CHAPTER XI
CREATING AND RETAINING KNOWLEDGE AND EXPERTISE

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1. INTRODUCTION

Recent investigations into significant failures of tailings facilities have not revealed previously unknown failure modes or required new and detailed technical research to be undertaken to understand why the failures occurred. Instead, commonly known and well understood mechanisms have been identified as the main physical triggers for failure. In seeking to explain why these triggers were activated, investigations have highlighted an overall governance challenge which has included deficiencies in management systems, poor decision-making processes, breakdowns in communication, and the lack of effective review and monitoring processes. These shortcomings have involved and impacted on the industry and its stakeholders, including local communities, owners/operators and regulators.

Such findings strongly suggest that the main challenge facing the mining industry in this area is not a lack of technical knowledge about the behaviour of tailings facilities: this information is already available if people know how to access and apply it. Rather, the main challenge is one of ensuring that all those involved in the design, construction, management, monitoring, review and regulation of individual facilities possess the requisite knowledge and expertise to make informed decisions across the full operations lifecycle from design to decommissioning.

Our assessment is that there is currently a relatively small group of specialists working in industry, consultancies, regulatory teams and as independent reviewers who possess deep technical capability in this area. Thereafter, there is a rapid fall-off of knowledge and expertise amongst operational management and other key actors such as regulators. Access to suitable education and training programmes and expertise is unevenly distributed around the globe and there is only limited capability in the area of tailings governance (defined broadly to encompass both internal organisational governance and regulation and oversight by the state).

If we accept the proposition that there are indeed significant shortcomings in knowledge management around tailings, then several questions emerge:

1. What depth of knowledge is required by different actors who have key roles to play in the governance processes relating to tailings facilities – including owners/operators, and government and community organisations?
2. How well do current education and training programmes prepare graduates and technical staff to work in roles related to the design and management of tailings facilities?
3. What are the best educational approaches for ensuring that all stakeholders, including those from outside companies, are able to develop their knowledge of tailings facilities to the level they require?
4. What resources will be required – and how long will it take – to build and sustain the necessary capacity across all relevant actors, including in critical functional areas in owners/operators and consultancies/reviewers?

Our aim in this chapter is to briefly explore these questions, and to identify priority focus areas. While we will use examples to illustrate existing approaches and initiatives, the chapter does not pretend to present a comprehensive inventory of all current education initiatives addressing tailings management.

We note that the primary focus of the Global Tailings Review (GTR), the Global Industry Standard on Tailings Management ('the Standard) and other recent initiatives such as the International Council on Mining and Metals (ICMM) forthcoming International Guide to Tailings Management is the prevention of catastrophic

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failures of tailings facilities. However, there are other important aspects of tailings management which should also be addressed in the design and management of tailings facilities. These include avoiding or minimising social dislocation and adverse environmental impacts (e.g. dust, groundwater contamination), and these aspects should likewise be a focus of education and knowledge management initiatives.

2. TAILINGS KNOWLEDGE – WHO, WHAT, AND WHEN?

Consideration of matters related to tailings commences at the point when a mining project is conceptualised and continues through to post-closure. During this time, a range of key actors (see below) will engage with information and decisions relating to the tailings facility, its risks and impacts. These actors will come from a variety of disciplinary backgrounds, and will invariably have different levels of knowledge of – and experience in – the design and management of tailings facilities.

2.1 INTERNAL COMPANY PROJECT TEAMS

These teams are formed to carry a mining project through the development and construction phases. It will be relatively rare for company personnel involved at the front-end of projects to continue through to operational roles at the mine.

Once a mineral resource has been confirmed, owners will usually conduct multiple studies, starting with an order-of-magnitude assessment of project viability, and then progressing through to a full 'bankable' feasibility study. Options for tailings treatment and storage will be considered from an early stage, and there will – or should – be communications with regulators and the community throughout this process. Internal knowledge will usually be supplemented by external expertise, with specialist consultants either embedded in teams or conducting options studies as independent operators.

The physical engineering aspects of different options and locations will figure prominently in these analyses, with input being provided from professionals with geology, mining and mineral processing expertise. Other critical, non-technical, considerations will also influence the final design decision, such as whether an option will necessitate displacement of communities from the proposed site for the dam and/or immediate downstream locations, or otherwise have a significant impact on local livelihoods. Environmental impacts will also be a key determining factor in design choices, particularly with respect to hydrological impacts.

2.2 CORPORATE TAILINGS SPECIALISTS

In recent years, the increased focus on tailings management and the broader challenges of mine closure have prompted several larger mining companies that control multiple sites to form internal teams of tailings specialists. Such teams mostly consist of just a few individuals, typically with a civil, geological/geotechnical or mining engineering background, although in some cases other science/engineering-based professionals may also occupy these roles. These individuals will usually have had direct experience of managing tailings facilities at different stages of the project lifecycle, and often in different global contexts.

2.3 SPECIALIST ENGINEERING CONSULTANTS

Some geotechnical and/or hydrotechnical consultancies, as well as some individual consultants, have developed a specific capability in tailings management. Several of these consultancies operate on a global basis. Specialist consultants will usually be involved in the design stages, including options studies and final design, and will often participate in reviews of design changes, expansions and closures as well. In many cases these specialists will also undertake quality assurance roles during facility construction, both at the startup stage and when significant changes are made to the facility, such as progressive raises of the tailings dam wall.

Often consultancies will provide owner/operators with the services of the 'Engineer of Record', who is the designated individual responsible for signing off on all designs. The Mining Association of Canada's Guide for Tailings Management (2019) is a widely used document defining the attributes for this role in relation to tailings facilities.

The dominant discipline amongst specialists in this area is geological engineering/civil engineering, with some individuals also likely to have specialised in geotechnical engineering

2.4 OWNER/OPERATOR MANAGEMENTS TEAMS

During the operational phase of a mine, responsibility for the management of a tailings facility will often fall to the Processing Plant Manager, who is usually under the direct supervision of the mine's General Manager. The Plant Manager is typically a professional with a mineral processing or chemical engineering background. Other functional roles, such

as environmental and community relations personnel, are also likely to have responsibilities in regard to monitoring the performance of the facility and engaging with local stakeholders and/or regulators.

2.5 GOVERNMENT AUTHORITIES AND AGENCIES

Final mine designs, including plans for tailings facilities, must be approved by the relevant regulatory bodies. Depending on the jurisdiction, this could involve officials from local, regional and national authorities. Regulators also play a critical role in the ongoing governance of tailings facilities, undertaking a variety of inspection and auditing activities according to local regulations.

In many jurisdictions, mining engineering is the most common disciplinary background for mines inspectors. Particularly in emerging mining economies, personnel in regulatory oversight roles can find themselves working well outside their areas of core expertise. In Indonesia for example, the duties of mines encompass all safety, environmental and community-related issues, including the performance of tailings facilities.

It is generally rare to find a high level of expertise in tailings design and management within regulatory bodies, and it is common for them to rely on external advice when conducting design reviews. A particular challenge for regulatory agencies globally is attracting and retaining highly qualified experts in the face of better opportunities within the resources industry.

2.6 LOCAL COMMUNITIES AND AUTHORITIES

The knowledge held by local communities and authorities regarding tailings will vary greatly, depending on the prior extent of mining in the region, as well as the experience of specific community members. Where community members are part of the construction or mining workforce, they may also acquire some knowledge and information about the tailings facility, through both formal and informal processes.

The design and location of a tailings facility will often be one of the most significant decisions in a mining project from the perspective of local communities, given the nature and scale of such facilities, and the possible consequences of failure. Reducing the potential asymmetry of knowledge between communities and project proponents should therefore be a priority in early engagement with local stakeholders, for both owner/operators and regulators.

2.7 OWNER/OPERATOR BOARDS, INSURERS AND SHAREHOLDERS

These groups of actors can range across the spectrum from being very knowledgeable to completely unaware of tailings issues. Knowledge is mostly acquired from experience, rather than from specific educational programmes or training courses. Owner/operator boards often include senior mining professionals who are very familiar with the issues. Where the owner/operator employs a designated tailings specialist, all board members will more than likely get at least annual updates from the specialist. Increasingly, insurers are also engaging knowledgeable sources in industry for advice on tailings risks.

3. THE CURRENT TAILINGS EDUCATION LANDSCAPE

This section provides an overview of existing tailings education options and addresses opportunities and challenges. Currently, the main options available in this area are: a limited number of dedicated tertiary programmes; coverage of tailings as part of broader degrees; competency-based skills training focussed on supervisory and monitoring roles; and a range of professional development options offered outside the formal education system. At the same time, the global landscape for education is changing at a rapid pace, with several new initiatives offering alternatives which allow for greater flexibility and easier access to material.

3.1 TAILINGS-SPECIFIC TERTIARY QUALIFICATIONS

Formal qualifications that cover the topic of the design and management of tailings facilities in sufficient depth provide some assurance that individuals in key tailings-related roles in industry, professional services and government have the requisite knowledge to perform these roles.

Currently there are only a limited number of tertiary institutions around the world that offer courses in mine waste management directly related to tailings, and taught by qualified instructors who have practical experience in this field. Less than ten educational institutes offer post-graduate training and instruction by staff with salient experience, and these institutes are concentrated in just a few geographical regions.

A recent survey completed by 33 Universities, undertaken as part of the consultation process for a Global Tailings Consortium, identified only two

programmes that were explicitly focussed on tailings management: one delivered by the University of British Columbia and the other by the University of Chile (Box 1). Another six thematic programmes included substantive content related to tailings. It should be noted, however, that, several institutions are currently at various stages of implementing additional postgraduate programmes in this area, so the situation may improve over the next few years.

Box 1: Example of a specialist tertiary qualification relating to tailings

The University of Chile currently offers a Diploma in Tailings Engineering, a three-month programme designed for engineers and geologists working in the sector to improve knowledge regarding the design, construction, operation, and closure of tailings facilities. The Diploma covers eight topics:

1. Introduction to Tailings Engineering
2. Earthquake and Geological risks
3. Geotechnical Elements of Design, Construction, and Operation
4. Environmental and Social Impact
5. Geotechnical and Chemical Instrumentation and Monitoring
6. Water Recovery, Management, and Disposal of Tailings
7. Management and Governance
8. Group Project

Source: https://portaluchile.uchile.cl/cursos/155096/diplomado-ingenieria-de-relaves

3.2 COVERAGE OF TAILINGS IN RELEVANT ENGINEERING DEGREES

The most common disciplinary background for specialists working in the field of tailings design is a Civil Engineering or Geological Engineering degree. These fields of study will normally include the fundamentals of soil mechanics, liquefaction, hydrology and fluid mechanics. While the mining context and specifics of tailings dams may not be addressed in depth, the principles of earthworks and generic dam construction and operation are usually covered.

Mining engineering and mineral processing degrees generally provide some coverage of issues associated with tailings, but this is usually done at a relatively broad level. For example, mining engineering students would normally study the principles of soil mechanics but would not be expected to analyse a tailings dam construction in detail. There are a small number of mining programmes globally that include a specific course on Mine Waste Management, for example one taught at the University of British Columbia.

The pragmatic managerial and technical challenges facing actual facilities – challenges that have been cited over and over as the leading causes for the catastrophic failures that have occurred – rarely receive much coverage in the university environment. While a basic theoretical understanding of the design and management of tailings facilities is clearly essential, it is also very important that university training programmes related to mine tailings incorporate a strong practical component and draw on experience and learnings from case studies of failures.

The challenge for educators is to find ways of raising the profile of tailings management within existing degrees without crowding out other important topics from the curriculum or attempting to turn civil or geotechnical engineers into mining engineers, and vice versa. One possible approach is to incorporate a tailings focus into established subjects that deal with cross-cutting topics such as mine planning, mine management and project evaluation. An example is a common final year Mine Feasibility Project subject delivered by several Australian universities, which includes the requirement for students to plan, design and cost a tailings facility as part of an overall feasibility study of a hypothetical mine project.

3.3 DAM AND TAILINGS-RELATED OPERATIONAL QUALIFICATIONS

At the Vocational Educational and Training (VET) level, there are isolated examples of specific qualifications designed to address the need to build competency in supervision and monitoring of tailings dams, and of dam structures more generally. For example, in Australia a specific competency unit was developed as part of the formal Mining Industry Skills Framework and is now included in the current Diploma of Process Plant Technology qualification (see Box 2).

Box 2: Example of a VET-level unit on tailings management

PMAOPS560 Plan and design tailings management facilities

'This unit of competency applies to health, safety and environment (HSE) managers/officers, frontline managers, site managers/officers or those in similar roles who are required to develop risk identification and management strategies (business and environmental) and scope and design tailings disposal management systems and facilities.'

Source: https://training.gov.au/Training/Details/PMAOPS560

Overall, however, qualifications which focus on the operational governance aspects of tailings facilities do not appear to be widely available, or to enjoy high levels of support.

3.4 PROFESSIONAL DEVELOPMENT IN TAILINGS MANAGEMENT

Currently, short courses offered as professional development activities by universities, consultancies and individual experts are the most visible mechanism in the mining sector for transferring knowledge about different aspects of tailings management (for an example, see Box 3.) These courses, which vary in scope and target audience, typically run for 3-5 days and are usually delivered in a face-to-face workshop format. Such courses are not normally accredited, but they probably have the best global coverage and the highest participation rates of any of the education and training initiatives discussed here.

Box 3: Example of an online short course on tailings management

Edumine online training course on Tailings Facility Design, Operation, and Closure

The online provider Edumine is based in Canada, but with a global reach. The total duration is of this course is 19 hours. According to the course description:

'The course covers tailings as part of the mining process, tailings types and characteristics, tailings facility types and components, and tailings facility design, performance, construction, operation and closure... illustrated by case histories.

This course is for anyone involved in the different aspects of tailings listed above, including engineers, environmentalists, geologists, operators and regulators.'

Source: https://learn.edumine.com/store/690638-tailings-facility-design-operation-and-closure

3.5 CROSS-CUTTING THEMES IN TAILINGS EDUCATION

Several cross-cutting themes have emerged in recent discussions on tailings education and engineering curricula more broadly. These themes are often closely linked. Together, they highlight the need to ensure that a broad disciplinary paradigm is applied when designing tailings facilities. Here we focus on three thematic areas in particular: risk management, economic valuation, and socio-economic impact analysis.

Risk management is the key framework applied in the mining industry (by both owners/operators and regulators) to understand and assess the likelihood and consequences of failures, and to minimise both from the design stage onwards. The new Global Industry Standard on Tailings Management is firmly embedded in this approach. Risk management is also the basis of safety legislation in many jurisdictions around the world.

Training in risk assessment is commonplace at all levels in the mining industry and is also introduced early in the curricula of most engineering programmes. However, confusion persists amongst both internal and external actors about how the concept of risk should be applied and interpreted, including in relation to tailings facilities. This is a strong reason for ensuring that risk management concepts and risk analysis techniques are explicitly addressed in all education initiatives in this area.

A less prominent but equally important cross-cutting theme is economic valuation, particularly with respect to decision-making regarding tailings facilities and technology options. The dominant approach to economic analysis in the industry – and in most engineering education programmes – remains Discounted Cash Flow or Net Present Value (NPV) financial analysis. It is now well-documented that this approach is not well-suited to dealing with issues of long-term liability, or with low risk but significant consequence events. This is because the high discount rates often adopted for mining projects result in a focus on short term outcomes at the expense of longer-term considerations.

As discussed earlier, understanding the potential socio-environmental impacts of tailings dams through the lifecycle is also critical, as is consideration of the direct social consequences of dam failure. Knowledge of the local social context is likewise crucial when it comes to emergency preparedness. All of those involved in tailings management need to understand these aspects at a basic level (at least) and be prepared to ask relevant questions of specialists engaged to work in these areas.

Most modern engineering curricula currently identify a set of graduate attributes that include such elements as systems thinking capability, the ability to communicate horizontally and vertically within organisations, and the ability to work in multi-disciplinary teams. These are increasingly being designed into assessment activities for courses. Developing these attributes should also better equip graduates to engage with the significant governance challenges associated with tailings management, particularly when combined with other initiatives discussed here.

3.6 NEW CHANNELS FOR EDUCATION

In recent years there have been several significant changes in the education landscape. One change of particular relevance to this chapter has been the emergence of new online platforms providing free – or low cost – globally-accessible content. Various universities around the world have formed international consortia to establish and support these platforms and are also developing suites of new 'micro-credential' offerings in many disciplines. These offerings typically take the form of individual modules which can be taken on a stand-alone basis, combined with other modules to form a subject, or aggregated into certificates or even diplomas. In contrast to conventional qualifications, micro-credentials are designed for flexibility and mobility, providing recipients with highly transferrable pathways to future studies, upskilling, recognition of prior learning and/or continued professional learning. Many observers have noted the trend towards alternative credentials, and several countries have introduced enabling policies for micro-credentials linked to national Qualifications Frameworks.

Until recently, mining education providers at the tertiary level have not shown a strong interest in online delivery of content at scale, or the development of micro-credentials. However, there are indications that this situation is rapidly changing, in response to shifting market conditions and the high costs associated with traditional teaching methods. By developing flexible and globally available material, education providers can significantly increase their reach while potentially lowering the cost of delivery. One of the benefits of this new model is that it could help to overcome the uneven geographic distribution of expertise and the knowledge asymmetries that we have previously referred to.

3.7 TEACHING CAPACITY

As noted above, practical knowledge of tailings design and management is a critical – but often missing – element of current curricula. However, finding capable and experienced people to teach this material is becoming increasingly difficult. In many jurisdictions, universities now rely heavily on indicators of research excellence and associated outputs (such as publications and grants) as key criteria for the selection and promotion of academic staff. This is sometimes at the expense of valuing practical experience, which in turn can hinder the recruitment of teaching personnel with predominantly industry backgrounds. At the relatively small number of universities that currently offer tailings-specific programmes or courses, several prominent faculty staff are nearing the end of their teaching careers without clear succession plans being in place. This is a critical issue for universities to address.

4. INDUSTRY NETWORKS, RESOURCES AND COMMUNITIES OF PRACTICE

Industry and professional networks, and communities of practice, play a valuable role in sharing knowledge amongst practitioners and keeping them informed about new developments. These less formal and often voluntary processes are particularly important in the field of tailings practice, given the relatively small number of specialists in the area. We discuss some examples below.

4.1 INTERNAL COMPANY KNOWLEDGE SHARING

As mentioned earlier, larger companies which operate multiple sites will often invest resources in creating an internal 'community of practice' led by experienced tailings specialists. Such individuals are playing an increasingly critical role in internal knowledge management relating to the organisation's portfolio of tailings facilities, including by providing internal training and leading the development and implementation of corporate policy and guidance documents. Increasingly, specialists from different companies are sharing knowledge amongst each other and/or offering their experience and knowledge to support global efforts, including by contributing to guidance documents and conferences.

4.2 NATIONAL AND INTERNATIONAL INDUSTRY ASSOCIATIONS AND GUIDANCE RESOURCES

At the collective level, national industry associations have played a key role in mobilising industry expertise and producing guidance documents. Examples include: The Mining Association of Canada's (MAC) *Guide to Tailings Management* (see Box 4), the Australian National Committee on Large Dams (ANCOLD) *Guidelines* and the South African National Standard (SANS) 10286:1998 *Code of Practice*. These and related guidance documents have often formed the basis of short courses. They generally have a strong focus on governance, in recognition that tailings facilities are complex engineered facilities that must be managed appropriately over long periods of time, often in perpetuity. (See Golder Associates [2016] for a helpful review of the various guidance documents in this area.).

Box 4: An industry-wide knowledge-sharing initiative from Canada

The initial version of MAC's *Guide to Tailings Management* was published in 1998 and the *Operation, Maintenance* and *Surveillance Manual for Tailings and Water Management Facilities (the OMS Guide)* in 2003. Both documents have been regularly updated since and are widely utilised in the global mining industry. The 2018/19 updates are available in several languages. The OMS Guide is particularly relevant to the practical operational governance aspects highlighted in this chapter.

4.3 INDUSTRY CONFERENCES AND EVENTS

There are several national and international conference events that bring together industry and government representatives to share the latest knowledge on tailings. Box 5 provides an example.

Box 5: Annual Tailings and Mine Waste Conference

Tailings & Mine Waste is an international annual conference started in the late 1970s through the Colorado State University (CSU) (Fort Collins), which has evolved to be a rotating event organised by CSU, the University of Alberta and UBC and offered at Canadian and United States venues. In 2019, the conference was held in Vancouver and saw a record of more than 800 delegates attend over four days of podium, poster presentations and other activities. Several short courses were also held as part of the overall programme.

These types of events are usually convened by professional associations working closely with industry groups and sponsors. They typically feature short courses and side events that encourage knowledge sharing and network development.

4.4 INTERNATIONAL CAPACITY BUILDING INITIATIVES

Over the last 30 plus years, various initiatives have been undertaken to improve the governance of mining activities in emerging resource economies. This work has been funded and co-ordinated by what can be broadly termed the 'international development' sector, comprising a mix of multilateral bodies (e.g. The World Bank) overseas aid programmes of national governments (e.g. The German Corporation for International Cooperation [GIZ], and the Canadian International Development Agency) and donor bodies (e.g. the Open Society Foundation). Capacity building activities undertaken by these bodies have included providing technical assistance to governments, developing guidance materials, convening conferences and workshops, and delivering or sponsoring training programmes. The main target groups for these initiatives have typically been government officials and, in some circumstances, civil society organisations and local educational institutions.

With good reason, the primary focus to date of these capacity building initiatives has been on legal frameworks and economic and fiscal issues, rather than on the more technical aspects of mining operations. However, there are a few examples of initiatives that have specifically focused on tailings management (see Box 6). Some organisations have also convened activities in related areas such as Mine Closure.

Box 6: A capacity building initiative for government personnel

The International Mining for Development Centre (IM4DC) was an initiative of the Australian Government which operated between 2011 and 2015. During these four years the Centre delivered five courses on the Management of Large Volume Waste, with a major focus on tailings. These courses were developed following ongoing requests from partner governments, and were led by experienced researchers from The University of Western Australia and The University of Queensland. The final two-week program was held in Baguio City in the Philippines. It was attended by 36 staff – predominantly Mines Inspectors – from the Mines and Geoscience Bureau and included site inspections at two nearby operations. Previous workshops had been held at partner Universities in Ghana and Zambia, targeted at government and academic participants.

Given the level of international concern about the safety of tailings facilities, the aid sector should be encouraged to undertake or support more initiatives to build regulatory and oversight capacity in this area. Entities that could potentially play a lead role here include the World Bank's Extractives Program, the Intergovernmental Forum on Mining Minerals, Metals and Sustainable Development (IGF) and the United Nations Environment Program (UNEP), as well as the national aid programmes of some countries. There are also opportunities for these various entities to exploit synergies in objectives, including by cross-promoting courses, running joint programmes and sharing course materials.

5. FUTURE DIRECTIONS AND PRIORITIES

We have argued in this chapter that knowledge and expertise regarding tailings management are limited and unevenly distributed, both geographically and between different actors (e.g. project proponents, consultants, regulators, local communities). The question of what should be included in the scope of tailings education also needs careful consideration. To address these and other issues, we suggest a focus on the following areas, all of them inter-related.

5.1 BROADENING THE FOCUS OF TAILINGS EDUCATION

A recurring theme in both this chapter and the GTR process has been the need to adopt a multi-disciplinary approach to the challenges of tailings management. In addition to dealing with the technical aspects of tailings, education and training programmes should be covering topics such as the socio-economic and environmental impacts of tailings facilities, and the application of appropriate economic and risk management frameworks in decision-making. Programmes should also aim to provide a balance between conventional tailings dam expertise and the application of alternative/emerging technologies.

5.2 DEVELOPING FORMAL QUALIFICATIONS IN TAILINGS DESIGN AND MANAGEMENT

Setting up dedicated postgraduate programmes that address tailings design and management will provide an incentive for individuals to specialise in this area, rather than tailings-related work just being seen as a 'tour of duty' within a more general career trajectory. An equally important aspect is therefore for the industry to establish career path options for those specialising in this area, and to support such programmes by ensuring that a critical mass of enrolments can be sustained.

Consideration should also be given to establishing appropriate certification processes for professionals in supervisory roles. One of the requirements for certification could be completion of a diploma or similar level course that focuses on operational and monitoring activities.

Wherever possible, courses designed for people already in the workforce should be taught in flexible and accessible modes to broaden their reach: for example, allowing the course to be taken on-line and/or on a part-time basis.

5.3 INCREASING EMPHASIS AND CONTENT IN RELEVANT DEGREES

Many industry personnel who occupy senior operational management roles with responsibility for tailings facilities are likely to have had only limited exposure to key principles of tailings management in their university courses. Looking to the future, universities have a responsibility to ensure that this critical aspect of mining operations is adequately addressed in the undergraduate curricula for mining engineering and processing degrees, and that teaching content includes relevant and recent case studies.

The linkages between design and operational decisions taken across the mine lifecycle and the performance of tailings facilities should also be emphasised. It is noteworthy that the survey of experts conducted by Morrison et al (2017) identified verification of tailings characteristics over the life of the facility as their number one concern – an issue closely linked to mining and processing operational management practice.

5.4 LEARNING FROM EXPERIENCE

Tragedies such as the recent tailings dam failures in Brazil offer important lessons which should be shared. Storytelling is a valuable form of knowledge transfer, both within organisations and more broadly in the public domain. Sharing information about failures, as well as successes, also helps to promote a learning (as opposed to blaming) culture within and between organisations.

There are several examples of powerful fact-based case histories that have been used in educational settings. One such case is a video describing the fatal air-blast incident at the Northparkes block caving operation in Australia (Minerals Industry Safety and Health Centre and Rio Tinto 2005). This was funded by the then mine owner Rio Tinto and was made publicly available in order to disseminate the lessons learned across the industry.

5.5 STRENGTHENING KNOWLEDGE NETWORKS

As discussed in the previous section, existing professional and industry networks play an important role in disseminating knowledge about industry developments, new technologies and innovations in tailings management. In our view, creation of a more formal alliance of key stakeholders would provide an additional mechanism for disseminating knowledge and promoting good practice. This alliance could include mining companies, universities, regulators and other stakeholders. A key focus of such an alliance should be on developing and disseminating public domain educational resources, designed to suit a range of different stakeholder groups according to need. This would also assist in reducing geographical disparities in the distribution of knowledge and expertise and asymmetries between different actors. A model for such a network is described elsewhere in this report (Franks, Littleboy and Williams, this volume).

5.6 HUMAN CAPITAL

An immediate challenge in progressing several of the initiatives proposed in this chapter is the shortage of educators with appropriate levels of competence and background experience. As flagged earlier, only a small number of educational institutions offer specialist expertise in tailings, and there are significant gaps in global coverage. One way to grow the pool of qualified educators in this area would be for the University sector and industry to work together to improve exchange of knowledge and experience through short term secondments or placements.

Enrolments in mining-related programmes are declining in most parts of the world. When coupled with a generally negative view of the sector in the wider society, this is reducing the potential pool of future tailings specialists. Support must be provided to encourage bright young people to become the tailings stewards of the future, taking up the design, operational, regulatory or civil society roles that will all be critical to meeting the target of zero failures.

6. CONCLUSION

In this chapter we have reviewed the existing landscape of education and knowledge management activities that relate to the design and management of tailings facilities. We have argued that there are geographical and organisational disparities in the current distribution of expertise in this area, and have identified gaps in coverage of important topics, particularly in the area of governance. Good design and management of tailings facilities requires access to capable professionals from diverse disciplines who are able to work together. However, at present there is a shortage of professionals who have the requisite expertise and knowledge required to undertake these roles effectively. Current industry knowledge sharing activities are designed to promote good practice in this area, but tend to be inward-looking and are not necessarily increasing the broader distribution of expertise.

Going forward, a collaborative approach will be essential for addressing the issues raised in this chapter, as no single stakeholder group can achieve the changes required on their own. It is beyond our scope to suggest specific implementation pathways. However, it is clear that improving the way in which we manage and apply existing knowledge, including through the integration of knowledge from different disciplinary domains, will be key to preventing further catastrophic tailings dam failures.

KEY MESSAGES

1. Technical expertise in the design and management of tailings facilities is unevenly distributed across the globe, as is access to relevant education programmes.

2. There is a need to go beyond a narrow engineering design focus and embed a multi-disciplinary approach within tailings-related education.

3. The ability to understand and apply Risk Management frameworks is a critical capability for tailings governance and needs to be explicitly addressed in education initiatives.

4. It is essential that all education and training programmes related to mine tailings, including university courses, have a strong practical as well as theoretical focus, and draw on experience and learning from case studies of failures.

5. At a time of increased concern regarding the management of tailings facilities, our ability to educate specialists and those charged with managing such facilities is limited by a shortage of qualified and experienced educators.

6. Globally, there are very few programmes that address the operational governance aspects of tailings facilities. The international development sector should be encouraged to support the development and deployment of such programmes in countries that cannot easily access this expertise.

REFERENCES

Golder Associates (2016). *Review of Tailings Management Guidelines and Recommendations for Improvement.* https://www.icmm.com/tailings-report

MAC (2019). *A Guide to the Management of Tailings Facilities Version 3.1.* Ottawa: Mining Association of Canada. https://mining.ca/our-focus/tailings-management/tailings-guide/

Minerals Industry Safety and Health Centre and Rio Tinto (2005). *Managing major hazards in the mining industry*. video presentation. Available at: https://www.youtube.com/watch?v=Qni0NhxWS3Y

Morrison K. et al. (2017). *What does it mean to be the Engineer of Record (EoR) for a Tailings Storage Facility (TSF).* http://knightpiesold.com/en/news/publications/what-does-it-mean-to-be-the-engineer-of-record-eor-for-a-tailings-storage-facility-tsf/

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