient their teams as 'groups of multidisciplinary professionals' rather than a 'multidisciplinary group'. In other words, geoscientists are also expected to have knowledge in the different components of the value chain, while at the same time demonstrating advanced skills in some of the core areas of their field of work (e.g. geochemistry, geophysics, etc.). If most of geoscientists are spending their time with 'data wrangling', then this underpins the potential application of techniques such as Machine Learning in order to take out the professionals from repetitive tasks, so that they can focus the major share of their time in more complex geoscientific problem-solving issues. However, this still needs to see adaptation from universities and training centres, as such 'data processing' techniques require good command of areas which are currently mostly out of programmes – from maths (e.g. linear algebra) to advanced programming (e.g. C++, Python, R).

Social Skills: The cornerstone of the 21st Century mining sector.

On the other side of the skills spectrum, challenges coming from the 'social' side of mining – frequently covered under the umbrella of 'social acceptance of mining' – are arguably one of the main challenges that the sector faces and it tends to become a new norm for the next decade. There is a clear gap in some geographies for offering specific, advanced programmes on e.g. 'Social License to Operate'. Also, 'Social performance' has emerged as a new profession, constituting a specialised professional competence of its own. This however does not preclude traditional roles such as mining engineers and geologists to require fundamental skills in community development and engagement. In fact, a new term is proposed: 'Social Responsibility', as it conveys a broader and more comprehensive scope. In general, 'Social and emotional skills' – communication, leadership, teaching & training others – are expected to increase in demand.

Both technological and social aspects are highly dependent on the size of operations since the raw materials sector comprises very small sites (typically quarrying activities) to multi-mine complexes moving millions of tons of materials monthly. The heterogeneity of the sector and its market structures should also be considered as the skill sub-sets needed can vary throughout different geographies (e.g. remoteness of operations, community engagement needs, available technologies, regulations etc.) and mineral raw materials value chains (geological and product complexities, market structure and size of operations).

The time horizon considered (fifteen years) also reinforces the need to think over aspects of mining rehabilitation and waste management with all its environmental implications – under the lens of the 'Circular Economy' – as current initiatives are pushing towards 'low-carbon' economies. Such developments are already featuring cases of companies seeking to brand themselves as 'raw materials providers' rather than "just mining" companies, with the prominent case of UMICORE[11] in Europe. This is in line with the idea of decreasing the footprint of mining operations also driven by factors such as responsible sourcing of minerals, as concerns from customers and shareholders over these aspects are expected to increase in the future. Moreover, a transition to a low-carbon economy is likely to push re-use and recycling of materials as much as it is likely to improve the economics of the heavily regulated secondary resources market.

INTERMIN SURVEY

As part of Work Package 1 "Worldwide Mapping of educational-research programmes", INTERMIN developed a 'Skills Catalogue' focusing on the mining sector and advanced level degrees (e.g. MSc., MEng., postgraduates, etc.). An internal survey assessed skills in terms of their current status: Consolidated skill, Emerging Skill or Decreasing Skill, where participants deemed each skill with one of the respective status. Table 1 below shows the results for each area according to the level of consensus (greater than 50%) over emerging skills, whilst Figure 1 shows the relative weight of 'emerging skill' responses per professional area.

[11] https://www.umicore.com/en/about/history/#background

Technical Skills	
Business Management	Facilitates the implementation of environmental, engineering, mining and social best practices (73%) Understands and applies the 'license to operate' philosophy (82%) Develops and implements risk management strategies and plans (73%)
General and applied geology - Exploration, resources and reserves	Ore body modelling and resource and reserves estimation: Demonstrates a knowledge of the JORC Code and other standards for resource classification requirements for reporting resources. (64%) Conducts sensitivity analyses recognising the geological, technical, financial, social and political uncertainties in mining operations. (58%)
Mining Equipment and Systems	Demonstrates proficiency in using 3D CAD software. (80%) GIS knowledge (55%) Mining software. Demonstrates proficiency in using at least one mining software package (e.g. VULCAN, DESWIK, SURPAC, DATAMINE) (64%)
Mining Services	Designs communication systems for Autonomous Mining systems (73%)
Recycling and Secondary Mineral Raw Materials, Circular Economy	Knowledge of quality assessment and certification. EU and international standards and labels. (57%) Ability to perform investigation and development in the field of new materials and new processes. (77%) General knowledge of the principles of circular economy, climate change and the recycling market. (77%) Capacity to design recycling plants. (58%) Knowledge on the regulatory barriers for secondary raw materials. (67%) Knowledge on the supervision and or operating recycling plants. (64%) Practical knowledge on waste management. (54%)

Soft Skills	
Communication	Ability to communicate Earth Science issues with the wider society. (64%) Communication in native language. (54%) Know and describes Social Geology and Geopolitics. (64%)
Creative thinking, problem-solving and research	Researches new products, technologies and processes (62%)
Sustainability	Engages with stakeholders. Recognises corporate social responsibility (57%) Know and apply principles of sustainable development (86%)
Working with people	Ethics. Transmit credibility and integrity (57%) Coaching and leading teams (57%)
Social Performance	Acquiring and using social data and baseline information. Capacity to understand and apply anthropological, ethnographic and archaeological Knowledge. (75%) Manage and apply concepts as a human right and gender equality (79%) Monitoring and evaluating social projects. Manages social research’s tools to measure outcomes during and at the end of the social project. (92%) Community engagement. Understand and practice dialogue skills in engaging with communities (86%)

	Grievance management, Prevention & management of conflict. Manage methodologies to detect previous or arising conflicts Apply conflicts resolutions techniques (64%) Cultural heritage management: Comprehend and apply Cultural Heritage Management (CHM). Recognise stakeholders to work within CHM. (64%) Engagement with Indigenous peoples. Identify potential conflicts related to the use of land and water by the project. Understanding and applying principles of Free Prior Informed Consent (FPIC) (77%) Resettlement & influx management. Leadership skills to develop and coordinate relocation processes. Enlightening. Influencing and convincing policy makers and stakeholders. (67%)

CONCLUSION

Increasing rates of technological change and socio-environmental concerns, underpinned by sustainability themes (Climate change, Resource Efficiency, Circular Economy etc.), are setting the scene for changing the nature of work in the raw materials sector. Risks stemming from the ‘Social License to Operate’, ‘Digital Effectiveness’ and ‘Future of Workforce’ are already being reported in top positions of concern[12]. Consequently, skill sets needed are likely to change.

It is important to highlight that many of the emerging skills that will be very relevant in the coming years are not taught in any universities and some covered only slightly in specific courses.

Acknowledging the potential developments in the future is critical for anticipating these changes and better preparing the workforce of tomorrow. This document points out to the importance of understanding how the supply chain of skills and competences has to be adjusted

[12] EY (2018). 10 Business risks facing mining and metals. Link: https://www.ey.com/en_gl/mining-metals/10-business-risks-facing-mining-and-metals

in order to ensure that employers can benefit from more efficient and productivity levels, while also improving and putting in place the best practices for guaranteeing socially and environmentally acceptable activities. This turns out to be informative for universities and training centres who would benefit from shaping and adjusting their curricula accordingly, as well as students to re-orient their study plans.

Focus Group: Highlights and key developments for the next 15 years in the raw materials sector:

- Moving away from the "bigger is better" mentality and economies of scale – in other words, rethinking approaches to develop mineral deposits;
- Social issues will continue to increase over the next decade, continuing as one of the main challenges for the sector;
- More autonomous operations and new technologies: changing the nature of work with more flexibility and professionals working remotely from urban centres – especially in developed economies;
- Increased availability of online courses and training in raw materials – though not every skill/competence may be acquired online[13];
- Progression of integrated teams to integrated professions, where skills deployment turns more agile;
- More companies seeing themselves as 'Raw Materials companies' – in response to ongoing sectoral dialogues and programmes, e.g. ICMM, H2020.

From the INTERMIN survey on skills, the following can be highlighted:

- **Technical skills:**
    - **Business Management:** improved practices in risk management accounting for sustainable and social acceptance principles. Business re-engineering for managing 'digitalization' of operations. Adapting more agile project management methodologies to increasing development and deployment of ICT solutions in the sector.
    - **Mining Equipment and Systems:** proficiency in using dedicated software packages, which may become more integrated with greater interoperability with different modules and areas.
- **Soft skills:**

[13] http://minetrain.eu/

- **Sustainability:** ability to translate sustainability principles (i.e. SDGs[14]) to raw materials related activities.
- **Social performance**
- **Recycling and secondary mineral raw materials:** baseline understanding of the principles of circular economy, climate change and the recycling market, and the ability to investigate and perform R&D in the field of new materials and new processes.

[14] UNSDS (2016). Mapping Mining: to the Sustainable Development Goals: An Atlas. Link: http://unsdsn.org/resources/publications/mapping-mining-to-the-sustainable-development-goals-an-atlas/

ANNEX 2 – DELPHI SURVEY

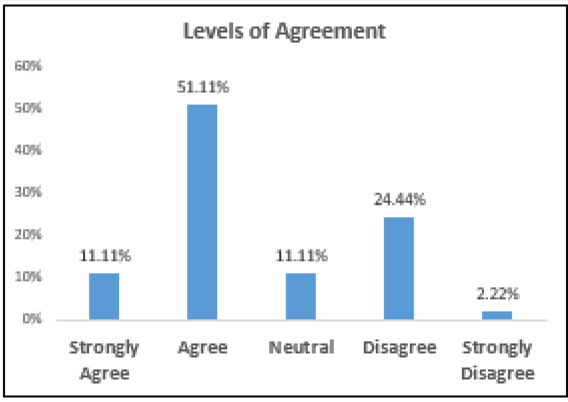
The survey entries of each round are made available in the links below in excel sheet format – with the exception of personal name and email in order to maintain anonymity.

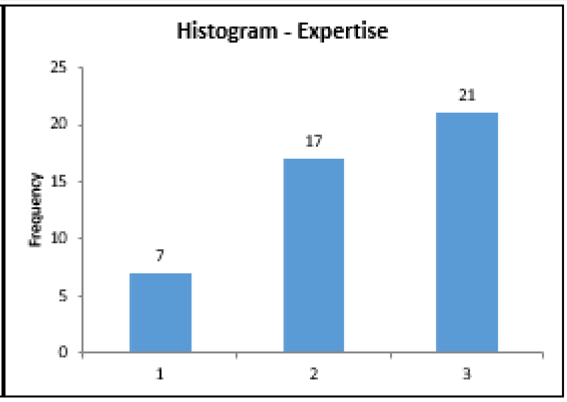
FIRST ROUND RESULTS

Thematic cluster links
Mass mining
Mineral Exploration undercover
Circular Economy
New frontiers

➢ Mass mining

Statement 1: “Primary production of raw materials will mostly come from the evolution of conventional mining – deeper and larger open-pits and ultra-deep underground operations (‘supercaves’) marked by one order of magnitude higher production rates.”



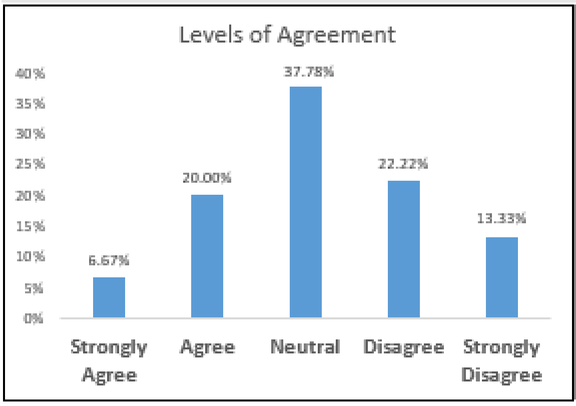


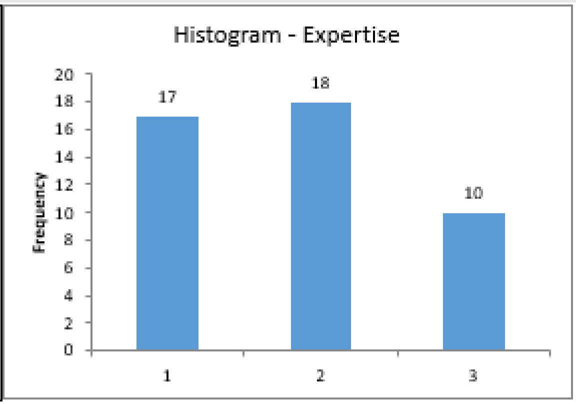
Agree
1. "I strongly agree with the statement. Mining will remain the primary source of raw materials and its evolution and optimisation of processes will help engineers reach higher depths, bigger production rates and capacities."   2. "I strongly agree with the statement, with the caveat that it is for bulk raw materials such as copper or iron. For "boutique" minerals such as rare earths, tin, nickel, etc, we will be looking at smaller, more focused operations, potentially with significantly higher tonnes/machine or tonnes/person. Also, while we aspire to an order of magnitude higher production, it remains to be seen if that is achievable."
Neutral

1. “Whilst there will be some production from very large low-grade deep bulk mining there will be a new frontier of small scale ultra-selective high-grade mining as well, using autonomous, swarming technologies or in-situ leach/extraction that is highly selective, highly specific and scaled to the orebody” 2. “Within 15 years this is likely to remain true, within 30 years in-situ mining is likely to emerge as an equal alternative.”
Disagree
1. “Development seems to be also toward smaller, "invisible" underground operations.” 2. “I think the way raw materials are produced itself will change. As an example, a by-product of geothermal production wells is gold deposition in the pipes. Also mining itself is being more and more automated using robots which will allow for a different approach than conventional mining.” 3. “Very large open pit mine does not comply with social acceptance. This will be possible only in large desert areas or in any case very far from urban settlements.”

Skills gaps
1. “Such operations will require a more integrated systems approach, as their impacts will be correspondingly larger. Block caving in particular will require greater depth in geotechnical expertise.” 2. “Skills needed in automation and sensors, in delivery methods for chemical reagents or for biotechnologies to extract metals, and in data management.” 3. “Demands on geotechnical, hydrogeological, and mechatronics/automation specialists will increase, there will be shortages in these skills and gaps in the required knowledge and expertise, and a generational gap in the 40-60 year age gap as experienced Post War Baby Boomers retire.” 4. “Multidisciplinary skills will be required since the future of mining will be more focused to robotics and automation” 5. “In my view there will be needed experts in life cycle analysis to certificate the less harmful operations in terms of both resource consumption and emissions to the environment.”

Statement 2: “Advanced mineral extraction techniques such as in-situ mineral recovery (ISR) will render traditional mineral processing in general and flotation in particular obsolete”

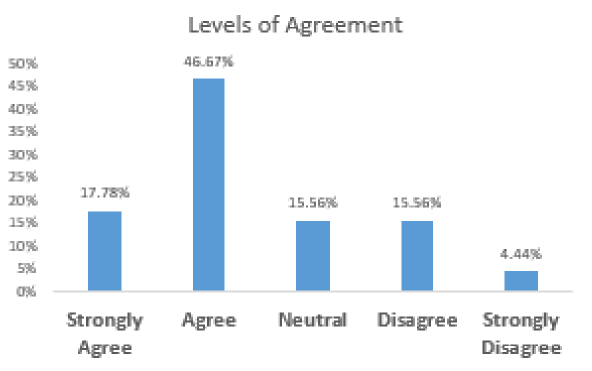


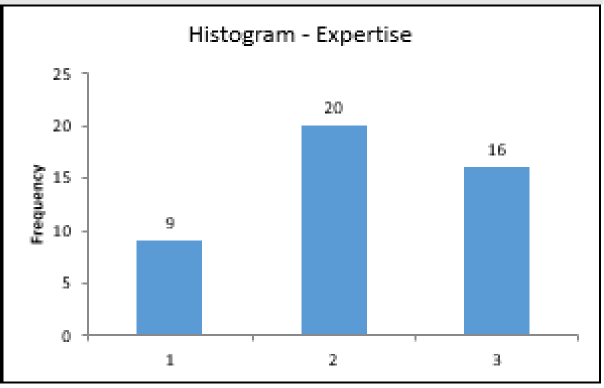


Agree
1. "There will certainly be an increase in ISR over conventional, the key drivers will be energy, footprint and Social licence to operate” 2. “New separation technology (chemical, optical nuclear, heat..,) will improve recovery at mining sites of interest (volume and access)”
Neutral
1. “Within 30 years in-situ mining is likely to emerge as an equal alternative to current practices, but this may include in-situ processing, not just leaching, in which case small-scale crushing and flotation may still exist.” 2. “ (…) not all commodities and not all deposits are geologically and geotechnically able to be exploited with in-situ recovery methods. Therefore, this statement may be true for some commodities but not for the whole of the mineral industry.” 3. “In-situ recovery methods are difficult to implement for some types of mineralization. Different approaches involving modular in-situ processing plants, swarms of robots, or advanced biotechnologies will be needed.” 4. “WE need to see more R&D in this field. At the moment it is only really uranium that see ISR. There is potential but long way from seeing it take over from traditional processing routes.”
Disagree
1. “Such drastic change is unlikely within this timeframe, it is more likely that various technologies will co-exist” 2. “I am no expert, but... Specifically for in-situ mineral recovery, I struggle to see a) how the lixiviants will be contained in the mining area, and b) for many minerals that occur in % or ppm levels, how the rock will be broken up or opened to allow the lixiviants to reach the payable minerals.”

Skills gaps
1. “will require greater understanding of Geomechanics (porosity permeability both natural and induced) and chemistry coupled with fluid dynamics, nanotechnology and environmental science” 2. “High level skill in mineral processing is necessary, as well as research works in the field of mineral recovery. At present the professional skill based only on traditional techniques is going to be not sufficient for future development.” 3. “The new technologies require new physical and chemical engineering skills well as new environmental impact assessments which could have implications for mine design which will require new engineering approaches and also communications skills to overcome fears of communities.” 4. “Gaps: Electro-mechanical systems, biotechnologies, data science and management, rock fragmentation at depth” 5. "Hydrogeology" of hard rock, and ability to model and forecast how to improve rock porosity predictably through some method, are probably going to be in short supply.

Statement 3: "By 2050, the majority of mine sites will be fully autonomous operations"



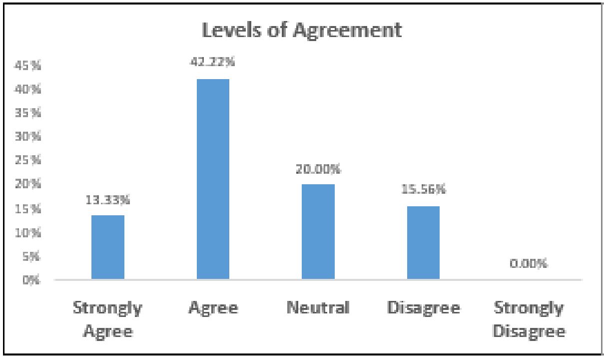


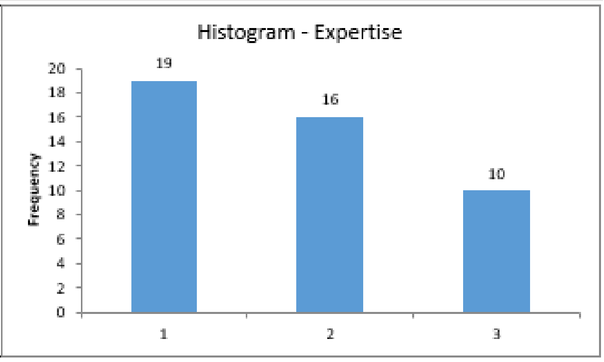
Agree
1. "Some of mass mining sites can be fully automated much earlier. The level for automation in the future will depend on development primary on data acquisition and data processing techniques in situ. Someone will say application of AI, but I don't like to use this expression, because it requires more profound approach." 2. "Full autonomy will progress very unequally across the different continents and countries." 3. "I agree to a certain extent. Automation will take over mining but not that fast. 2050 is relatively a short period of time for an industry that has a slow pace in evolution like the mining industry. Let's not forget that countless active mining projects have a lifetime of several decades ahead and have already a specific (non-automated) infrastructure and equipment and this cannot change easily. Moreover, potential projects that could benefit from automation already are in areas or are governed by other boundary conditions (e.g. small projects, short LOF, cheap labour) that may not favour the implementation of automatic systems. At least not yet and probably not for the next 30 years. Automation will take over but maybe in 50-60 years from now." 4. "Developments in autonomous systems are proceeding rapidly. Swarm robotic systems will also play a role." 5. "will not be 100% but will be a high percentage, there are too many benefits for this not to occur" 6. "The utilization of robot in mining can be very useful in most operations, especially where the environment is dangerous, or the stress upon operators can be a cause of accident. Nevertheless, we are still very far from the point where we put everything in the hand of computer/machinery. The ratio machine/man will surely increase in the future, but when hazard toward people and/or environment is high, the human control is necessary anyhow."
Neutral
1. "While many operating environments including underground mines may be entry-free, there will always be staff present in supervisory, coordination and communication roles amongst others. The displacement of manual roles will also affect the engagement with local communities."
Disagree
1. "This is a very difficult statement to evaluate. There will certainly be a lot of autonomy by 2050, but there is a level of uncertainty associated with geology that makes me wonder whether full autonomy can ever be

achieved. In my mind, this is a very difficult call about our ability to create real artificial intelligence. Right now, I am not seeing enough progress in that direction - towards creativity and problem solving, rather than dealing with repetitive tasks. I don't think we have the fundamental idea of how to do this, so I don't see full autonomy as viable as I write. On the other hand, 2050 is a long way away, and perhaps something fundamental will change. To elaborate: computers are getting better and better at doing things that are bounded, like playing chess or identifying traffic lights in photographs. When it comes to unbounded problems, like designing a bicycle, there are computer assistants around that will do generative design, meeting a specification for a design by calculating exactly where to place material and where to take it away, but there is not yet a computer program that can generate the specifications for itself. Given the extreme uncertainty associated with geology (and I don't see the uncertainty going away - it may get smaller but it is not going away) I don't see computers generating mine models in unguided ways.

Skills gaps
1. "Development knowledge in IT, coding, data processing, in situ measurements, sensor application."
2. "Mine Engineers need to learn to plan differently for an autonomous operation compared to today's planning methodology."
3. "For professionals skill in automation, a strong background of electronic engineering is supposed to be a relevant part of own technical culture."
4. "Whatever the case, people working in mining will have knowledge in computer science. This would be true for e.g. engineers, responsible for setting up the autonomous systems, but also for operators who are to operate these systems. Knowledge in designing technology on human terms will be crucial."
5. "Increased requirements for automation, robotics, systems skills. Traditional engineering roles will need to incorporate more of these elements, as well as systems thinking."
6. "Gaps: electromechanical systems, sensors, data science"
7. "I think the professional differentiation will by higher in future and create new jobs like mining computer scientist etc."
8. "The mining sector needs to see a development in understanding of robotics and computer programming to facilitate the transition."

Statement 4: "Virtual Reality technology will be used to link all raw materials production functions underpinned by Cyber-Physical Systems (CPS)/Industrial Internet of Things (IIoT)."

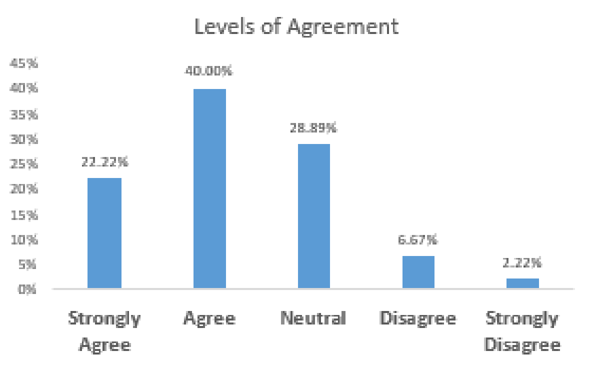


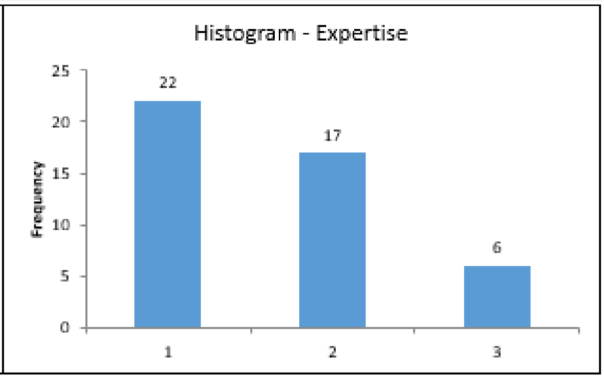


Agree
1. "I would not call virtual reality since we are focusing the future it might be new ways of visualization of data. I would say data visualization rather than virtual reality" 2. "There are two issues here: VR - which is not going to be huge; and CPS/IIoT, which is. The IIoT is already gaining traction in mining and will continue to do so." 3. "At present the virtual reality reconstruction is very interesting and promising technology, but still it does not look to be developed enough. A huge work to put data inside computers, at the beginning and following every changes, is the bottleneck. Moreover a very large computer capacity and speed are also required. Nevertheless, considering the continuous progress in computer technology, we can suppose a wide use of virtual reality in the near future." 4. "This is close to my expertise and will become a major technology for use in automated mines. It will allow experts to visually evaluate the information from automated systems to enable a global overview of the processes. However, it will need development on VR platforms as well, like social interactions."
Neutral
1. "The IoT is already here and is applied in the mining industry. So do advanced digital tools like Cyber-Physical-Systems and other technologies of the digital era. Virtual reality is also applied in the mining industry in terms of education, mainly in Australia and South Africa. Nevertheless it is still early to say that VR can be used in actual production and in mining operations even with the support of the Internet of Things."
Disagree
1. "I think we will go far beyond what is currently understood as VR and IIoT to integrate Spatial and Temporal data and activities (which IIoT doesn't do) and produce and fully simulatable physics model based digital representation of the operation" 2. "Again this will depend on the size of the mine. This sort of integration may be worthwhile in larger operations; it is less clear if smaller mines will see the same benefits. Moreover, even if all production is underpinned by CPS/IIoT, it is less clear that VR will be what links it all together. Other technologies may be just as likely."

Skills gaps
1. "A need in mining professionals for at least some level of skill in data-wrangling."   2. "Greater IT/AI skills will be required, and the system will go beyond human control, requiring many safety routines, as for modern aircraft."   3. "The use of virtual reality in mining is just another branch of science in computer modelling. It is necessary strong background in case of software developers, but not so much for utilizers. It is more a question of mentality in digital approach to mining."   4. "For many geologists touching the rock and inspecting it up close is key to their understanding. When data is gathered remotely / autonomously VR is the closest to the experience of being their."

Statement 5: "Biotechnology will see a huge increase in research and development for extracting metals through biological processes."



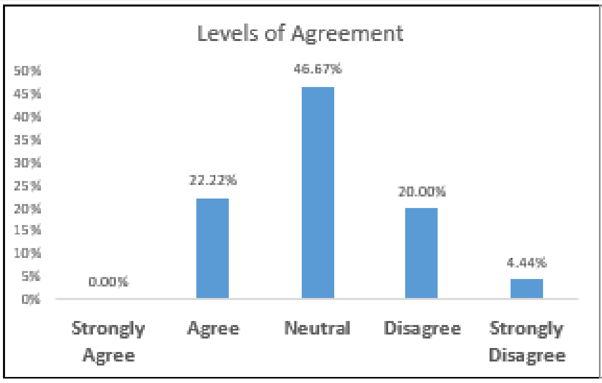


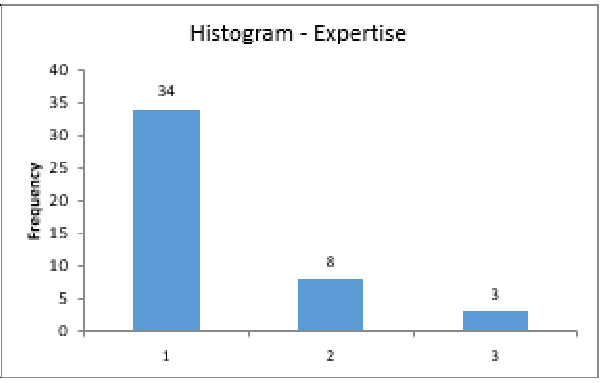
Agree
1. "There is an opportunity, and biotech is looking for applications, so there's an obvious match."   2. "Not all the ores can be treated with biotechnological methods, but a see interesting developments specially in recovery of different metals from scrap."   3. "This is already happening. There are big research projects investigating the use of biohydrometallurgy for the extraction of metals (BHMZ - TU FREIBERG). The low costs and low energy consumption needed in such processes makes them a favourite to be used in the future in mining operations (heap leaching, in-situ leaching). When it comes to research development it is expected that the following years, biotechnology will see a huge increase."   4. "Biotechnologies have the potential to completely redefine the current metal extraction sequence. See Trends in Biotechnology 2017, 35:79-89"   5. "With dwindling ore sources, more and more companies are looking at refractory ores particularly for gold. Given the need to reduce environmental pollution there will likely be a move away from roasting refractory ores to bio-oxidation. With this move to biotechnology there will be more rapid advancements in this sector."

Neutral
1. "I am not entirely sure it will be a huge impact, but yes it may create new mining methods"
Disagree
1. "This isn't new, Chile using biotech for recovery more cooper from stockpile"

Skills gaps
1. "Current professions will need to develop knowledge in biotechnology. So It needs to gather experiences of Its application in soil and water remediation, application in food and pharmaceutical industry."
2. "knowledge of biological processes, knowledge of inorganic and organic chemistry"
3. "Gap in training of industrial biotechnology professionals with an interest in mining"
4. "The level of expertise in bio-oxidation and biotechnology in the mining sector is still limited and requires more development of trained professionals."
5. "Biological knowledge and skills (geology, botany, zoology, climate) would be needed to extract and mainly process metallic ores"

Statement 6: "Phyto-mining will become a relevant source of raw materials."





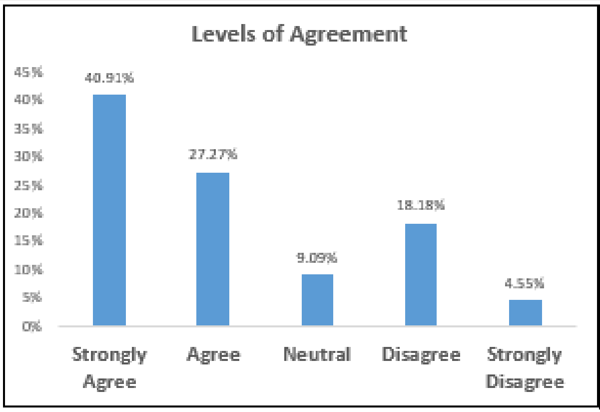
Agree
1. "Plant hyperaccumulators of metals need to be identified or developed. Processing methods for obtaining metals from plant residue need to be developed."
2. "Again, as with biotechnology - which I have taken to be intended to relate to the (potential) used of processes based on micro-organisms - it is inconceivable that Phyto-mining will not come into ever greater play. Again, too, I have seen it in small-scale, semi-commercial operation in the 1980s and 90s. There is much research to be done in relation to the potential bases - i.e., plant types, etc. - of Phyto-mining, to be followed by the long process of development, but there is no doubt that the capability is there and it can be done."
Neutral
1. "the amount of raw material obtained is unlikely to be large and will require considerable space"
Disagree

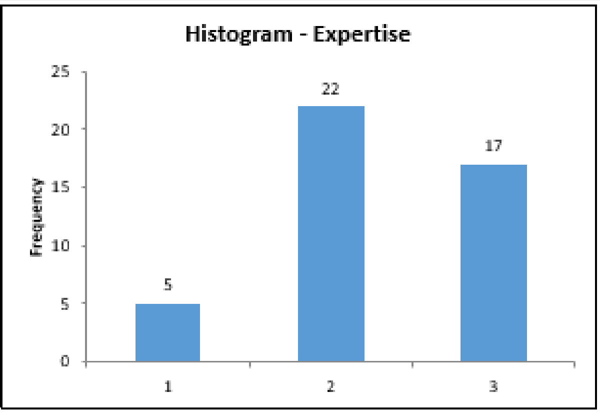
1. “These technologies still have a long way ahead before demonstrating real application in an industrial project.” 2. “Phyto mining has an important role to play in remediation and rehabilitation activities, but is unlikely to be responsible for significant levels of metal production” 3. “Plant uptake of metals is very specific, relatively slow and can be low-yielding.”

Skills gaps
1. “knowledge of botany, organic chemistry” 2. “Gap: Training in molecular biology, plant processing methods” 3. “Mineralogists and farmers would be involved plus engineering people and equipment to extract (burning) the metal and do that at a competitive price (mineral nature and site size).”

- **Mineral Exploration Undercover**

Statement 7: “Improvements to professional competences will come about much more on improving ‘exploration thinking’ rather than data processing – a computer is not the solution to discovering ore.”



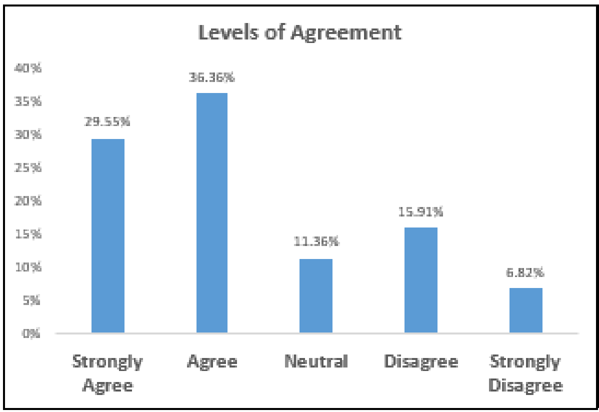


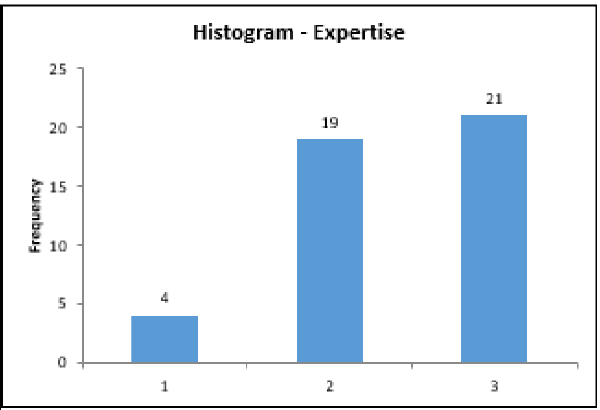
Agree
1. "Data on its own won't find new deposits, thinking out of the box to create new search space will” 2. “Computers are still needed to assist in the ore exploration. But how to apply them is the crucial issue.” 3. “Exploration Thinking require problem solving competences and the conclusions should be guideline for further data processing, computer is just a tool.” 4. “fully agree - it needs a mix of better data and modelling - the man/machine interface is critical. some prototype systems already exist, e.g. IGS Xplore”
Neutral

1. "I think both are needed. Competencies will need to extend beyond data analysis, but recent results from Hackathons etc do suggest that exploration thinking is enough on its own."
Disagree
1. "I believe that with big data and computer learning the digital technologies will strongly assist in finding new deposits." 2. "Data processing is one of the most important issue in mineral exploration."

Skills gaps
1. "There will be need for a lot of "philosophy" coupled to the innovative needs for exploration." 2. "Geoscientists will need much more coding and data analytical skills. Also, holistic thinking and integration of all disciplines will be necessary" 3. "Coding, Database management, Statistic, System Management"

Statement 8: "Professionals will have to effectively operate in predictive exploration platforms that use analytics, modelling and simulation to identify targets in largely unexplored global regions with minimal (or no) drilling."



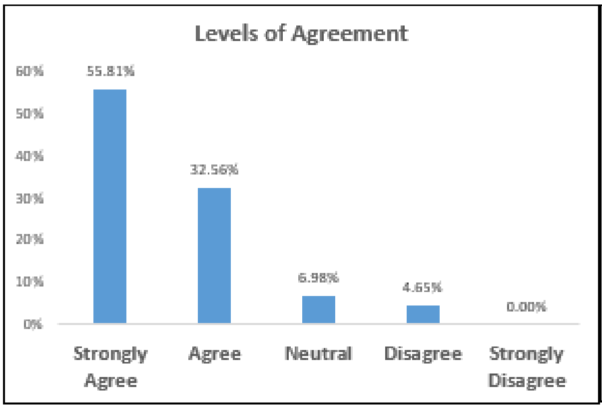


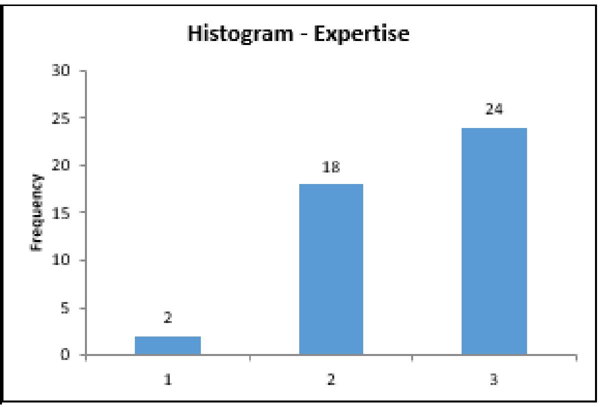
Agree
1. "It will be smart and broad thinking geoscientists that are also able to use data analytics and mathematical techniques that will be successful (its not one or other it is both)" 2. "Predictive models will become more important, although there will always be a requirement for a fundamental understanding of the regional geology" 3. "Use analytics, modelling and simulation to identify targets are the primarily work. The results direct further exploration activities Geophysics, Exploratory Drilling (I can't agree there will be no drilling - it is too brave), Test Exploitation."
Neutral

1.	"I think a lot or research is needed to come up with better exploration tools to find deposits at depth. They will need proper validation and until then drilling is the only tool to provide that validation. Drilling provides the ground truth, similar to taking biopsies in medical sciences. Until a technique can be developed that has been proven to predict successfully in any condition, drilling will remain the main source for validation and possibly understanding."
	Disagree
1.	"no matter how good the predictive modelling is, without drilling it is unlikely that the project will get the certification (e.g. JORC) on which the investment depends"

	Skills gaps
1.	"Greater focus on data analytics in exploration geology programs"
2.	"Much more knowledge will be needed on new forms of modelling and big data interpretation working in perfect synergy with a better understanding of orebody formations and geological processes in 4D"
3.	"Systematic Approach to data management, in order to prioritize activities. Work in GIS environment and software toolbox. Coding abilities in database (SQL, Access), statistical (R, Statistica) and other languages (MATLAB, Python)."
4.	"Regional evaluations require extensive experience of many different types of mineralization, terrains, tectonics etc. - you are only as good as the amount of geology/projects you have seen."

Statement 9: "Geophysical and geochemical knowledge in parallel with data sciences, modelling and geographic information system (GIS) skills will be a requirement for geologists working in mining."





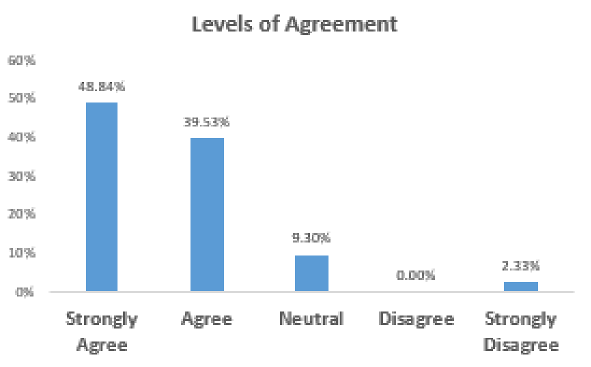
	Agree
1.	"All geologists should be Geo-chemists as well. According to my opinion it is even more important since geochemical environment affects mineralogy. Geophysics is important as well, but it is necessarily to have in mind that methods are mostly inductive, so before geophysics it is necessarily to have some preliminary overview to direct surveys efficiently."
2.	"As orebodies get further from surface, the need to use remote techniques such as geophysics becomes more important."

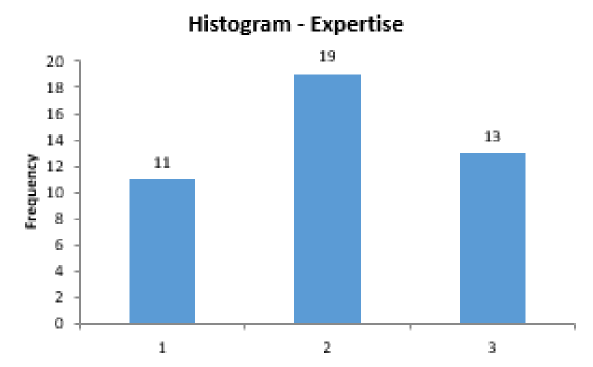
Neutral
1. "Not every geologist will need to have all these skills, but mining teams will need to cover these skills." 2. "Is that not already true?" 3. "This is likely to become a new profession, perhaps positioned somewhere between a geologist and a geophysicist"
Disagree
1. "I think this remark is a bit too broad. Within mining there are numerous expertise within geology: exploration / operations etc. I think in general it will be a benefit for a geologist to understand about other disciplines, but I see more value is good collaboration between experts, like with doctors: radiologists for data interpretation and surgeons specializing in operations. The main thing is that everybody needs to be able understand each other. So an exploration geo needs to be able to communicate with an operations geo."

Skills gaps
1. "A better understanding of the integration of geophysics into geology, and particularly into ore systems than is currently taught in most geology syllabuses." 2. "Both Geophysicists & Geochemists will most probably play a larger role in the mining environment. I.e. more of these disciplines needed" 3. "Rounded exploration professionals with experience in many fields tend to have the best grasp of mineral potential. Risk taking is also a function with a continual optimism when confronted by failure of an exploration model, then try a new one!" 4. "Need for rounded economic geologists - includes EHS, community experience as well as understanding of geochemistry and geophysics."

➢ Circular Economy

Statement 10: "New and improved techniques for waste retreatment and processing will be developed for multiple commodities with multiple applications – dedicated, competent professions will deal exclusively with tailings re-use as well as working together with downstream users for identification of new products and applications."

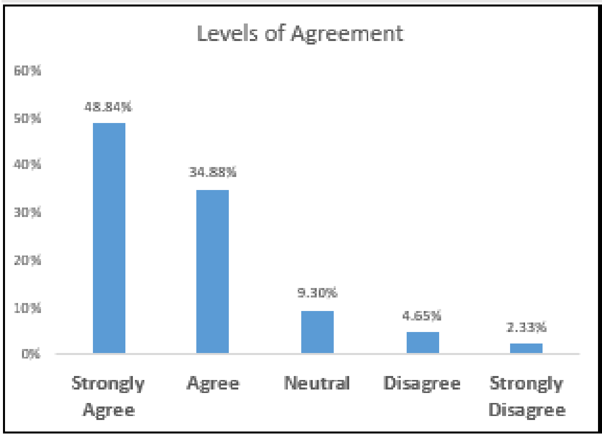


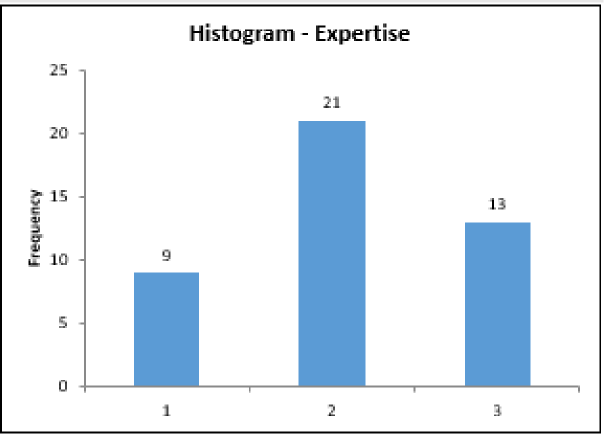


Agree
1. " It is an ongoing process. What is lagging in some places is the legislation that still see tailings as toxic waste. That is also hampering financing of innovative techniques.” 2. “Perhaps not as "dedicated professions" - these applications will need to be tailored to particular needs” 3. “The drive towards a circular economy is here and the industry needs to embrace it or be left behind. Waste retreatment and processing are obvious ways to do this and make a big positive benefit to the environment. Working down the value chain is also key from a product stewardship and responsible source perspective both of which are of have the consumers' attention.” 4. “This will be one way of future mining strategies. It is much cheaper to use the remaining of the past than building new mines.”
Neutral
2. “it sounds good, but is often inefficient and energy intensive”
Disagree
3. “To make the reworking of tailings economically viable they will most likely have to be linked to new or existing operations, therefore it is the same engineers that will be dealing with the reworking of tailings.”

Skills gaps
1. “Waste management, waste processing technology, legislative,” 2. “Gap: advanced mineral processing, chemical and biological engineering” 3. “Increased knowledge in processing of complex and low grade materials will be required.” 4. “Some universities are already training recycling engineers. This area of jobs will grow.”

Statement 11: “Sustainability professional roles will be consolidated including competences in social and environmental performance, Corporate Social Responsibility and post-mine rehabilitation and restoration.”

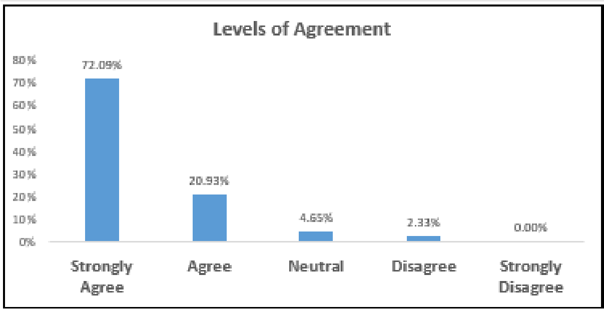


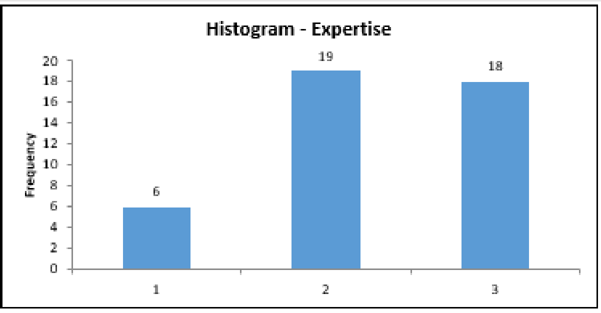


Agree	
1.	"Teams in this area will become prominent in mining companies. Get rid of the word "sustainable" - mining is not sustainable. It uses up a resource which disappears forever. It can only be a motor for other development around the mining activity.”
2.	“Yes, a PR-type professional but with stronger engineering/scientific background (participating also in planning not just in communication) could provide additional credibility and problem-solving ability”
3.	“Corporate Social Responsibility and post-mine rehabilitation and restoration will become the most important issues in 2050 Mining”
4.	“The future handling of post-mine rehabilitation will be central question if societies will allow mining activities or not. The knowledge of raw materials and raw material extraction has fallen massively in the population. The argument "That's what we need" is no longer understood by many parts of the population. They immediately suspect the evil industry lobby.”
Disagree	
1.	“There are two major issues in sustainability - the social and the environmental. I don't see easy opportunities for consolidation as the underlying skills are so different. An effective sustainability team will always consist of experts on both sides working together.”

Skills gaps	
1.	“More social skills as part of baseline training + specialised postgrad programmes”
2.	“social skills, communication, science for society”
3.	“These various professions each require upskilling, but not necessarily merging.”
4.	“In future mining the department of public relations will have a central role in the pre-mining Phase (and they have this role already today).”

Statement 12: “Between 2030 and 2050, social acceptance and community relationship will still be important issues requiring continuous improving and adaptation from raw materials companies.”

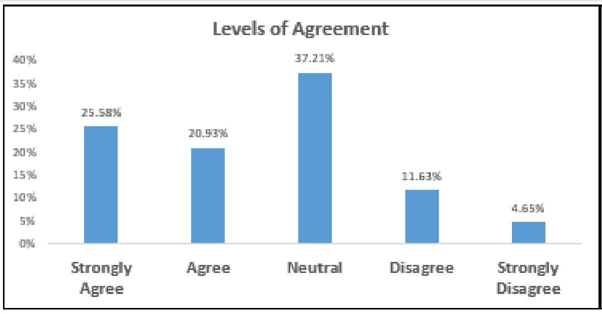


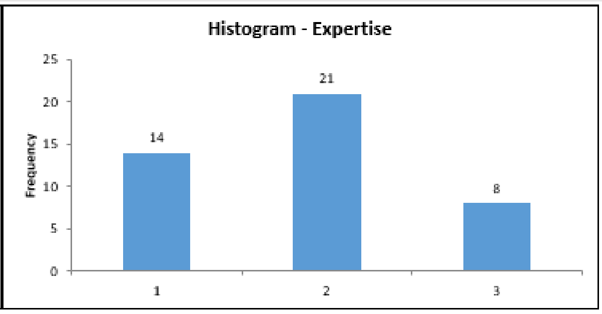


Agree
1. " The "anti" side of mining are strong in the rhetoric. The miners need to improve.”
2. “These concepts are to be more integrated in the reserve/resources reporting. social acceptance and community relationship are very important for definition of proved reserves”
3. “The 'connectedness' of the world via the internet means that poor social, community or environmental performance will not be accepted, and the industry needs to understand that this will grow in importance.”
4. “Again, geoscientists must be better to communicate with the society”

Skills gaps
1. “More knowledge about social mechanisms is required on the curricula for miners”
2. “Political and social skills, and particularly training in these for senior mine and corporate managers who often come from a technical or financial background. In some countries, most managers spend a large percentage of their time dealing the community issues (South Africa for example).”
3. “No big impact. Already happening. Maybe the consolidation of community engagement will result in an increase of jobs for people coming from local communities in mining projects.”
4. “The is a clear gap in knowledge of mining professionals in regard to acceptable and appropriate social engagement.”

Statement 13: “Millenials will be the decision-makers in the mining investors room, representing a huge shift in how investment in the metals and mining sector is approached.”





Agree

1. " Not a huge shift in how investment is approached, but it will be different, more careful, more risk awareness”

2. “Millennial are already decision makers and politicians. They generally have a much different views on current issues. (See e.g. the Green Deal in the US.)”

3. “Millennials think differently from previous generations so the industry needs to be prepared that the old paradigms will no longer be valid.”

4. “There is going to be a big change on how mining and oil business as well as other major industries will be regulated in the future.”

Neutral

1. “Not sure why millennials would be so different when it comes to mining investments? The remark seems to almost indicate that they are like a new species. Investing is still about making money. If anything there is an ongoing change, not a sudden shift.”

Disagree

1. “I think that finance and risk will continue to be the drivers for analysts, although shareholder activism is likely to increase driven by changing expectations.”

2. “Also millennials want to make Money. I think this may be influence only societies in central Europe, and this Generation will sell their grandmothers, if Coltan for the iPhone is not available.”

3. “This is a nonsense pseudo-question. The decision-makers will be those working as managers in the materials industries and in the boardrooms at the time. Whether they were born around the year 2000 or not is entirely irrelevant.”

Skills gaps

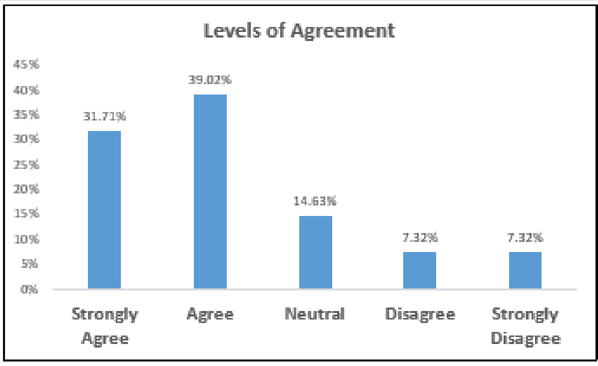
1. “The need for greater adaptability means that professionals will have to have a range of core competence or develop theses through their career with continuing professional development training.”

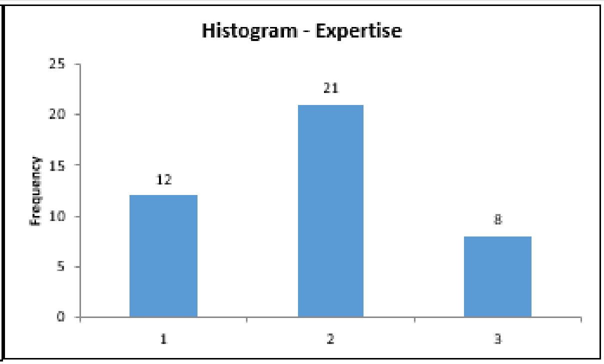
2. “communication between generations”

3. “Decisions-making will be subjected to the sustainability experts panel advisement”

➢ **Mining in New Frontiers**

Statement 14: "New tailored deep-sea mining training programmes/ specialisation will be needed, covering the following modules: • Exploration and Resource Estimation • Technology Development (Mining & Metallurgical processing) • Environmental Studies • Impact assessment and monitoring – Environmental Management Plan • Project Execution – Techno-economic Assessment + Legal Framework."





Agree
1. " I think deep sea mining will be something very rare and located in only certain parts. I do not think is the future, it is only profitable for certain ores. and before those deposits are exploited, we will re-open many closed mines .... too expensive"
2. "Geology has traditionally been about being able to touch the rocks, hold it and evaluate it. Deep-sea mining presents a problem with that traditional approach that can be overcome by specific training."
3. "Absolutely right - here the faculties of engineering, biology/ecology and geology of the universities have to react."
Neutral
1. "I believe that some short courses will address most of these areas, building on existing land-based approaches. For examples metallurgical processing is likely to use conventional technologies, JORC statements of resources are already being prepared for deposits off PNG. Underwater impact assessments are probably one of the more challenging areas to consider."
2. "Every way to increase efficiency is welcome, but the future is not use the increase of efficiency to increase the production, but to make the production more sustainable"
Disagree
1. "Disagree with that. In spite of the enthusiasm, submarine mining technology has shown all his immaturity (see the case of Nautilus Minerals). But more importantly: environmental impacts of submarine mining operations are largely underestimated. And will remain a fatal hurdle"

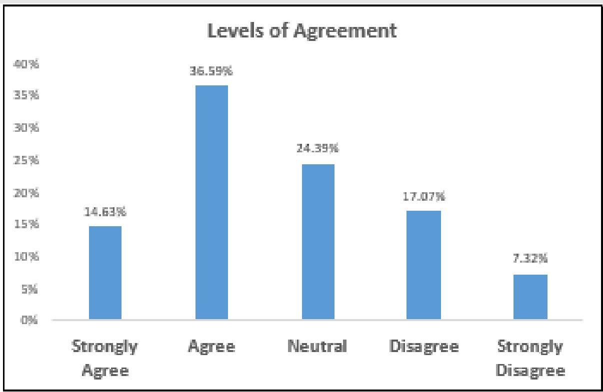
Skills gaps
1. "Required competences will be in Maritime, Legal, Fishery, Ecosystems, Technology, Waste processing, Remediation techniques"

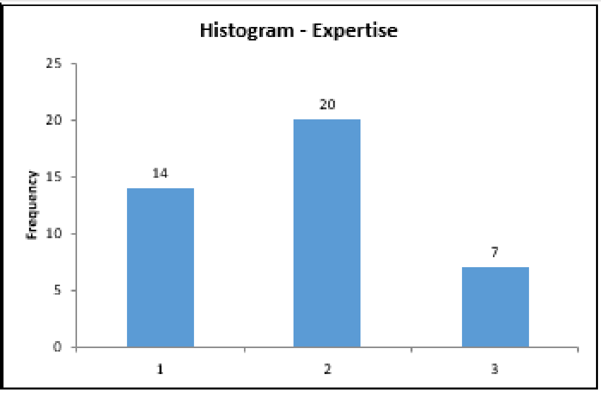
2. "New Engineering with deep-water skills need to complement traditional Mining/Metallurgical Engineers and scientists"

3. "Ocean sciences should be built into training for those looking to work in deep sea mining."

4. "A lot of skills needed, but probably not a lot of professionals compared with other areas, in my view"

Statement 15: "Deep-sea mining has evolved in close synergy with mining, oil & gas and space research."





Agree

1. "It is logic that deep sea mining has evolved in close synergy with mining, oil & gas, because obtained data from exploration and exploitation of oil & gas represents input for deep sea mining development."

2. "Deep-sea mining, oil & gas drilling, space travelling and (in some cases) deep conventional mining have something in-common; unusual, very harsh and unpredictable boundary conditions. Hence it can be said that any evolution or idea applied in deep drilling or in safe space travelling can be adopted by deep-sea mining engineering and thus contribute to the ongoing research."

3. "As far as I know, yes, cross-collaboration seems to be the key. But also with machine manufacturers."

4. "The skill-set is similar. The sampling and data are derived from indirect methods (geophysics, remote sensing, robotics etc.)"

5. "Application of O&G technology has been used e.g. Nautilus."

Neutral

1. "Yes, there will be synergies for sure, especially on some sub-component levels"

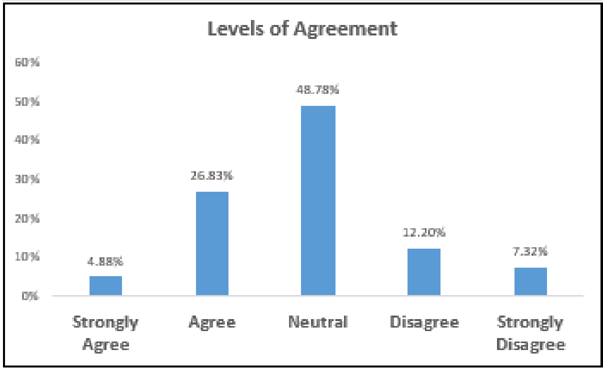
Disagree

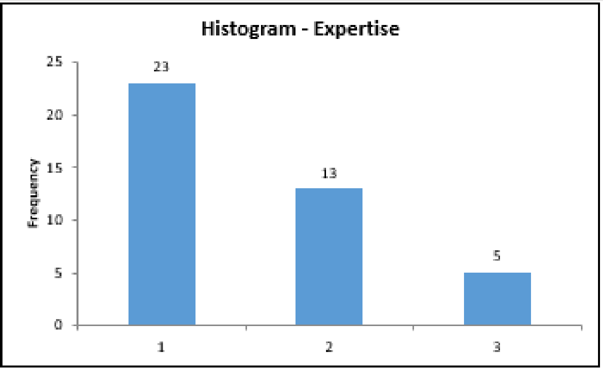
2. "I've been in mining research a long time and have not seen any synergy with deep-sea mining. The one deep-sea mining operation I have had contact with did have strong links with oil&gas, based on the nature of the equipment they use. To be honest, space research is a very long way in the other direction to sea mining. I don't believe the synergies have been close in most of the areas, and even the synergies with oil and gas are more with production available equipment than with R&D"

3.	"Oil and gas industry have developed many offshore projects, the technology is completely different, deep sea petroleum and gas extraction is a reality, mining is science fiction, only feasible in few projects"

Skills gaps
1. "Could draw on offshore oil and gas skills and experience, but oil and gas is "separate" from mining." 2. "marine geophysicists and oceanographers are needed, working with environmentalists and PR experts" 3. "Develop training to link with O&G and space technology that may help in this field."

Statement 16: "Main adaptation for a space mining training program will be courses on 'Systems Engineering' focusing on In Situ Resources Utilization (ISRU) and interplanetary geology. Much in line with what is already being proposed by the Colorado School of Mines."



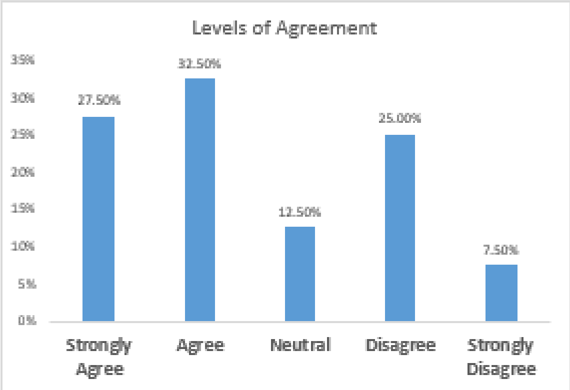


Agree
1. " I would like to put the point on "Systems Engineering" since it is neglected in other surveys and other issues: In Situ Resources Utilization and interplanetary geology are the only logical choice." 2. "Seems like a sensible way to go. The challenge of space is always going to be at the systems level."
Neutral
1. "Courses dedicated to "applied geology in space" i.e. what can be mined and where and how to explore for minerals would probable need to precede and programmes on mining and processing" 1. "Don't know much about the specifics for space mining. It depends how it will be developing, either for bringing materials to earth (e.g. rare metals) or for building communities outside of earth (e.g. aggregates). The focus will largely depend on that evolution."
Disagree
4. "The early issue for space mining will be mining for water and other simple resource needs for interplanetary travel that are expensive to deliver to space (due to weight). Space mining is not about mining for earths needs as its far cheaper and easier to mine it on earth." 5. "2050 scenario is too close"

Skills gaps
1. “System management, Astronomy”   2. “Remote sensing tech will rule!”   3. “Formal training will be needed on applied planetary geology.”

- **Future of Education**

Statement 17: “Education system will be revolutionized, moving from certification and general preparation to a flexible needs-based education – professionals won’t have professions, but a portfolio of abilities and skills.”

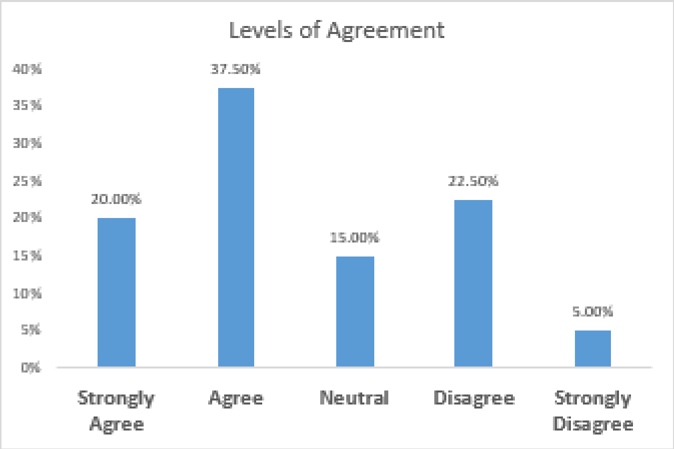


Agree
1. " I do think that conventional professions such as mining engineering will be affected, and in general the trend is towards greater flexibility and customisation of programs”   2. “Quite possibly, I can see that traditional professionals will change but exactly how is somewhat hard to understand.”   3. “Depending on where you are in the world this is already in place. I.e. small European universities train very flexible future engineers who know a bit about everything but nothing in too much detail. This helps them maintaining a good overview of all processes and reacting quickly to new situations.”   4. “learning will be life long, while specific skills will be required knowing across a broad spectrum is essential”
Neutral
2. “This is one possible development although new professions may also arise especially in lucrative areas such as deep sea mining or space resources”   3. “Possibly - but this will not just apply to mining. I would like to see more "dual" learning courses whereby companies hire good students and provide practical training during the studies.”
Disagree

6.	"(…) For example, it is very difficult to teach robotics to people who don't have graduate level maths. It is therefore difficult for an individual to add a needs-based skill quickly, if there are underlying proficiencies required; and without those underlying proficiencies, the portfolio of skills will not have the required depth. There is a move to earlier and earlier specialisation. This isn't helpful because it is very difficult for 18-year olds to know exactly what they'll be doing at age 50. There is a need for more general education with a layer of specialisation going over the top only once it is obvious for an individual what they require. The certification (at Professional Engineer level) is not of a specific skill, but some measure of ability to learn, that will remain."
7.	"It is unrealistic to expect everyone to be experts across many domains, the key is integrated teams. In any case, "a portfolio of abilities and skills" is what people have now, coming from a combination of formal education and career experience."
8.	"You need a happy medium between depth and breadth in education and skills vs learning. Certification assumes responsibility, a vital issue on any project, from finance and construction to operations. "
9.	"Professional training will still be required, however it should be more practical and closer aligned to industry requirements"

Skills gaps	
1.	"I firmly believe that professions (like that of the mining engineer or geologist) will remain as they are now. However, additional skills and expertise will be needed, especially multi-tasking."
2.	"not so many details but a broader view, based on basic STEM will be necessary for any profession."
3.	"Fundamental science should be prior: Mathematics, Physics, Chemistry, Biology"
4.	"University lecturers should be required to work in industry so that they can pass on practical knowledge rather than just theoretical"

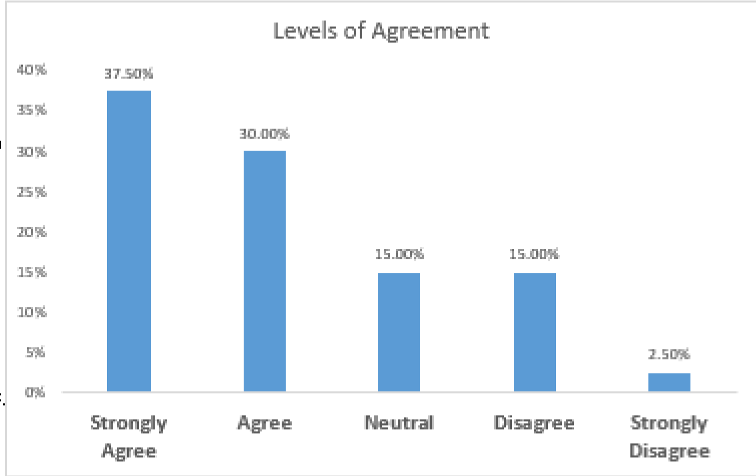
Statement 18: "Professionals will be more demanded in scientific education (physics, math and chemistry) as well as higher cognitive skills such as creativity and critical thinking than technological skills."



Agree
1. " I think having strong basic knowledge coupled with creativity and critical thinking are good qualities for effectively working in the adaptive and rapidly changing world of the future.” 2. “Already moving that way - science building blocks needed rather than single disciplines” 3. “This is already the case, although some things – e.g. creativity - are very difficult to provide an educational base in, as yet.”
Neutral
4. “Critical thinking is necessary, not to mention creativity. But these are not enough without basic technological skills and knowledge. A combination of all is the optimum.”
Disagree
10. “Your suggestion of what will be more demanded: scientific education, creativity and critical thinking are exactly the skills of an engineer. Therefore technological skills will be important. (or am I missing something here)” 11. “The industry already decries the lack of basic scientific education in geoscience graduates.” 12. “Scientific education (physics, math and chemistry) as well as higher cognitive skills are important, but technology skills are driving critical thinking in an engineering projects, e.g., mining. “

Skills gaps
1. “The training of engineers in applying science to solving problems will be key to future mines.” 2. “Basic technological education must and will not change, so no big potential impacts in current 3. professions. Creativity and critical thinking are skills that nowadays' engineers already have and use” 4. “adaptable, flexible skills - no jobs-for-life.”

Statement 19: “Employers will need multi-skilled workers who can operate in several areas and functions within the company.”

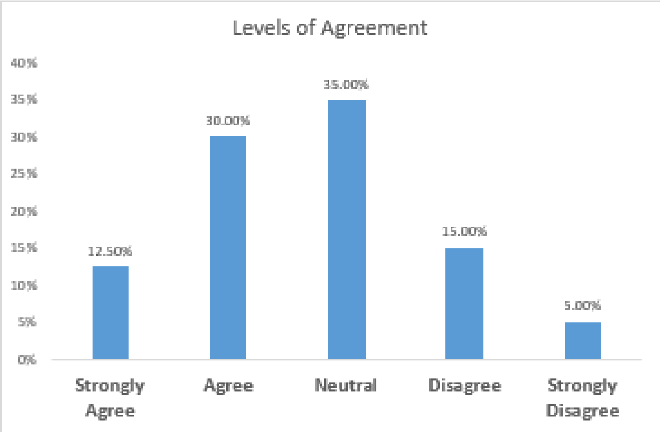


Agree
1. " Need for Specialists and Generalists as well as Versatilists who take learnings from one industry to another” 2. “Management theory strongly pushes multi-skilling, as does much social sciences literature. It makes sense: in the future we will probably move between activities quickly, because much of the routine drudgery will be removed by computer assistance, so multi-skilling will be important. It is also important for individuals, because the process of learning (required for multi-skilling) imparts a sense of self-worth and value.” 3. “The advanced technologies will imply less staff but multiskilled” 4. “Specialists will need to span traditional discipline areas e.g. the emerging field of geo-metallurgy, although there will always be a need for core technical discipline strength.” 5. “It seems rather obvious that this will be true. It is and has been true for some time, at almost levels above semi-skilled and in most types of work, for some decades - at least since the 1970s.”
Neutral
1. “Depends on the type of operation, not necessarily true for "big mining" 2. “I am not sure that people will be employed by companies to a great extent, rather more that companies will outsource what they need to skills based areas”
Disagree
1. “The role of wide player in the Company is very difficult, because it requests knowledge and experience in several fields. Better to put well instructed people in defined positions.” 2. “Mining uses specialists e.g. metallurgists, mining engineers etc. not multi-skilled”

Skills gaps
1. “Education/training is going to take longer and cost more - we need to be ready for that.”

2. “If a professional want to stay in the job he must be accustomed to change”
3. “Flexibility to changing requirements will be required.”
4. “adaptability, flexibility and self-reliance in an increasingly gig-economy of outsourcing”
5. “Transverse education in sustainability”

Statement 20: “Raw materials jobs will be decoupled from specific geographical locations.”



Agree
1. " A certain proportion of jobs will be based in remote centres as automation becomes more common.”
2. “Possibly - more "home office" style working”
3. “Many jobs will not have a specific location because of automation and remote working”
Neutral
1. “Depends on the type of operation and commodity. In simple settings the job could be decoupled from locations in other settings this will be impossible, especially in some of the "new frontiers" such as deep sea or space”
2. “Will always be the need for on the ground involvement cannot make entire industry "remote controlled"”
Disagree
1. “Raw materials are obtained from particular jurisdictions. There is an international trend for the governments of those jurisdictions to be suspicious of, and unwelcoming to, companies that do not use local staff. The number of countries requiring indigenous employment is growing, so the future of raw materials jobs is likely to become more and more coupled to specific locations, for political reasons.”
2. “raw material jobs cannot be completely separated from the raw material deposit locations”

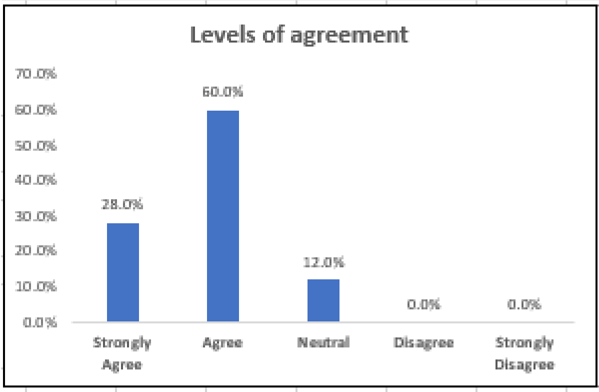
Skills gaps
1. "This is going to impact in training. In reality, not many countries use enough mining people to warrant setting up their own training programmes, so how training is going to work internationally remains to be resolved.   2. "The human factors aspects of remote working will need focus"   3. "be open to other cultures and working attitudes"   4. "Team coordinators"

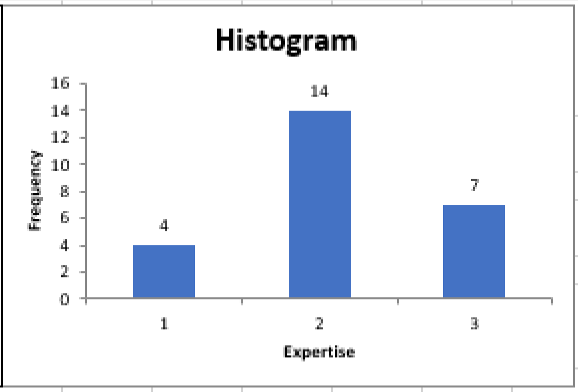
SECOND ROUND RESULTS

Thematic cluster links
Mass mining
Mineral Exploration undercover
Circular Economy
New frontiers
Future of education

➢ Mass mining

New Statement 1: "While conventional mining will evolve to deeper and larger open-pits and ultra-deep underground operations ('supercaves'), it will co-exist with novel, not yet developed mining methods."

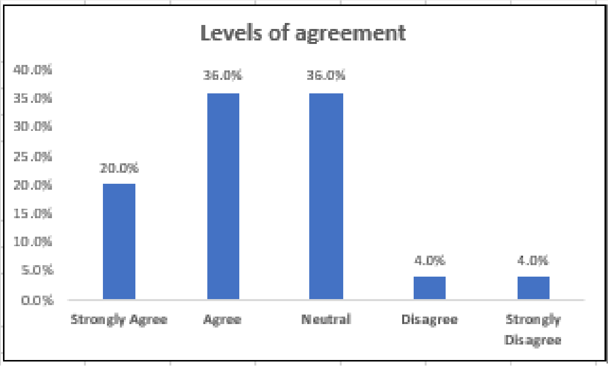


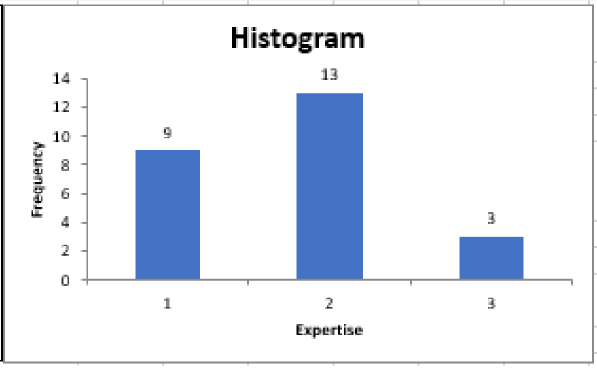


Agree
1. " I think I might flip it - that the novel ways will become dominant and pervasive - micromines in essence"
2. "There's a lot of near-surface (<300m) deposits still to be discovered"
3. "Agreed: horses for courses - bulk materials will come from larger operations, and particularly larger underground operations, while other minerals may come from small, rich but complex orebodies, mined in novel ways."
Neutral
1. "I think that super-pits (large open-pits) will become less acceptable in the future."
2. "Mining, especially ore, will be concentrated in economically viable large-scale mines outside populated areas"

Skills gaps
1. "Knowledge requirements will also be placed on areas related to the environmental impact of mining, especially in hydrogeology, air pollution issues. Much greater demands will be placed on knowledge associated with mining areas reclamation."
2. "All the traditional mining skills will still be required, however mining engineers will need to expand their repertoire by working closely with minerals processing and robotics and automation people at a level of integration that is not common at present."

New Statement 2: "Advanced mineral extraction techniques such as In-situ Mineral Recovery (ISR) will evolve, increasing its application share (in production volume) for a specific set of mineral raw materials/mineral deposit types."



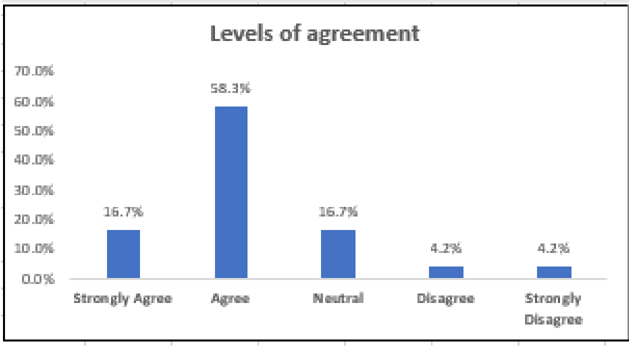


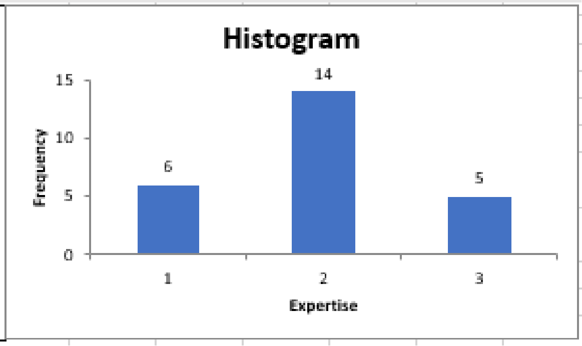
Agree
1. "The question is how fast the transition will be - much dependent on how fast current extraction operations are retired"
2. "The technologies are widely under discussion but except for rare examples none is yet commercially successful. R&D will have to do a better job to get them under way"
Neutral

1.	"Mineralogy will be supreme in determining the success of ISR"

Skills gaps	
1.	"I think the advance crossing of chemical and mechanical engineering skills will be rare and a limiter in deployment"
2.	"People with pairs of skills such as hydrogeology and minerals processing, or mining and processing will be increasingly important to bring together tasks that are currently undertaken by different people."

Statement 3: "By 2050, the majority of mine sites will be fully autonomous operations."

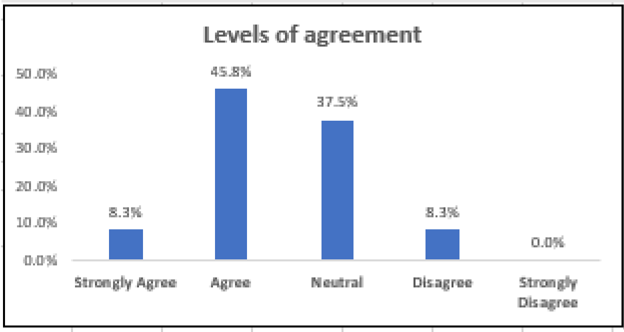


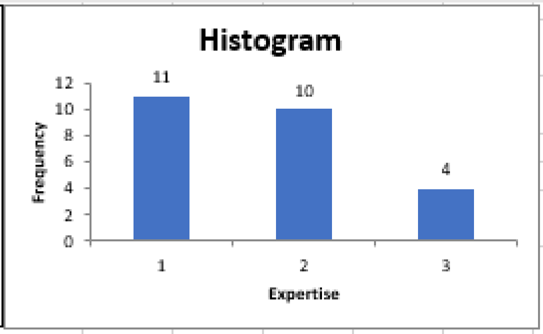


Agree	
1.	"Because of cost, health, and safety issues, this migration will happen even faster than expected."
2.	"I do not agree that all mining operations can become fully automated. There will always be, especially in poorer countries and smaller mines, the so-called conventional means"
Neutral	
1.	"Full autonomy remains a very big ask, even by 2050. We are not seeing the raw general intelligence of computers increasing fast, although their task specific intelligence is increasing rapidly. Even by 2050, I suspect that all routine operations (trucks, shovels, drilling) will be automated, but I don't see mine design and operations management going the same way - geology will never be perfectly understood prior to mining."
Disagree	
1.	"many ores cannot be mined in big scale or automated processes"

Skills gaps	
1.	"Current professionals need to learn robotics and these skills need to be taught at University."
2.	"Gap: Integration of data science into mining engineering - we will need people who understand how to design and operate mines, but who also have a reasonable understanding of the capabilities of machines and automated methods. Alternatively, the mining industry/academia needs to make it easier for experts in fields such as robotics or computing to obtain the necessary mining engineering skills. The future miner will definitely be a hybrid, with a strong flavour of electronics and automation."

Statement 4: "Virtual Reality technology will be used to link all raw materials production functions underpinned by Cyber-Physical Systems (CPS)/Industrial Internet of Things (IIoT).."

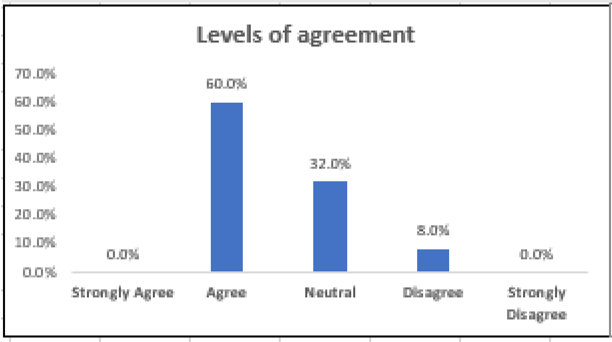


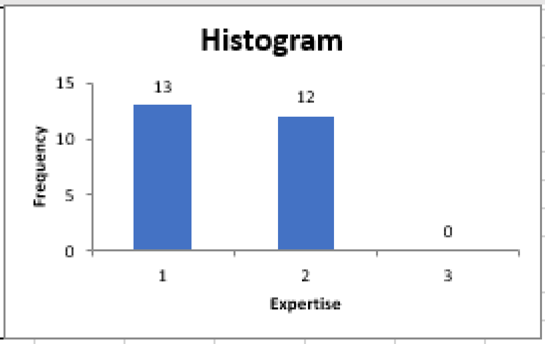


Agree	
5.	"As we move people out of mining areas, it becomes more important to represent those areas more accurately to people remotely and VR will become increasingly important."
Neutral	
2.	"VR cannot replace a full human overview, it is a tool that can be used to assist"
3.	"VR is not going to be relevant at all. With automation, even visualization will be less and less important, but the IOT/sensor space will be everything"
4.	"Whilst VR is good to show and demonstrate complicated environments, some things are better understood when done manually. Hence, we will always see a mixture. I believe that the current trend to VR, i.e. in education, is bringing people away from the mine-site, instead of giving them more exposure. So, don't just rely on that. IOT is different, we need to let the machines do some thinking and recognise patterns etc to be able to perform tasks autonomously."
Disagree	
3.	"it cannot be applied to small mines and certain sites."

Skills gaps	
1.	"A shift to strong programming/data skills to combine with the mining core skills."
2.	"data management and handling along with general IT-knowledge is definitely desired. Don't forget old-fashioned hands-on education, though. This is very important for get a comprehensive picture and understanding!"
3.	"There will be a greater emphasis on the purely visual, which will take some creativity to add a sense of things like vibration or climate that influence how people perceive conditions in mines."

Statement 5: “Biotechnology will see a huge increase in research and development for extracting metals through biological processes.”

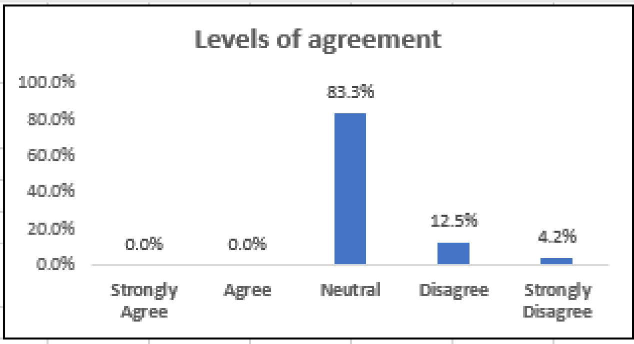


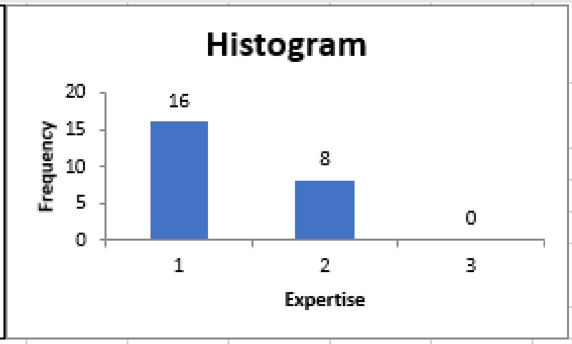


Agree
1. "It will help with some of the minor elements”   2. “Biotechnology needs to more applications to mineral processing and face challenges such scaling and recovery rates.”   3. “If biotech can produce better results in terms of recovery, energy consumption and environmental impact then it will become more widespread.”

Skills gaps
1. “Better links between geology, industrial mineral and biotechnology is required in research and innovation.”

Statement 6: “Phyto-mining will become a relevant source of raw materials.”





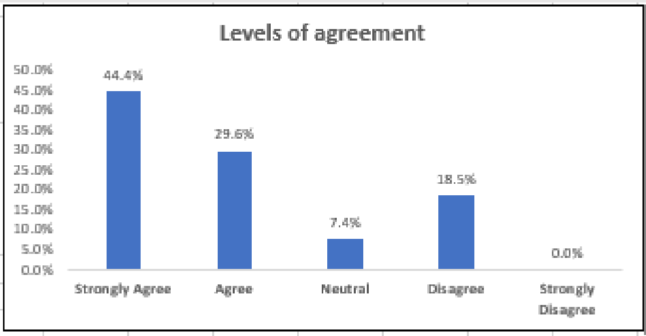
Neutral
1. “The throughput is not sufficient and in competition for crops, this will always lose.”
Disagree
1. “Does not have the production capacity”   2. “If the material being mined is high volume (copper, iron ore), it won't be there at sufficient grade in plants. And if it is low volume (gold, platinum) it probably won't be recovered very effectively. I don't think phyto-

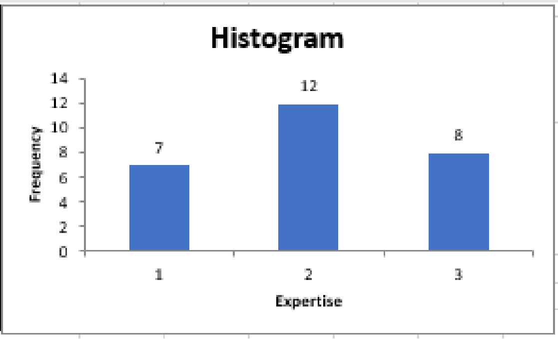
mining will be huge, but it might occupy specific niches. It is also probably going to be competing with agriculture for land, which will be a challenge.”

Skills gaps
1. “The necessity of biological and biochemical specialization of the staff.” 2. “engineers usually are not highly skilled in botany”

➢ **Mineral Exploration Undercover**

Statement 7: “Improvements to professional competences will come about much more on improving ‘exploration thinking’ rather than data processing – a computer is not the solution to discovering ore.”

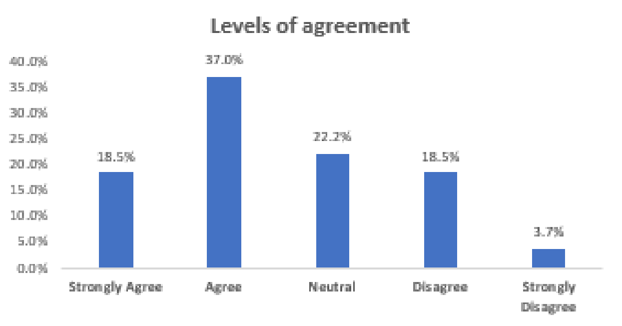


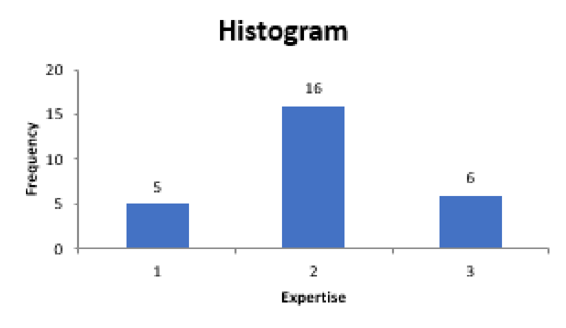


Agree
1. "Despite anticipating an increasing development in the processes of artificial intelligence I believe that human intelligence will always be important for validation” 2. “Good exploration thinking has been behind most of the recent major discoveries. It becomes increasingly relevant as the cost of exploration goes up for deep orebodies or orebodies under cover.”
Disagree
1. “we need both, a good understanding and exploration thinking combined with well structured data and digital decision making tools/helpers. probably a computer won't find a deposit but it dramatically increase the chances when operated properly.”

Skills gaps
1. “good mixture of hands-on and digital skills is needed (i.e data structuring and interpretation)” 2. “Emphasising systems thinking in geology courses” 3. “There is an over emphasis on the use of computer modelling and a loss of core competencies, such as geological mapping, interpretation and simple geological common sense”

Statement 8: "Professionals will have to effectively operate in predictive exploration platforms that use analytics, modelling and simulation to identify targets in largely unexplored global regions with minimal (or no) drilling."

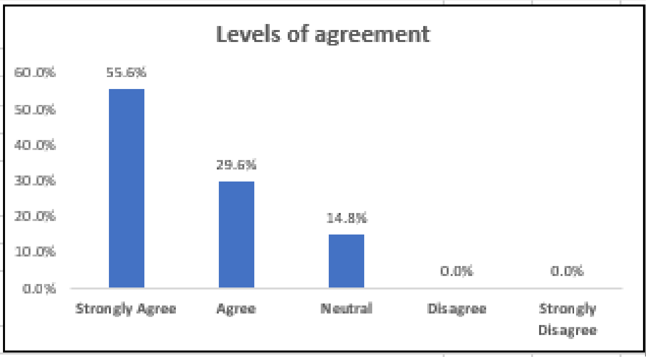


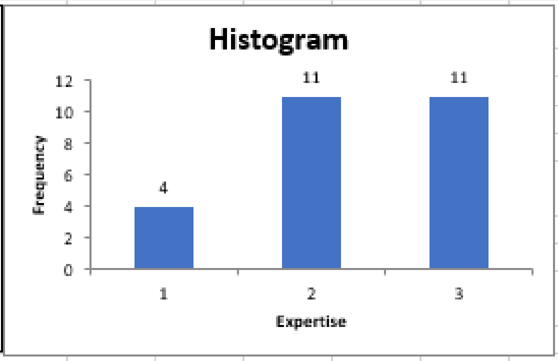


Agree
1. "predictive platforms Will slowly be improved and as better results are obtained machine learning Will enter the arena to improve predictions" 2. "Drilling is always going to be required for ground truth. I think this shows an opportunity for faster drilling technologies, or for technology combinations that can produce assay or structure results without core at high speed."
Neutral
1. "algorithms are only as good as the data they were constructed on, there will always be a need for drilling until we can develop a truly transparent subsurface"
Disagree
1. "It appears to work in oil, which is contained in sedimentary beds, minerals exploration is quite different" 2. "Predictive models are great at identifying location, but they are not going to be precise enough to substitute drilling"

Skills gaps
1. "Better exploration design methods are required" 2. "Core geology and mining skills will remain relevant, its the users ability to integrate with more quantitative approaches that will be key."

Statement 9: “Geophysical and geochemical knowledge in parallel with data sciences, modelling and geographic information system (GIS) skills will be a requirement for geologists working in mining.”



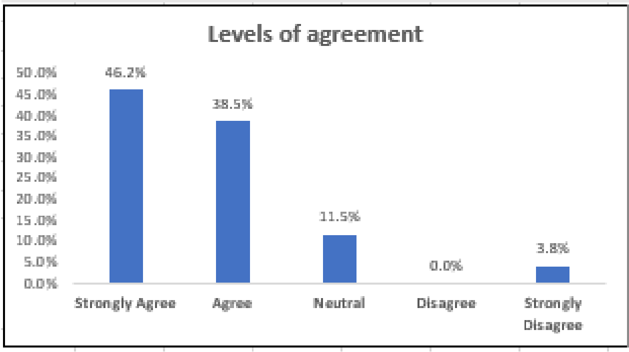


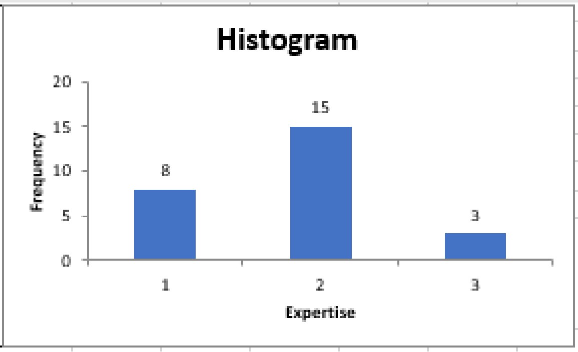
Agree
1. "I think geologists Will need more a more basic science in the future, but without GIS and modelling they Will not be able to work” 2. “Any exploration geologist requires these skills now, and there is no reason to question that this will radically change in the future.”
Neutral
1. “I agree with the medical analogy. While there needs to be a "chief surgeon" - the geologist - it makes more sense to put in a team of specialists than to try to give one person all the skills. A good team is also more likely to have the diversity in approach that enables good creative problem solving.”

Skills gaps
1. “More "integral" professionals or professional that know how to integrate many data disciplines are needed.” 2. “Not all curricula include GIS and modelling today”

➢ Circular Economy

Statement 10: "New and improved techniques for waste retreatment and processing will be developed for multiple commodities with multiple applications – dedicated, competent professions will deal exclusively with tailings re-use as well as working together with downstream users for identification of new products and applications."

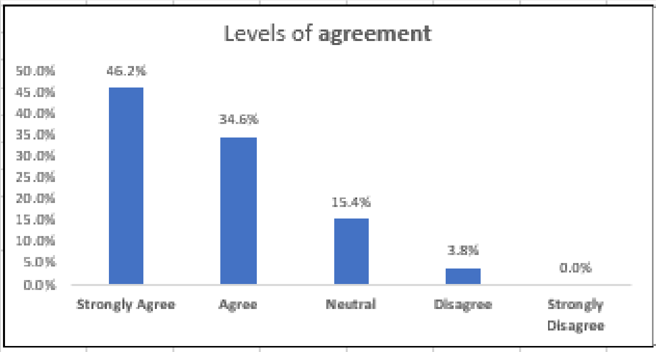


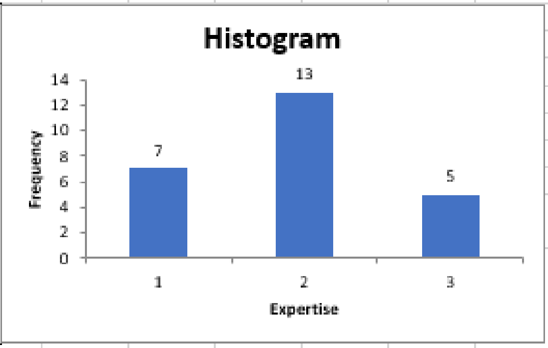


Agree
1. " nothing new in this statement, widening of this resource base will require economic fundamentals to reach a certain level before real development occurs" 2. "It will take time for people to shift from looking at this as waste to being a resource. Critical will be the environmental management of stirring this material up again."

Skills gaps
1. "we need tailored courses for mineral processing in the circular economy" 2. "Advances in chemical engineering and stronger understanding and modelling of aeolian and hydrological transport of the tailings when stirred up. This is a space that the manufacturing industry has dealt with for decades (PCBs, etc.)"

Statement 11: "Sustainability professional roles will be consolidated including competences in social and environmental performance, Corporate Social Responsibility and post-mine rehabilitation and restoration."

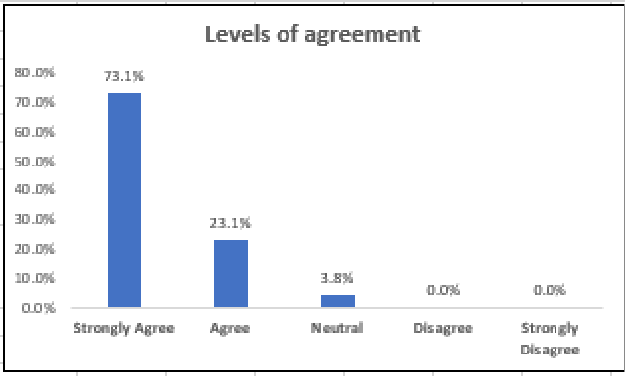


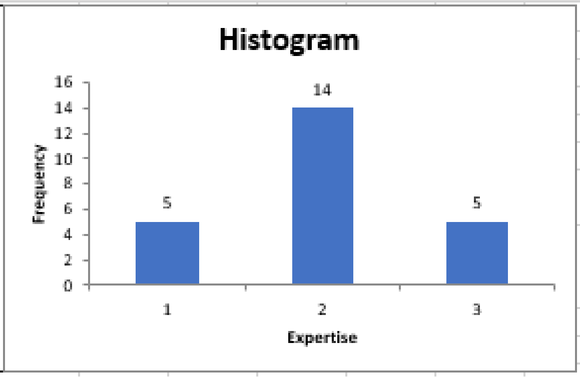


Agree
1. "HR, PR and finance people should be kept well away from this area, only geologists and mining engineers should be involved." 2. "This is going to be a must immediately not in the long future"
Neutral
1. "These are diverse skill sets that are most effective if applied by a dedicated professional. But understanding of these skills by everyone will be needed for the operation to be effective"
Disagree
1. "As for integration of different geoscience professionals, sustainability professionals also have a wide range of professional skills that cannot easily be obtained in one person, and that are going to be a lot strong in a team with diversity, particularly of social and environmental skills."

Skills gaps
1. "Geologists mining engineers with social and political skills, who understand the meaning of "place" 2. "Mutual understanding, again possibly through project teams at higher undergrad/postgrad level that have to cooperate across professional boundaries."

Statement 12: "Between 2030 and 2050, social acceptance and community relationship will still be important issues requiring continuous improving and adaptation from raw materials companies."

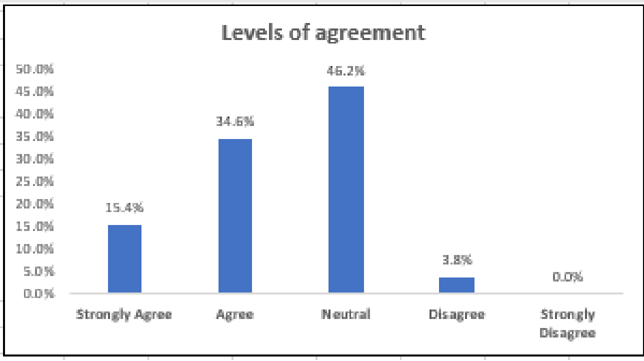


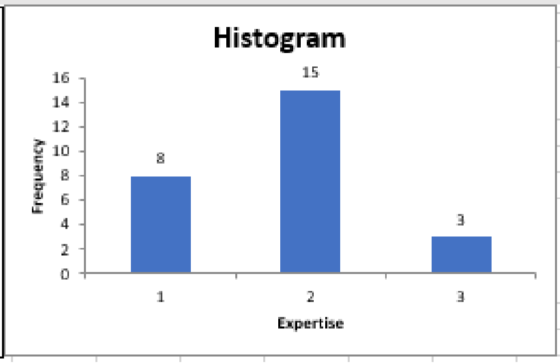


Agree
1. "Social license is already a major issue in the developed world, and will increase globally, bringing about exactly this." 2. "Social license to mine remains the number one challenge in many countries, particularly countries with very large orebodies. Ignoring this requirement is going to be very costly for mining companies, and most of the big ones are already strong in this area."

Skills gaps
1. "All workers will need some social license skills regardless of their role."   2. "More links between social sciences and mining is required"

New Statement 13: "Future leaders in mining will have greater socio-environmental awareness and will objectively influence how value is perceived in mining."



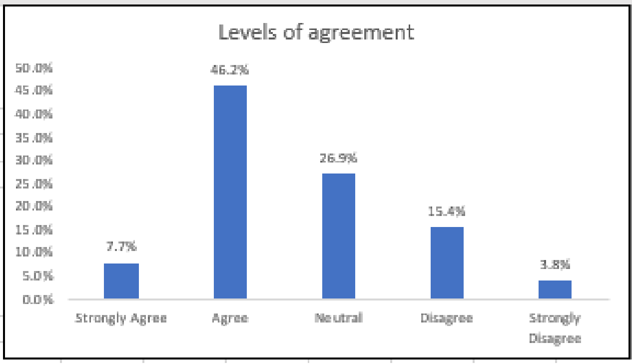


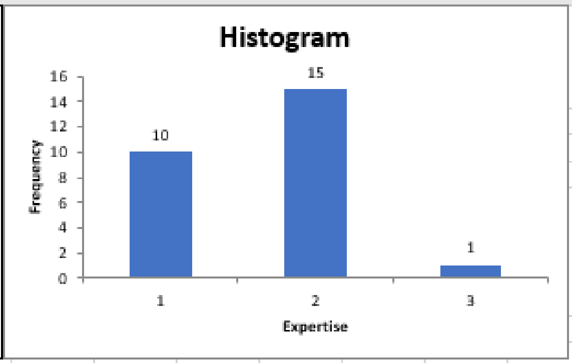
Agree
1. " This ties in with the previous question on license to mine. I am not sure how future leaders will objectively influence perception, as perception is subjective, but future mining leaders will need greater socio-economic awareness, or they will become victims of social license to mine issues."
Neutral
1. "There is an overall societal shift this way - but Churchill's adage about the young being liberal and the old conservative will remain unchanged, thus the investors will tend more conservative...."
Disagree
1. "Millennials are not a new species. Human nature does not change overnight. At the end of the day profit is the driver if any entity is to survive."

Skills gaps
1. "Awareness of the other professions and an understanding of just how much influence withdrawal of the social license to mine can have on an operation, should be part of the training of all mining professionals, especially future mine managers."

➢ New Frontiers

Statement 14: "New tailored deep-sea mining training programmes/ specialisation will be needed, covering the following modules: • Exploration and Resource Estimation • Technology Development (Mining & Metallurgical processing) • Environmental Studies • Impact assessment and monitoring – Environmental Management Plan • Project Execution – Techno-economic Assessment + Legal Framework."

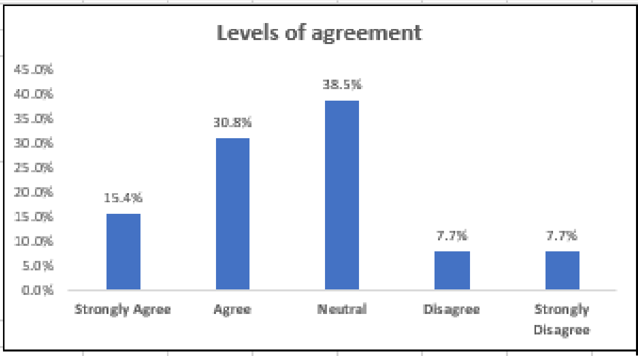


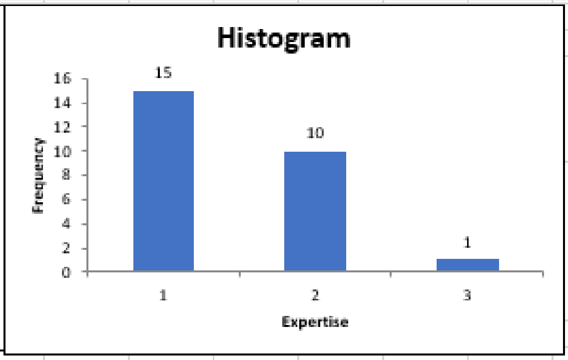


Neutral
1. "Deep sea mining areas have to be selected according to existing environmental conditions (fauna), using adequate technical means (poly-metallic nodules & geothermal fluid)"   2. "Right now I don't see that the market for such courses is big enough, for all the reasons given above. At least for the foreseeable future, teams can be assembled with the necessary knowledge, and individuals can quickly come up to speed to use their existing skills in a deep-sea mining environment."
Disagree
1. "At best deep sea mining will be for very specific minerals that have some level of restriction in access on the terrestial env. The cost differential will always been marked."

Skills gaps
1. "There will be select workers in this space, and they will need strong understanding of legal requirements and the physical oceanography that will represent the environment they work."   2. "Some awareness during undergraduate studies, but no more."

New Statement 16: “By 2050, Deep-sea mining has evolved in close synergy with mining, oil & gas and space research.”

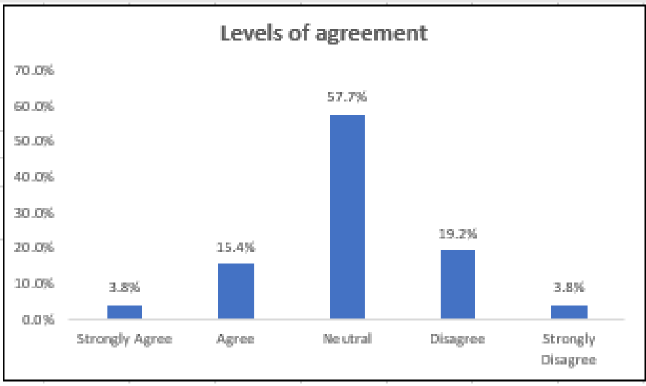


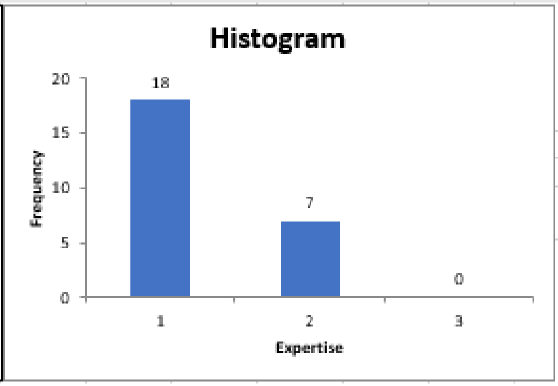


Agree
1. "Oil and gas logistical means for deep marine investigation will be needed for mining and environmental assessment but the exploitation technical phase will be self-supporting”   2. “deep sea mining will have to use as exotic and difficult techniques as, if not more, than aerospace exploration. This will be a problem due to the associated costs.”
Neutral
1. “Even by 2030, the synergies are not going to be huge. The mining value chain will be important for deep sea mining, the technology from oil and gas may be important, but I'm not sure about space technology, other than in a very vague sense. Deep-sea mining will develop its own identity, around its own skills, if it becomes more cost effective than on-land approaches for mining. It also needs to overcome the environmental hurdle, which will only grow by 2050.”
Disagree
1. “This is a different domain of issues - just because those other sectors do lots in mechanical engineering in extreme environments doesn't mean it tackles the geological and environmental challenges posed by DSM.”

Skills gaps
1. “Processing deep-sea minerals in current processing plant need better understanding.

Statement 17: “Main adaptation for a space mining training program will be courses on ‘Systems Engineering’ focusing on In Situ Resources Utilization (ISRU) and interplanetary geology. Much in line with what is already being proposed by the Colorado School of Mines.”



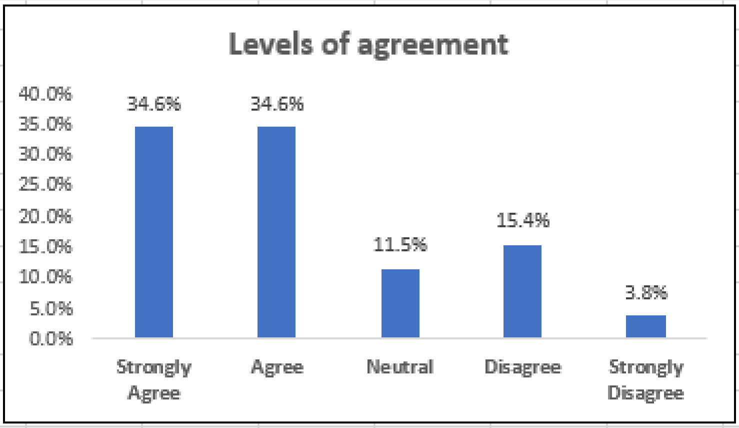


Agree
1. " it is the current approach of the space industry so is how things will develop at the start. Developments will continue in the field and other approaches will develop, space mining like mining on earth will require a whole raft of approaches to differing situations”
Neutral
1. “not sure. some programmes might have a space mining specialisation but, despite the technological fascination, I believe that it won't be a huge boom.”   2. “Systems engineering is a critical discipline for all mining, but becomes all-encompassing for space mining. But whether there will be a demand by 2050 is an open question - they can still use systems engineers and other more focussed disciplines from the existing skills pool.”
Disagree
1. “The timeframe doesn't work - the overarching mission needed to require insitu resources of that scale requiring mining in space is a long ways off.”

Skills gaps
1. “There Will be specialized education but reserved to close edge research groups”   2. “This mining development in new frontiers is first seen as a large research project to go safely where minerals are resting. Mathematics, physics are then required competences and later chemistry and geology s.l.”

Future of Education

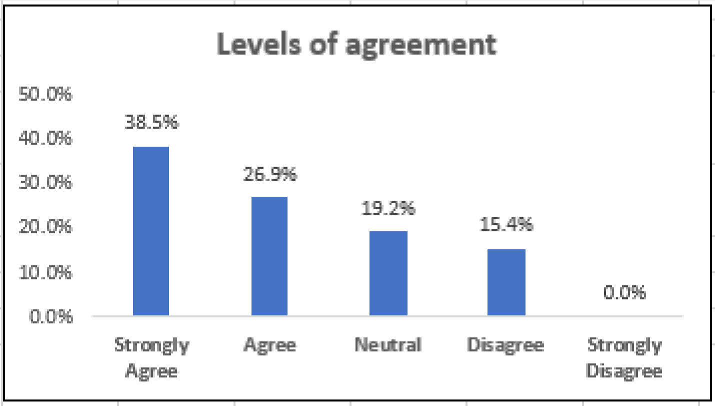
New Statement 18: “Education system will be revolutionized, moving from certification and general preparation to a flexible needs-based education – professionals won’t have fixed professions, but lifelong learning, developing a dynamic portfolio of abilities and skills.”



Agree
1. " Skills will be valued more than knowledge, but certification still will be needed in a global labour market” 2. “whilst the statement is partly true, there are so many different pathways to success. Formal education is necessary to prepare a baseline on which professionals can build their expertise and develop. For sure, with the tremendous speed of technological development lifelong learning will become even more important than it is nowadays.” 3. “A flexible needs-based education will be needed for geologists to be moving between different competences with a must: knowing what they are doing and understanding practically the result signification in term of applied geology.”
Disagree
1. “While this statement is better, it still ignores the underlying need for graduate maths and physics skills. While professionals may not have fixed professions, they will all require literacy in maths, physics and computing. So, while there might not be "mining" engineers, there will still be need for engineers who can add mining skills, and that means engineers with maths, solid mechanics, geology and fluid mechanics. These aren't skills you'd want to add to a liberal arts degree. Lifelong learning is going to be important, but then, it already is. There is a danger that "revolutionizing" education may result in people who don't have the underlying skills to learn quickly in the fields that mining will require in 2050.”

Skills gaps
1. “the ethos of education will need to change, specialised skills for some, broad for others, there is no one size fits all” 2. “Lifelong learning is already a real need so it Will be even stronger in the future”

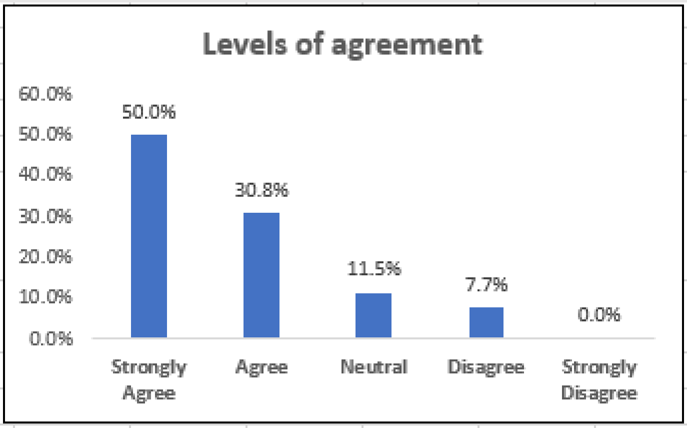
Statement 19: “Professionals will be more demanded in scientific education (physics, math and chemistry) as well as higher cognitive skills such as creativity and critical thinking than technological skills.”



Agree
1. "AI and ML will take care of much of the underlying work - freeing time and mind-space for thinking about the geologic/engineering problems and thus tackling ever harder challenges.”
Disagree
1. “Technical skills are needed at a personal level; higher cognitive skills should be expected at group level”

Skills gaps
1. “I dont think that education in basic sciences will change a lot” 2. “I don't think mining schools train basic science as rigorously as other engineering disciplines do and this is leading to miners not being up to some of the technical tasks that they face (this is a very general statement, I know).”

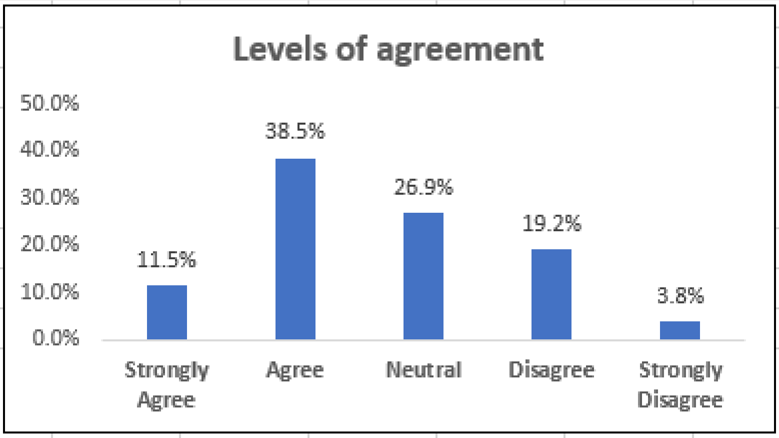
Statement 20: “Employers will need multi-skilled workers who can operate in several areas and functions within the company.”



Agree
1. " Broader knowledge and adaptability will be compulsory because mining operations and tools will become numerous and quite variable." 2. "We already saw this in the last downturn. Pureplay geologists and engineers were laid off, while multi-faceted people were lane changed into new roles until the system recovered."
Neutral
1. "there will always be both: those who can oversee a complex problem / operation and those who are specalists in performing a specific task. We will need both."

Skills gaps
1. "Multitask training will be compulsory"

New Statement 21: "Raw materials jobs will be decoupled from operation sites."



Agree
1. "With increases automation, this will be generally true, but there will still require local workers to fix issues when they fail" 2. "More professional roles are going to be able to happen away from mine sites, but there are still going to be people on site."
Disagree
1. "You can only do and learn so much in front of a screen, at the end of the day a boot is needed on the ground for a final informed decision."

Skills gaps
1. "The addition of several specific competences during just weeks or months will match the full array of operations split in different places. This for environmental and economic purposes." 2. "We don't yet fully understand the implications of remote working on workers. For example, military drone pilots are having problems integrating into home life in a way that pilots away on deployment do

not. Will we see similar problems as remote working becomes more widespread? I suspect not, but there is a gap here in skills and competencies that will probably be closed as it emerges."