Operationalising a process model of innovation for the mining industry

Abstract

Technological innovations in mining help improve the efficiency, sustainability and productivity of the mining sector. However, most research on the development and implementation of technological innovations is at the level of the organisation and often not context-specific, providing limited insights into specific practices underpinning the innovation process and the role of individuals and teams in innovation. This study operationalises a process model of innovation for the mining industry. Using data from 25 interviews with mining experts, our study identified and mapped actionable practices that mining organisations can adopt to effectively identify, develop and implement innovation. Three main contributions emerged from the study. The study offers an actionable process model of innovation for mining that considers the mining context at the level of individual and team behaviours. The study reveals the need to involve multiple types of stakeholders and that the mix of stakeholder types varies between innovation phases. Finally, the study finds that the innovation practices identified map to six innovation culture enablers, all of which are required but vary in importance across each phase of the innovation process.

Keywords: innovation culture enablers, technological innovation, stakeholders, mining

1. Introduction

Innovations, including technological innovations, are acknowledged as an essential activity through which businesses can enhance their competitiveness and ongoing viability (Crossan and Apaydin, 2010). The importance of innovation is evidenced by scholarly works spanning several decades (Garud et al., 2013). This extensive and mature body of literature contains several models of innovation of increasing complexity and varying explanatory power (Rothwell 1994; Dodgson et al., 2008). However, most models of innovation that practitioners tend to draw on are quite general and lack the degree of specificity required to be of significant practical benefit (West et al., 2014). In the absence of models of innovation that can provide useful insights for particular circumstances, innovation practitioners often rely on previous experience. Planning efforts can only consider foreseeable occurrences and, as innovation by its nature involves new activities and new artefacts, innovation initiatives are often unpredictable, difficult to manage and have poor success rates (Seelos and Mair, 2012).

Enhancing innovation management is particularly important to the mining industry. Mining is an economically and socially important industry but is noted to have implemented fewer innovations than other industries (Gruenhagen and Parker, 2020). Additionally, the mining industry is facing several challenges that require new technological solutions, including remote-area operations, safety, increasingly difficult to locate and process ores, water supply, energy consumption and transitioning to non-fossil fuels (Upstill and Hall, 2006). Mining faces particular barriers to technology innovation because of the nature of the industry. Mining innovation practitioners are constrained in their efforts by the lack of an actionable process model of innovation that reflects the nature of their industry, is framed in their language and recognises the nature of innovation in mining. This study is part of a broader program of work investigating barriers and management tools for innovation adoption in mining. Building on the latest research on the innovation process in mining (Kashan et al., 2022), this study aims to operationalise an innovation model for the mining context to enhance its utility in practice. This study was guided by the research question: 'What are the actionable practices that mining organisations can adopt to effectively identify, develop and implement technological innovations?' To address this question, we operationalised a process model of innovation tailored to the mining industry by drawing on the innovation literature and by using detailed data collected from experienced mining personnel to identify the successful practices they had used to accomplish innovation development and adoption. We then mapped these practices to elements of organisational culture that supported innovation in the mining context that we identified abductively (Dubois and Gadde, 2002). The resulting practices that support this process model of innovation, operationalised for the mining industry, can be used by practitioners to inform their innovation strategies within their companies.

The study makes three contributions to innovation management theory and practice. First, we present specific practices for agents and decision-makers undertaking innovation work in the context of mining. In doing so, we further enrich the process model of innovation in mining (Kashan et al., 2022) by operationalising the model and developing actionable practices for individuals and teams. Second, we contribute to the operationalisation of the innovation process in mining by identifying relevant groups of stakeholders and proposing practices for their involvement in each phase of the innovation process. In particular, our research reveals that stakeholders, including research and development (R&D) staff, academics, students, technology providers, senior leaders, operations supervisors, users of the new technology, developers and clients, enable the important exploratory function at the early stages of the innovation process related to ideating and strategising. The composition of stakeholders changes as the project progresses through each innovation process phase; hence, the practices also change, moving from activities driving exploration to activities driving exploitation. Finally, by drawing from the innovation culture literature and empirical data, we identified that the innovation practices can be mapped to six innovation culture enablers (ICEs). In particular, we found that practices promoting openness to new ideas and opportunity recognition are the most important practices in the early stages of the innovation process, whereas practices related to adjusting resources, role descriptions, work plans or revising the incentive structure to promote idea implementation are more significant in the later phases of the innovation process.

The paper proceeds as follows. First, we present an overview of the literature relating to innovation processes and how innovation culture influences how innovation is carried out and the resulting innovation outcomes. We then set out the methods used, beginning with a description of the mining context, followed by explanations of how we collected and analysed the data. We then present our findings and set out details of each of the three phases of the operationalised innovation process, including the practices that supported innovation in each phase together with the ICEs that they mapped to. This is followed by a discussion of the findings in light of the innovation literature, our contributions and a discussion of potential limitations and ideas for further research.

2. Literature review

2.1 The innovation process

Innovation is an important means of creating social and economic benefits through the development of new products, services and processes (Crossan and Apaydin, 2010; Garud et al., 2013). Innovation is understood to involve "identifying, developing and exploiting new ideas to generate value" (Prabhu, 2014: 53). In the mining context, innovation involves developing new processes for achieving the extraction and refining of mineral resources, addressing water and energy shortages, and ensuring more sustainable mining practices. These new processes usually involve new technology and so involve developing the new practices for integrating that technology into existing operations. Some recent examples include autonomous vehicles and operations, information technology (IT) platforms and control systems, high-volume resource characterisation and deep-sea mining (Endl et al., 2019).

The innovation process has been extensively theorised using a number of theoretical lenses, including learning and knowledge management, network theories and economic theories (Randhawa et al., 2016). Over the decades of interest in innovation, models have evolved from the early linear technology-push and market-pull models to models with multiple stages (Rothwell, 1994), stage-gate sequences (Cooper, 1990), integrated models (Hobday, 2005) and non-linear dynamic models involving convergent and divergent activities (Dodgson et al., 2008). While there are multiple conceptualisations of how innovation processes unfold, the core processes of innovation are generally agreed to involve three overlapping sub-processes relating to the stages of development of an innovation: (1) the generation of a new idea or invention (Hansen and Birkenshaw, 2007; Pavitt, 2005); (2) the transformation of that initial new knowledge into products, services or processes, (Fagerberg et al., 2013); and (3) the diffusion or implementation of this newly developed knowledge (in the form of products, services or processes) into its user context (Garud et al., 2013). The first phase involves the identification or creation of ideas and options (Abernathy and Clark 1985). Research demonstrates that in the initial phase of the innovation project, it is useful to engage a broad range of stakeholders to gather diverse viewpoints (Giezen et al., 2015). Information divergence directs decision-makers to focus on accommodating and integrating diverse knowledge and experiences, which in turn helps the group to work through possibilities to select a viable option to pursue. The second phase involves the selection of promising options (Bosch-Sijtsema and Bosch, 2015) and includes developing the idea to match the proposed context of use, exploring risks and potential benefits, and developing proofs of concept or prototypes (Pavitt, 2005). The third phase involves implementation in the commercial environment, with activities focusing on realising the potential benefits of the innovation (Tidd, 2006). This third phase, if executed successfully, results in a new 'business as usual'. Innovation scholars have argued that the early phase of innovation tends to be relatively chaotic while the final stage is more amenable to planning (Gassmann and Schweitzer, 2014). Thus, the early phase of innovation (i.e., Phase 1) is understood to involve divergent thinking (Acar and Runco, 2019) in generating ideas and options, whereas later phases (i.e., Phases 2 and 3), which occur after an innovation strategy has been decided, involve more convergent than divergent thinking.

Despite extensive studies, the current theorisation of the innovation process still has some limitations. Most research on the innovation process is at the level of the organisation (Bogers et al., 2017; Crossan and Apaydin, 2010; West et al., 2014), which limits insights into the role of individuals in innovation. Limited research exists on the micro-foundations of innovation, such as what practitioners actually do to accomplish successful innovation (West et al., 2014) and how the innovation evolves at the project level (Salter et al., 2014). Furthermore, current theorisation has difficulty explaining the different innovation processes reported in different industry sectors (Crossan and Apaydin, 2010). These limitations of existing theory mean that innovation practitioners, who currently struggle with problems including risk, uncertainty, long time frames, conflict (Hansen and Birkenshaw, 2007) and a low rate of success (MacVaugh and Schiavone, 2010), need to translate theory at the organisational level to their specific environment at the project level and their individual team-member level.

This study addresses this shortcoming by operationalising the recently developed three-phase model of the innovation process, contextualised for the mining environment (Kashan et al., 2022). The contextualised model involves three phases: (1) ideating and strategising, (2) developing and piloting, and (3) implementing and embedding. In this study, we operationalise this model to include specific behaviours or practices at the level of individual innovation practitioners.

2.2 Innovation culture

An organisation's culture is acknowledged as a critical factor in organisational success (O'Reilly and Tushman, 2008), and there is a strong link between the nature of an organisation's culture and its ability to innovate successfully (Dobni, 2008). Organisations whose cultures do not sufficiently support innovation activities often fail to innovate successfully (Caiazza and Volpe, 2017).

Organisational culture is defined as the values, beliefs and hidden assumptions that an organisation's staff share (Schein, 1982). Schein's model (1992) is often used to explicate organisational culture in three layers: organisational assumptions on the bottom, organisational values in the middle and organisational artefacts at the top. Organisational culture is usually discussed with respect to its values, which are enacted by individuals in forms that support innovation, such as learning, risk-taking and testing (Hogan and Coote 2014), or inhibit innovation, such as rigidity, control and predictability (Jassawalla and Sashittal, 2003).

An 'innovation culture' is therefore defined as the degree to which an organisation's cultural values, norms and artefacts support the company's innovativeness (Stock et al., 2013) and can be understood as a subset of an organisation's overall culture (Büschgens et al., 2013). Innovation cultures are supportive of staff looking outside the organisation, being open to new ideas, being flexible and responsive, and collaborating to share information (Caldwell and O'Reilly, 2003; Cameron and Quinn, 2005). This type of culture also enables conditions that support learning, creativity and calculated risk-taking (Jaiswal and Dhar, 2015). Innovation culture enables organisations to overcome barriers to innovation and adaptation like rigidity, control, resistance to change, narrow mindedness, risk avoidance, predictability and stability (McKinley et al., 2014). Under such conditions, trust, respect and quick decision-making can be achieved (Kenny and Reedy, 2006). Risk-taking and tolerance of failure as organisational values provide employees with the psychological safety to engage with experimentation and question the status quo and critical thinking without the fear of negative consequences to self-image, status or career (Tellis et al., 2009). From an important practical perspective, an innovation culture allows the required resources to be allocated to innovation efforts (Černe et al., 2013). Organisations that are able to develop such innovation cultures are able to achieve improved implementation of new solutions (Aarons and Sommerfeld, 2012) and enhanced innovation outcomes (Dobni, 2008). Organisations with an innovation culture therefore have a different orientation to those that are primarily concerned with ‘business as usual’ and focus on stability and efficiency.

Several scholars have attempted to identify the various elements that comprise an innovation culture. Dobni (2008) argues that there are seven factors that describe and measure an innovation culture: organisational constituency, organisational learning, creativity, empowerment, market orientation, value orientation, and implementation context. Later, Rao and Weintraub (2013) identified six building blocks of an innovative culture: values, behaviours, climate, resources, processes and success. Each of these building blocks was further refined into three factors to give 18 factors overall. Hogan and Coote (2014) argue that success, openness, internal communication, competence, inter-functional cooperation, responsibility, appreciation and risk-taking are value dimensions of innovation culture. A more recent review (Tian et al., 2018) of the literature identified multiple aspects of innovation culture, including risk-taking, openness to new ideas, learning, information interpretation, and implementing and sharing ideas. Thus, multiple factors have been identified that contribute to an innovation culture. However, most of the elements identified are conceptual rather than tangible, making it difficult for practitioners to discern actionable advice from this literature.

However, innovation is known to be context-dependent (Dobni, 2008) so for the purpose of this study, we draw on a study that reviewed the limited literature of innovation culture in the mining context (Kashan et al., 2021). That study identified 12 specific cultural characteristics that affect innovation in the mining context: risk tolerance, creativity, empowerment, continuous development, proactivity, external orientation, teamwork and collaboration, flexibility, trust, learning, employee recognition for innovation and diversity. To add to innovation culture theorisation, this study identifies actionable practices at the individual level and maps those practices to the elements that support an innovation culture in the mining context.

3. Methods

The objective of this study was to identify practices that support the development and implementation of innovations in the context of mining. We begin this section by describing the mining context, pointing out aspects that impact innovation. We then set out our methods for data collection and data analysis and describe how we validated the model.

3.1 Mining context

Mining is a complex, global industry with multiple stakeholders. It is complex both with respect to its technology and its multiple and varied stakeholders. Mining produces commodities via continuous processes rather than products, and so innovation in mining is process innovation rather than product or service innovation, rendering innovation in mining fundamentally different from innovation in many other industries (Shook, 2015). The process of mining consists of the extraction, processing and transportation of minerals from their source (usually in geographically remote areas) to their users (usually in urban areas) (Muduli et al., 2013). Mining operations are usually located near the mineral deposit and are capital intensive, involving large and complex installations often amortised over decades

(Bartos, 2007) and can involve extreme hazard levels (Shook, 2015). A mining operation involves multiple stakeholders, including the organisation's workforce, its competitors, customers, shareholders, suppliers, government regulators and policymakers, research organisations and, importantly, members of the communities in which it operates (Gruenhagen and Parker, 2020). A mining organisation needs to engage successfully with the competing demands of this diverse group of stakeholders. Of particular importance is how well a mining company engages with its local communities to earn and maintain its social licence to operate (Fordham et al., 2017).

The nature of mining presents significant challenges to implementing innovations which have resulted in the mining industry introducing fewer technological innovations than other industries (Deverell, 2016). These challenges include remote-area operations, high levels of staff turnover, difficulties in attracting staff with the required skills and experience (Scott-Kemis, 2013) and the necessity of maintaining daily production targets. Any changes made as part of an innovative effort impact all parts of the value chain and impact multiple stakeholders (Gruenhagen and Parker, 2020). However, the industry has embraced significant change over the past three decades, including technological change (Kaplan, 2012), its enhanced commitment to safety (Aleke and Nhamo, 2016), and its responsibilities to the environment and the communities in which it operates (Deloitte, 2016). Equipment suppliers to mining companies are becoming active innovators (Deloitte, 2016), and some significant successful innovations have recently been achieved, including autonomous vehicles and operations, IT platforms and control systems, high-volume resource characterisation and deep-sea mining (Endl et al., 2019).

3.2 Data collection

Semi-structured interviews, each lasting approximately one hour, were conducted in person or virtually (via Zoom) with senior mining practitioners who had extensive experience with innovation in the mining industry. Data saturation occurred after 25 interviews, where we did not learn anything new from the data. Participants included senior managers, middle managers, technical specialists, R&D personnel and technical service suppliers to the industry. Overall, they had an average experience of 26 years. Between them, interviewees' experience covered all phases of innovation, from idea generation through to implementation. Interviews were recorded with participants' permission, and transcripts were prepared professionally for analysis.

Our questions focused on learning about participants' involvement in the innovation processes (either as a leader or participant), with a particular focus on elements that contributed to successful and less successful outcomes. Examples of questions we used to elicit this data include: Could you give us examples of projects that involved the implementation of new technological solutions in mining you have been involved in? How was the solution implemented? What was successful? What did you learn from that? Who was/should have been involved in implementing the project? How was the need for the solution communicated with the workforce? How did the organisation manage resistance to change? Were any steps taken to ensure that the new solution is sustained (i.e., people do not go back to the old ways)? What groups of external stakeholders were/should have been engaged in that project? We also used probing questions to supplement each of these key questions to ensure we collected data that would enable us to understand the innovation process in each instance. Interviewees spoke about the strategies used and reflected on the lessons learned, in some cases for multiple projects they had been involved with. While such interviews dealing with past events can involve retrospective bias, our data gave rise to consistent themes and practices across participants, suggesting that our data were reliable.

3.3 Data analysis

The data were analysed using an abductive approach (Dubois and Gadde, 2002), drawing from the literature and interpreting the data iteratively during our analysis, as described later in this section. In this way, we did not force data to fit pre-determined categories but allowed the themes to arise from the data while taking into account existing theoretical frameworks (Glaser, 1978). The process of data analysis is described below and is also shown schematically in Figure 1.

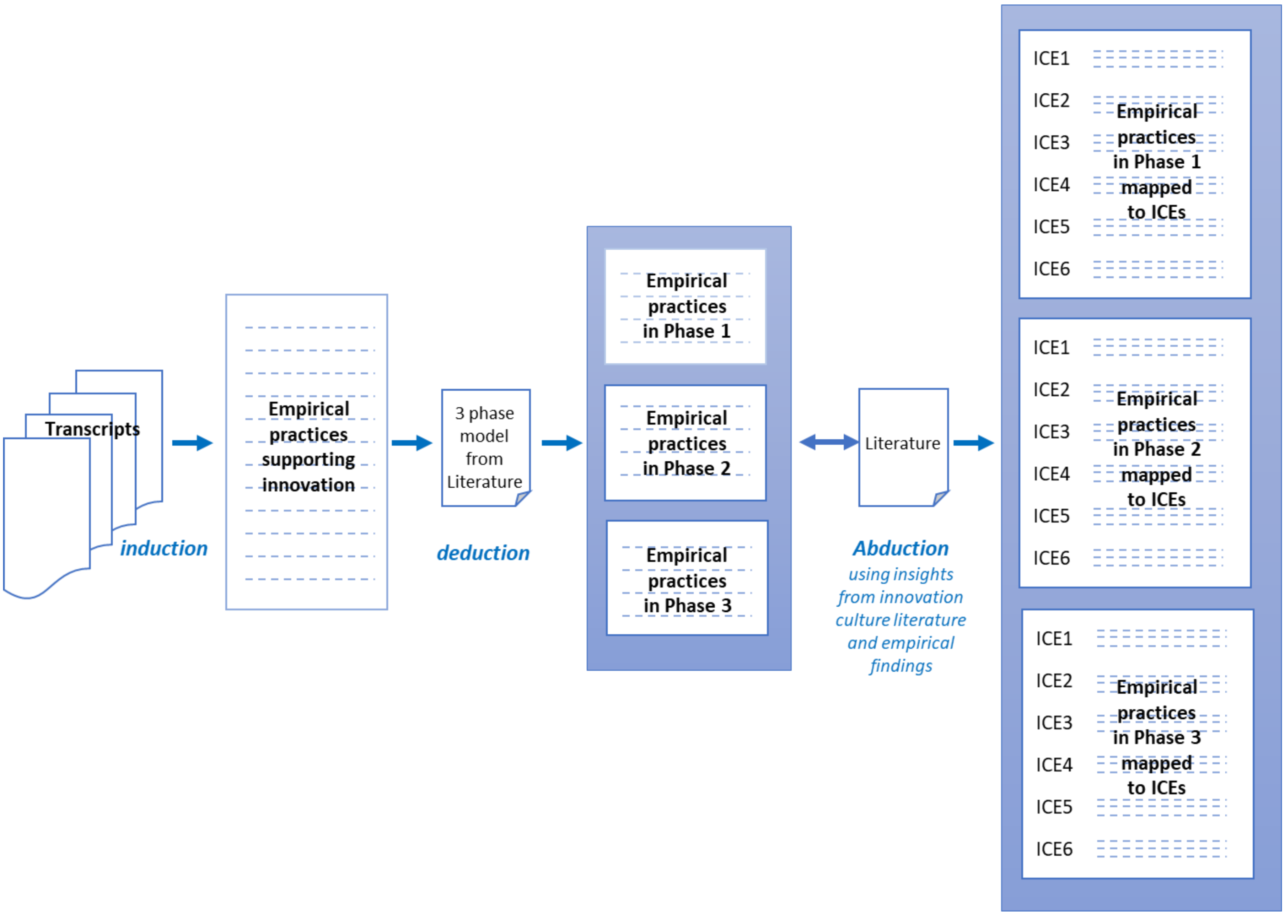

Fig. 1. The data analysis process.

We began the analysis process by thoroughly examining interview transcripts to develop a deep understanding of the data, in particular how the participants conceptualised the innovation process unfolding and the practices they used in each phase. This step involved making notes as themes emerged (Thompson and Hirschman, 1995) and drawing diagrams to capture our initial understanding of the data. This understanding was shared with the research team for further discussion and sense-making.

Next, we inductively identified the practices that supported innovation within the mining context. With the assistance of the text analysis package NVivo, we identified fragments of text relating to the activities participants had undertaken to accomplish innovation, as well as barriers and enablers to innovation they had encountered. For each text fragment, we then identified the practice that supported innovation and then operationalised the wording by incorporating relevant details of the mining context. We discussed these practices and the language used to capture the practices with the mining experts from our sponsor organisation. This process helped us to further refine the language and ensure that it is appropriate for the mining context. For example, from the text fragment:

> *You need the Head Office to say, "This is a great way to do things. We can make a whole lot more money and put our share price up," to force that all the way down; then you have got to have all the receptors open and everybody on side.*

we identified the practice:

> *Senior management visibly supports the project, and this support is propagated down through all stakeholders*.

To operationalise this practice so that it was readily understandable by mining personnel and also sufficiently specific to be useable, we worked with mining experts to identify who in a mining operation would typically undertake the action and if any existing processes would be used; we also drew on the innovation management literature to incorporate the relevant aspects of best practice. Through this process, we operationalised the practice above as:

A senior leader or project champion generates support for the decision by articulating the benefits of solving the problem and promoting the idea to stakeholders (clients and users) in ways tailored to their needs.

Table 1 illustrates this process of linking quotes from the transcripts to the corresponding practice that supports innovation and our refined wording of that practice.

Table 1

Examples of practices identified from interview data that supported the innovation process, their operationalised forms and the building block they were assigned to.

Illustrative quote from transcripts	Identified practice	Operationalised practice
We know they do it in oil and gas, you know, before mining, but probably the industry wasn't quite ready until the mid-2000s.	Watching what technology is used in similar industry sectors.	R&D staff establish contacts with global providers of technology through participating in conferences and business networks.
Previously, individual assets could be optimised and, generally, that meant a good outcome for the whole system, but it was becoming harder to make that assumption, and there was a desire to work on more holistic system integration. And it was also becoming difficult and expensive to have a lot of roles based in the Pilbara, and it was harder to get good quality people there as the assets increased…two drivers came together at that time. … there were 13 of them at any one time; probably with rostering, there was more like 50 of them. But they were all operating at single sites, so they were in a room by themselves, usually. And there was a thought that bringing them together would enable the sharing of best practice	Recognise opportunities for creating value.	R&D staff search for potentially useful technology by connecting with global providers and drawing on solutions used in similar sectors.
You need the Head Office to say, "This is a great way to do things. We can make a whole lot more money and put	Senior management visibly supports the project, and this support is propagated	A senior leader or project champion generates support for the decision by

Illustrative quote from transcripts	Identified practice	Operationalised practice
our share price up," to force that all the way down; then you have got to have all the receptors open and everybody on side.	down through all stakeholders.	articulating the benefits of solving the problem and promoting the idea to stakeholders (clients and users) in ways tailored to their needs.
You really have to explain where the value is going to come from. For a general manager they are typically interested in safety, production and cost. So, if the technology will improve one of those three things, then you will get their attention.	Staff argue convincingly for project value by demonstrating a positive impact on safety, production or cost.	The project leader or innovation champion develops a convincing, detailed business case for the proposed technology development and/or adoption using the company's business planning process.
The other really important part within the project is: the site team is part of the project. It is not something that we do to them; it's something that we do with them. They are engaged from day one.	Project managers include the site team and central staff in the innovation team.	Internal stakeholders (operators, superintendents, managers) and any external stakeholders (e.g., vendors, universities) develop the project proposal collaboratively and maintain their connections as the project progresses.
So, I think being clear about that, the expectations around ownership of information that's generated from a technology is aligned with the vendor's expectations around that; because that's kind of a fundamental point to get clear early on before you get very far down the road.	Staff working with externals discuss, clarify and agree on intellectual property conditions at the outset.	The project leader, company legal counsel and external parties agree on intellectual property conditions before the project starts, using the company's legal policies and practices.

Following on from this inductive approach to identify the practices, we then used a deductive approach to sort the practices into one of the three phases of the innovation process model identified in the literature: (1) ideating and strategising, (2) developing and piloting, and (3) implementing and embedding (Kashan et al., 2022). The clean mapping of practices to phases and the similarity of language used for the phases by participants and in the literature supported our choice of the three-phase framework to represent the innovation process in mining.

Having the list of practices assigned to the phases of the model, we then grouped them into sets reflecting ICEs. To do that, we used an abductive approach in which we iterated between the data and the literature on innovation culture. By iterating between the elements of innovation culture identified in the literature and the empirically identified practices, we found that six ICEs best mapped to the practices identified. These were openness to new ideas, opportunity recognition, new idea implementation, risk awareness, teamwork and participation in innovation ecosystems. Table 2 outlines these enablers and corresponding descriptions.

Table 2

Innovation culture enablers

Innovation culture enabler	**Description**
Openness to new ideas	The extent to which an organisation and its leaders encourage staff to consider and experiment with ideas that are outside the organisation's traditional stock of knowledge, including diverse ideas and knowledge sourced from external parties such as competitors, suppliers or research institutes.
Opportunity recognition	An organisation's ability to be aware of emerging internal and external knowledge and to identify this knowledge as relevant and potentially useful to address the organisation's challenges.
New idea implementation	The ability of an organisation to translate a new idea into a workable solution that is integrated into the organisation's 'business as usual'.
Risk awareness	The extent to which an organisation has thoroughly investigated potential risks associated with adopting a new technology, has developed strategies to ameliorate these risks where possible and, as a result, has made the considered decision to accept the residual risk and is prepared to deal with uncertainties that may arise.
Teamwork	The extent to which an organisation's multidisciplinary teams work productively together to co-create, translate and implement new ideas.
Participation in innovation ecosystems	The extent to which an organisation forms alliances with other organisations for overall mutual benefit in accomplishing innovation outcomes.

This process resulted in six groups of practices corresponding to each of the above ICEs. The outcome of these steps was a process model consisting of three phases, with each phase containing the multiple identified practices that support innovation in mining, each assigned to an ICE. The full innovation process model in mining, showing all three phases, is shown in the next section.

4. Findings

This section presents our operationalised model of innovation in the mining context. As discussed in the literature review, we used the three-phased innovation model to guide our analysis. The model comprises three phases: (1) ideating and strategising, (2) developing and piloting, and (3) implementing and embedding. Phase 1 involves scanning the internal and external environment for potential problems and opportunities, exploring ways to address these collaboratively with a range of stakeholders and proposing a tentative solution. Phase 2 involves assembling a project team in order to develop and test the solution at increasing scales. In this phase, the team progresses the development to proof of concept, liaising with key stakeholders, including users and project sponsors. The phase concludes with handing over the solution and its ownership to the operations. Phase 3 consists of communicating implementation benefits to key stakeholders, re-designing workflows and role descriptions, providing training and adjusting organisational levers to support embedding the new solution. A more detailed description of those phases can be found in Kashan et al. (2022).

In this research, we operationalised the model by assigning each of our empirically identified practices that support innovation in mining to one of the three phases of the innovation model. Being guided by the analysis of data and literature on innovation culture, we then categorised these practices into six sets of ICEs. Together, these tables of practices and ICEs for each phase comprise our operationalised process model of innovation in mining.

The practices and ICEs identified in each phase of innovation are presented in the sections below.

4.1 Phase 1: Ideating and strategising

Phase 1, ideating and strategising, describes the activities involved in the early stage of innovation in mining. This phase spans the activities that underpin the identification of a problem or an opportunity, examining options to address the problem or opportunity and developing a strong business case for action. Activities in this phase include searching for and identifying key sources of relevant knowledge within and outside the organisation, watching what other organisations are doing in related areas and identifying problems and opportunities within the company's current operations. Together these activities provide a solid foundation for the need for innovation. This early phase also includes examining and evaluating possible solutions to address the problem or pursue the opportunity. This could be from outside the company:

> *So we said, "Okay, what can we learn from other industries? And how can we bring some of the thinking from other industries into mining?"*

Or, where external knowledge wasn't available, it could be developed within the organisation:

> *So it's from the process of either identifying existing technologies that are world-class and bringing them in and applying them, or identifying a problem where we can't find existing technologies and then doing the innovation and the development of the solution, and putting that into our operations.*

To begin the process of innovation, a new proposed initiative needs to be converted into a project and approved by senior management. Participants told us that this was achieved by developing a strong, clear business case for the potential benefits:

> *At the end of the day, I do think you have got a compelling business case to get anyone interested. And the simpler you can make that, the better. So, if it is hard to make a convincing business case, it's very hard to sell something about this to anyone*.

Participants revealed that involving all the relevant stakeholders is important to ensure that all of the necessary knowledge is captured to allow full evaluation of long- and short-term value and to establish awareness of all potential risks.

Practices in Phase 1 involved multiple stakeholders, ranging from R&D staff and operation staff through to suppliers and research institute staff. These quotes demonstrate participants' experiences in engaging with a diverse group of stakeholders in the first phase of the innovation process:

> *We* [R&D] *create communities of practice across the mines…in a meeting, one site might be saying, "Look, this process is taking us* [operations staff] *six hours to do. It's just completely impractical." Another site will pipe up and say, "What are you doing? It takes us 15 minutes."*

> *One of my colleagues* [operations technical specialist] ... *attended one the conferences* [research institute attendees] ... *and he discovered this technology that was used quite effectively in other industries like the fruits/food industry…He then came back, he ran those pilots, and it came onto our radar* [operations] *as one of the technologies that we could use.*

In particular, participants stressed the importance of putting in place a project champion to motivate and align efforts from the multiple stakeholders involved:

> [Senior manager] *was personally very supportive of this project, and that was very well-known…and that was very helpful in particularly getting the middle management on board. You know, we didn't have to use it many times, but it was certainly well-understood that the project had very, very senior level sponsorship.*

Not having a project champion in place made the innovation process much more difficult, for example, regarding staff turnover:

The other thing that's happened to me a number of times that really makes it difficult is when you establish a champion on a mine site who is pushing your project or pushing a new technology, and that person leaves, and then you are back to that square one.

Next, we mapped all of the practices identified in Phase 1 to the ICEs. The 28 practices identified from the data were fairly evenly spread across the ICEs: new idea implementation (6 practices), participation in innovation ecosystems (6), openness to new ideas (5), risk awareness (5), opportunity recognition (4) and teamwork (2). This indicates the broad range of activities involved in Phase 1, in addition to the diverse range of stakeholders. While we did not expect Phase 1 to involve specific practices involving the ICE of new idea implementation in his phase as the innovation project has not yet begun, an inspection of these practices shows that they all deal with preparation for implementation in terms of how it will be achieved, who will be involved, generating support for the project and communicating its benefits. The smallest number of practices mapping to an ICE in Phase 1 was for teamwork. While teamwork was important in all phases, in Phase 1 the innovation team has not yet been established and staff are involved in either accumulating knowledge individually and sharing it in their communities of practice or are in a very specialised small group developing the proposal. The set of practices identified in Phase 1 is shown in Table 3.

Table 3

The practices supporting innovation in Phase 1 (ideating and strategising) grouped by their corresponding ICE.

Innovation culture enabler	**Practices supporting identifying and strategising phase**
ICE1: Openness to new ideas	R&D staff build and maintain strong and ongoing relationships with universities and research institutes to access and understand cutting-edge information through collaborative activities such as co-supervision of students, participation in collaborative research centres and secondments.

	R&D staff establish contacts with global providers of technology through participating in conferences and business networks. R&D staff, senior leaders and supervisors gather and evaluate information about new technical developments in the field with experts (academic and industry) by using creativity and innovation techniques such as brainstorming, systems thinking and design thinking. R&D staff identify and maintain a suite of technologies to draw on by using the company's knowledge management system. Supervisors provide opportunities for team members to voice their opinions and encourage them to share their diverse views.
ICE2: Opportunity recognition	Senior leaders engage a diverse set of stakeholders to assess external threats and opportunities and internal strengths and weaknesses by using diagnostic tools (e.g., iCAT, SWOT, PESTLE analysis). Supervisors and operators actively identify pain points in the operation and propose potential solutions by using creativity and innovation techniques such as brainstorming, systems thinking and design thinking. R&D staff search for potentially useful technology by connecting with global providers and drawing on solutions used in similar sectors. Leaders and supervisors encourage staff to maintain an open mind to possibilities by establishing an environment in which staff can discuss possibilities and voice their opinions.
ICE3: New idea implementation	Senior leaders identify a suitable leader to act as a 'project champion' by considering staff knowledge of the technical domain and their stakeholder-network connections of influence. A senior leader or project champion decides whether to develop technology internally or jointly with a vendor, university or other research institution by examining the suite of technology options available, as captured in the knowledge management system. A senior leader or project champion evaluates the practicality and feasibility of the potential solution by engaging with a diverse range of stakeholders, including developers and users. Senior leaders identify the internal stakeholders (e.g., staff, users) and external stakeholders (e.g., collaborating vendors or universities) likely to be involved in the technology development and adoption processes by leading a stakeholder mapping exercise. A senior leader or project champion generates support for the decision by articulating the benefits of solving the problem and promoting the idea to stakeholders (clients and users) in ways tailored to their needs. Senior leaders, managers and superintendents communicate how the technology implementation will affect relevant internal and external stakeholders and seek feedback from them, listen to their feedback without punishment and consider it in moving forward.

ICE4: Risk awareness	The project leader or innovation champion develops a convincing, detailed business case for the proposed technology development and/or adoption using the company's business planning process. The project leader or innovation champion develops a detailed, well-specified project plan that covers risk management, communication and stakeholder management, as well as the project schedule. The project leader or innovation champion selects a risk assessment methodology that is appropriate to the new technology, based on the extent and quality of data available, by drawing on the organisation's risk management tools and methodologies. The project leader or innovation champion values the proposed technology using a methodology that is appropriate to the extent and quality of data available, considers potential long- and short-term value and draws on the expertise of staff over a range of disciplines and experience. The project leader or innovation champion communicates project progress to each internal and external stakeholder and seeks feedback from them by drawing on available stakeholder management tools, listening to their feedback without punishment, and considering it in moving forward.
ICE5: Teamwork	Managers, superintendents, operators and R&D staff share problems and solutions, for example, by participating in communities of practice centred on key operational areas across the company. Internal stakeholders (operators, superintendents, managers) and any external stakeholders (e.g., vendors, universities) develop the project proposal collaboratively and maintain their connections as the project progresses.
ICE6: Participation in innovation ecosystems	The project leader, company legal counsel and external parties agree on intellectual property conditions before the project starts, using the company's legal policies and practices. R&D staff and technical site-based staff build and maintain long-term, trust-based relationships with each other and external stakeholders (vendors, universities, technology providers) by engaging in shared activities (e.g., conferences, trade shows, co-supervising students, collaborative research projects, secondments). The project leader or innovation champion seeks potential solutions from external providers via open innovation platforms (e.g., hackathons, crowdsourcing and competitions). Senior leaders engage a diverse set of stakeholders to assess external threats and opportunities and internal strengths and weaknesses by using diagnostic tools (e.g., iCAT, SWOT, PESTLE analysis).

The project leader and technical staff work collaboratively with vendors to identify opportunities, potential barriers and potential solutions to problems.

R&D staff, senior leaders and supervisors engage with experts in the field and academic and industry partners to gather and evaluate information about new technical developments in the field by using creativity and innovation techniques such as brainstorming, systems thinking and design thinking.

4.2 Phase 2: Developing and piloting

Phase 2, developing and piloting, describes the activities involved in the middle phase of the model of innovation in mining. These activities span developing, testing and piloting a new solution, proving the solution and preparing for implementation. As such, these activities include prototyping, exploring the viability of the solution and developing it through small-scale test work in order to prepare for a large-scale demonstration and implementation. Having a dedicated space and a project team with appropriately set key performance indicators (KPIs) to enable them to focus on the project were important aspects of Phase 2:

> *Well, I think* [Mining Company] *have done a really good thing in that they have created a trial mine. There is a mine that they can – when the innovators have something to show – they can put it in the trial mine. Now, that trial mine does not have the same KPIs as all the other mines.*

Participants commented that it is vital that the project team has the required knowledge and skills. Participants commented:

> *And as much as possible, we tried to involve the business. So, we embedded engineers and geologists in our program. So, they were embedded in our teams through our proof of concept and our prototype phases.*

> *And there's some really fundamental structural issues here. For the early-stage work, up until* [the] *completion of* [the] *pilot, there was a separation of the innovators from the operators.*

Knowledge of operations is key to ensuring that a workable innovation is developed, as is cutting-edge knowledge of the technology involved. As this phase progresses, the number of operations staff may increase, reflecting an increasing focus on operation at scale and interoperability with the existing operation, and project ownership may transition to the site of implementation. As in Phase 1, senior leadership support and the ongoing role of the project champion are critical in this phase for staff motivation, communication of progress and challenges, and to ensure project milestones are achieved and project funding is maintained:

> *Senior management support? Really strong. The Head of* [Business Unit]*…was personally very supportive of this project, and that was very well-known…and was very helpful in particularly getting the middle management on board. You know, we didn't have to use it many times, but it was certainly well-understood that the project had very, very senior level sponsorship.*

Practices of Phase 2 predominantly involved members of the development team, though the team's composition could change over time as additional members joined to bring required knowledge and skills to the project:

> *… the important thing is when you get to the second part* [Phase 2], *the nature of your stakeholders' changes and the nature of your project changes; from being a concept to a prototype to something you can implement. So, it's about stakeholder engagement in that second one, besides technically knowing what you want to do and having the right skills available to make the best decision.*

Communication officers and community liaison officers had an important role in communicating information about the project and its outcomes to other stakeholders:

> *We had a dedicated person whose job was to basically listen and communicate regularly up at site as to what was happening with our project; to enable people who*

did have concerns to voice those concerns and be heard, and I think that was important.

The set of practices identified in Phase 2 is shown in Table 4. Mapping the 20 practices identified for Phase 2 to the ICEs produced a slightly different distribution to that of the practices in Phase 1: new idea implementation (8 practices), teamwork (5), risk awareness (3), participation in innovation ecosystems (2), openness to new ideas (1) and opportunity recognition (1). While all the ICEs had associated practices, in this phase, most practices centred on new idea implementation and teamwork. The focus on new idea implementation can be understood as the team working to actualise or materialise the concept captured in the business case at increasing scale and thus different contexts (e.g., laboratory, pilot plant, demonstration site). Actualising the concept is complex and requires the coordination of multiple diverse activities and, hence, the strong emphasis on teamwork. In contrast, openness to new ideas, opportunity recognition, risk awareness and participation in innovation ecosystems have relatively few practices associated with them, reflecting that the focus that was on this type of work in Phase 1 has now shifted to actualising the ideas which formed the business case.

Table 4

The practices supporting innovation in Phase 2, developing and piloting, grouped by their corresponding ICE.

Innovation culture enabler (ICE)	**Practices supporting the developing and piloting phase**
ICE1: Openness to new ideas	The project leader, innovation champion and relevant supervisors lead by example and enable the conditions that support innovation by allowing team members to share their diverse views without punishment, considering multidisciplinary experiences, diversity and inclusiveness.
ICE2: Opportunity recognition	Leaders encourage staff to maintain an open mind to possibilities by establishing an environment in which staff can discuss possibilities and voice their opinions freely.

ICE3: New idea implementation	Senior management minimises the layers of approval and decision-making to avoid project roadblocks and to enable steady project progress. Senior leadership visibly supports the project and encourages managers and superintendents to make their support known to their staff. The project leader and relevant supervisors integrate the project tasks into project team members' individual work plans and ensure that their individual KPIs relate to the project, rather than site operations, using the company's work planning and human resources processes. The project leader and technical staff use an iterative series of propose–test–improve cycles to develop the technology, using the company's innovation process management tools (e.g., the stage-gate model) and tools to support analytical and creative processes, such as root cause analysis, brainstorming or Delphi method. The project team tests the developing technology at increasing scales (laboratory, pilot, test site) to determine the specific modifications required for the adoption operation, using the company's innovation process management tools. The project leader regularly updates the project sponsor with progress to maintain project momentum and visibility within the company. The project leader evaluates the readiness of the technology for implementation by comparing its performance against target levels written into the project plan and seeks and evaluates feedback from staff involved in its scale-up and testing. Site leadership takes over funding and responsibility for the technology-adoption project as it transitions from development to implementation to enable site processes and accountabilities to be enacted.
ICE4: Risk awareness	The project leader refines the risk assessment by incorporating knowledge generated from testing and piloting into the company's risk assessment model. The project leader encourages staff to freely voice their opinions and ideas about the development work without fear of negative consequences by putting in place appropriate motivations and protecting them from negative career consequences. Senior management ensures that risks and benefits are shared fairly between the company and any collaborating external stakeholders by engaging in legal negotiations.
ICE5: Teamwork	The project leader identifies key stakeholders in the development process (such as site staff, R&D experts and relevant external stakeholders) and adjusts the team composition as the project progresses to ensure the required skills and experience are available over the life of the project and to seamlessly integrate partners into the development processes.

	Wherever possible, the project leader negotiates with relevant managers for the temporary relocation of staff in order to co-locate the project team to allow for effective collaboration in the design and execution of the work.
	The project leader/champion holds regular cross-functional meetings to reward and recognise the project team, celebrate project wins, generate an understanding of project benefits and progress, and motivate support for the project.
	Project team members ensure the ongoing connection between the problem and the developing technology by engaging in ongoing mutual questioning and listening.
	Senior management enables job rotation for key staff who will be impacted by the technology to help break down work 'silos' and disseminate understanding of the new technology and its implications for the operation.
ICE6: Participation in innovation ecosystems	Senior management involves external stakeholders (e.g., vendors, universities), R&D staff and site staff in the project team as required as the project progresses to ensure the required skills and experience are available to the project.
	Wherever possible, the project leader negotiates with relevant managers for the temporary relocation of staff in order to co-locate the project team to allow for effective collaboration in the design and execution of the work.

4.3 Phase 3: Implementing and embedding

Phase 3, implementing and embedding, describes the activities involved in the final stage of innovation in mining. This phase includes transitioning to new operations, new routine production and scaling out the innovation to other sites. Participants stated that a critical factor in successful implementation was senior management allocating dedicated staff to the implementation and ensuring that their KPIs focused on that implementation only and that they received the necessary training:

> *There was a special project team, and we had a person come out of their role to lead the whole implementation process, and we had a special building project manager.*

So, if there was a delay for a week, no one worried, so removing production pressure. And because the people involved in it needed to be relieved from that production pressure, we changed their KPIs.

Successful implementation involves managers adjusting organisational levers to ensure optimised operation, including incentive structures and measures to ameliorate the effect of staff turnover, such as job rotation and ongoing training:

So, one thing is understanding the value of the impact; and the other one is making it part of one's routine, sort of work…the science was there to deliver all this new information, but the practical workflows weren't there to actually use it in an operational sense.

…have seen a great number of projects that get implemented and run for maybe six months and then abandoned and never used ever again…the critical reason is that you have a really high turnover of staff in Operations. If you, I only train one or two people in how to operate a piece of instrumentation – especially a piece of instrumentation that's not used anywhere else in the world – as soon as those people move on, no one knows how to use it; no one knows what it does. It just gets switched off, and all that money and time and all those benefits are gone.

Once the new technology is operating successfully and its associated processes and practices have been incorporated into organisational routines, senior management and R&D may identify an opportunity for other operations to benefit from the technology:

Another thing that can really help is if you share the project across the whole portfolio. You talk about it with other sites and try and build some excitement about it. And that has two effects. It gets them interested, and they start to pull for the technology, and you are also advocating the good work at that original site.

There's a competition between the operations. If they see an operation jump ahead, "How they have done it? What are they doing?"

As with Phases 1 and 2, the support of senior management and an effective project champion are critical to implementation success. Phase 3 practices mostly involve operational staff, in line with a focus on implementation activities:

> *I think it's important that you get your people* [supplier] *as close to the work and the teams impacting* [sic] *as possible because then you become part of the team. That would be a really important take-away for me.*

However, R&D staff and other external agents who were part of the development team were also involved but in a lesser capacity than in previous phases. Again, communication officers and community liaison officers were important, and indeed their roles ramped up to match the increased scale of the work in Phase 3:

> *If you are in Phase 2 and about to go into Phase 3…you need to know who your key stakeholders are; you need to know how they are a stakeholder; you need to know how this technology will change their lives; you need to make sure that they are advocates of that change, they won't resist that change, so that when it comes to implement, they adopt the change.*

The set of practices identified in Phase 3 is shown in Table 5. We identified 14 practices for Phase 3. The practices were distributed between the ICEs in a similar way to those in Phase 2 and, as with Phase 2, were significantly different to those in Phase 1. The Phase 3 practices were distributed as follows: new idea implementation (8 practices), teamwork (2), openness to new ideas (1), opportunity recognition (1), risk awareness (1) and participation in innovation ecosystems (1). In this phase, there was a clear focus on the implementation and the practices involved, ensuring the success of the implementation team's work, such as enabling the team to focus on completing the project by assigning them the necessary resources and implementation-related KPIs and assessing the project's progress to ensure that it achieves its targets. Other practices mapping to the new idea implementation involve ensuring that operations staff are encouraged to use the new technology through motivation, compliance, training, clear roles and work plans. The other practices, which mapped to the other ICEs, support these practices mapped to new idea implementation ICE. For example, the practice mapping to risk awareness concerns meeting the project target, the practices mapping to teamwork relate to communication of project outputs to encourage sustainable staff use by reward and reinforcement. The practice mapping to openness to new ideas concerns staff being open to observing feedback from the implementation process, while the opportunity recognition practice concerns identifying potential specific additional benefits from the innovation, compared with those practices in Phase 1 mapping to this ICE (which concerned identifying overall opportunities for innovation in general). Finally, the practice mapping to the participation in innovation ecosystems ICE relates to maintaining relationships in the specific innovation ecosystem that enabled this implementation.

Table 5

The practices supporting innovation in Phase 3, implementing and embedding, grouped by their corresponding ICE.

Innovation culture enabler (ICE)	**Practices supporting implementing and embedding phase**
ICE1: Openness to new ideas	Project leaders, innovation champions and relevant supervisors lead by example and enable the conditions that support technology implementation by allowing team members to share their diverse views without punishment, considering multidisciplinary experiences, diversity and inclusiveness.
ICE2: Opportunity recognition	Senior leadership promotes the initial adoption site as a demonstration site of possibilities for other operations within the company by sharing wins through the company's communication network.
ICE3: New idea implementation	The site, through the project champion, now funds, leads and is accountable for the technology implementation and communicates the business reasons for the implementation, including negative consequences of not doing so, to site staff.
	Senior leadership enables the implementation team to focus on the new technology implementation by revising their KPIs to solely reflect the implementation.

	The project leader, endorsed by senior leadership, adjusts staff and resources to the new operations by allocating dedicated support staff to the project team (e.g., human resources, communications, change management) and providing the required training to staff to be able to undertake their new roles. Managers adjust the role descriptions, work plans, guidelines and procedures of their staff, setting out for each individual the implications of the new technology. In so doing, managers need to anticipate any possible negative consequences for staff and advise them as soon as possible so that the managers can discuss options with the staff, such as retraining or reassignment to other roles. Senior site leadership adjusts organisational levers to ensure the ongoing success of the implemented technology by revising the incentive structure, capturing new knowledge, revising organisation strategies, retaining skills through job sharing to combat staff turnover, building support for the new technology with their prospective successors and embedding training in the new technology in staff inductions. Managers reinforce the new practices and discourage opposing views by rewarding implementation performance and offering constructive feedback. Site management assesses the performance of the implemented technology against target levels and seeks feedback from operations staff about the technology's utility as implemented and ideas to reap further benefits from it or to address any issues that have emerged. Managers encourage staff to engage in continuous evaluation and improvement of the embedded technology and to capture those insights in the company knowledge management system. This can be done by seeking feedback on how the implemented technology is performing over time and capturing lessons learned from the process.
ICE4: Risk awareness	The project leader checks the performance of the implemented technology (the new routine process) against the safety, production and cost expectations specified in the business case (e.g., by monitoring variances from the project plan).
ICE5: Teamwork	The site leadership holds regular cross-functional meetings to reinforce, reward and recognise staff for embedding and using the new technology in their operational routines. The site leadership ensures the sustainability of the embedded technology by providing users with sufficient operational experience with the new technology by working closely with the implementation team while they are still on site and through job rotation, secondments, etc.
ICE6: Participation in innovation ecosystems	The site leadership ensures that operational staff maintain contact with external technical experts to enable future continuous improvement of the embedded technology through regular catch-up meetings about the ongoing performance of the technology.

In this section, we have presented our operationalised form of the process model of innovation in mining. This form comprises a set of practices that support innovation in mining in each of the three phases of the innovation process: ideating and strategising, developing and piloting, and implementing and embedding. Each practice has been mapped to its corresponding ICE and has been phrased in mining language. The utility of the model has been further enhanced by specifying who typically undertakes these practices and which company processes may be involved, wherever possible.

5. Discussion

This study set out to operationalise a process model of innovation for the mining industry. Most research on the innovation process is at the organisational level (Bogers et al., 2017; West et al., 2014). These process models are often not context-specific, providing limited insights into the micro-foundations of innovation and the role of individuals and teams in innovation. Our study makes an important contribution to this body of knowledge by identifying specific, actionable practices that mining organisations can adopt to effectively identify, develop and implement innovations.

The study makes three novel contributions to the theory and practice of innovation. First, we contribute to theory and practice by presenting the actionable process model of innovation operationalised for mining and validated with the study's participants. This is the first model to be developed that takes into account the unique mining context and is framed at the level of individual practitioners. These unique features of the model contribute to practice by enabling it to be readily engaged with and taken up by mining practitioners. Second, we contribute to the theorisation of the innovation process by showing that successful innovation requires the involvement of multiple types of stakeholders in each phase of development and that the mix of stakeholder types varies across the innovation phases. This is the first time to our knowledge that the pervasive, ongoing roles of multiple stakeholder types in each phase of the innovation process have been articulated. Our third contribution is to further extend the theorisation of innovation by showing that the innovation practices identified from the data are associated with six ICEs, which vary in importance in each phase of the innovation process. We now discuss these contributions before commenting on limitations and future research opportunities.

5.1 Operationalising a process model for innovation

Our research contributes to the literature on innovation processes (Hobday, 2005; Hansen and Birkenshaw, 2007) by operationalising an innovation process model and identifying specific individual- and team-level practices that mining organisations can implement to ensure more successful innovation adoption outcomes. Existing innovation processes are developed and explored at the organisational level (Bogers et al., 2017; Crossin and Apaydin, 2010; West et al., 2014), which limits insights into the role of individuals in innovation. Further, the effectiveness of a firm's innovation depends on how effectively individuals carry out their roles in that strategy, yet relatively little is known about how individuals respond to the challenges involved (Bogers et al., 2017). Our study explored innovation at the level of the individuals charged with carrying out the work of innovation. We identified specific actions of agents undertaking innovation work in the context of mining, hence contributing to a better understanding of the role of practitioners in the innovation process. We therefore responded to Crossan and Apaydin's (2010) call for a theory of innovation that connects individual actions with management theory by understanding the role of practitioners.

By drawing on the empirical data and insights from the innovation and innovation culture literature, we developed an actionable model of innovation, specifically tailored to the context of mining. We based the model's structure on the three-phase model of the innovation process and empirically identified practices that innovation practitioners had used successfully to support their innovation initiatives. Using insights from the interview data and consultations with mining experts, we then framed the practices in the language of the mining industry such that mining personnel could readily recognise their context and the familiar activities in those practices. The model thus engaged our participants at the level of their everyday experience and provided much needed specific support to mining personnel not currently available from the generalised models in the innovation literature. We argue that we achieved this operationalisation of the model based on its validation with our participants. This choice of structure fitted well with how participants conceptualised the innovation process, as evidenced by how readily the set of practices we identified mapped onto the three-phase framework and its validation by our participants.

5.2 The changing mix of stakeholders as the innovation process unfolds

Our research contributes to the innovation management literature by providing insights into the types of stakeholders involved in each phase of the innovation process. Existing research asserts that in the initial phase of the innovation project, it is useful to engage a broad range of stakeholders to gather diverse viewpoints (Giezen et al., 2015). The general models of innovation available in the literature have only recently begun exploring the role of multiple agent involvement in the innovation process (Kazadi et al., 2016) and theorising the process of stakeholders' engagement in the innovation process (Gould, 2012). Our study contributes to this research by identifying typical stakeholder groups involved in mining innovation projects in each phase and, in so doing, shows that multiple stakeholders are involved in all the innovation phases, as evidenced by the suite of practices identified for each phase. This finding demonstrates the reality of innovation work in mining: it involves multiple stakeholders at each stage; therefore, practitioners need to be aware of this and proactively manage their innovation activities accordingly by paying attention to social aspects of innovation as well as the more obvious technological aspects.

Our research further reveals the dynamic nature of stakeholders' involvement in the innovation process. Existing research on stakeholders' involvement in the innovation process is currently scattered and focuses on specific groups of stakeholders, for example, users (Bjørkquist et al., 2015). There is also some research focusing on the process of identifying relevant stakeholders in the context of innovation projects (Vos and Achterkamp, 2006), but that research does not explore specific practices that underpin such involvement. Our research builds on these studies by identifying relevant groups of stakeholders and proposing practices for their involvement in each phase of the innovation process in the context of mining innovations. Inspection of the practices identified in this study shows that the practices assigned to Phase 1 are predominantly exploratory. This is in marked contrast to Phases 2 and 3, where the majority of practices are exploitative. While the practices assigned to Phase 1 are distributed more or less evenly between the ICEs, illustrating the diversity and exploratory nature of the work in this early phase, those in Phases 2 and 3 are predominantly in the ICEs of new idea implementation, teamwork and risk awareness. The concentration of practices in these areas reflects the focus in these phases on realising a solution – that is, exploitative work – rather than generating potential options. The different nature of practices in each phase suggests that a different mix of stakeholders is involved in each phase. Our findings demonstrated that the biggest difference in this mix of stakeholders is between those involved in Phase 1 and those involved in Phases 2 and 3. Inspection of the practices mapped in Phase 1 revealed the involvement of a number of stakeholders, including R&D staff, academics, students, technology providers, senior leaders, operations supervisors, users of the new technology, developers and clients. This broad range of stakeholders enables the important exploratory function of Phase 1. The participation of operational staff in this very early phase as the ultimate users of the innovation enables co-creation with other team members of potential solutions appropriate to the context of ultimate use that set the trajectory of innovation efforts. Phase 2 practices predominantly involve members of the development team – itself a multidisciplinary team comprised of internal and external participants. The formation of a team is possible following the definition of scope in the business case at the end of Phase 1. Phase 2 requires focus (exploitation of the solution proposed in Phase 1) but also exploration, as the proposed solution needs to be developed, scaled and proved prior to implementation. The mix of stakeholders in Phase 2 is different from Phase 1 in that there is a well-defined team that persists over Phase 2 though additional stakeholders may be brought in as the development requires. The balance between exploration and exploitation needed in Phase 2 is accomplished through the project team's multidisciplinary nature. In Phase 3, the focus is on implementation, so most stakeholders are operations staff, with handovers from the development team. This dominance of operational stakeholders enables the high degree of practical focus and achievement required for successful implementation. In this way, by identifying the practices that support innovation in each phase, we were able to identify the stakeholders involved in each stage and show that the mix of stakeholders changes as the innovation process unfolds. Looking back at the practices in each phase, we note that there is a constant foundation of practices across the phases relating to communication, teamwork and the support of a champion. Therefore, we suggest that the stakeholders participating in these practices need to be involved in every phase.

5.3 Relative importance of innovation culture enablers over the innovation process

Findings from our research contribute to the literature on innovation management and innovation culture (Rao and Weintraub, 2013) and, more specifically, innovation culture in mining (Kashan et al., 2021) by showing that the innovation practices identified from the data are associated with six ICEs, which we identified abductively as (1) openness to new ideas, (2) opportunity recognition, (3) new idea implementation, (4) risk awareness, (5) teamwork and (6) participation in innovation ecosystems, and were present across the three phases of the innovation process but varied in their importance.

In line with the exploratory, qualitative nature of this work, we cannot quantitatively compare practices across the phases; however, a high-level comparison between the number of practices supporting each ICE across the phases shows the relative importance of each ICE change over the innovation process. For example, practices supporting ICE6 (participation in the innovation ecosystem), ICE1 (openness to new ideas) and ICE2 (opportunity recognition) were the most prevalent in Phase 1 of the innovation process, compared to Phases 2 and 3, which focused predominantly on practices supporting ICE3 (new idea implementation). This further confirms our proposition that Phase 1 practices are mostly exploratory in nature, while practices underpinning Phases 2 and 3 focus mostly on exploitation and only to some extend on exploration.

In Phase 3, implementing and embedding, participants reported many more practices that mapped to ICE3 (new idea implementation) than practices mapping to other ICEs, leading us to conclude that practices supporting new idea implementation dominate innovation activities in this phase. This is consistent with the overarching purpose of Phase 3: to bring the innovation into operation (Kashan et al., 2022). In contrast, in Phase 1, ideating and strategising, there is a more even distribution of practices among the ICEs, with the fewest practices mapping to the teamwork ICE. This observation is consistent with the nature of Phase 1 activities, which tend to involve divergent thinking and draw on knowledge from multiple sources outside the project team (Kashan et al., 2022). Phase 2, developing and piloting, showed practices of ICE3 (new idea implementation) and ICE5 (teamwork) dominating. This is consistent with the nature of Phase 2 work, which involves translating information and ideas into physical operation (Kashan et al., 2022), and its emphasis on assembling a multidisciplinary team that brings together the necessary types of knowledge and experience. Innovation teams in Phase 2 may be recently assembled and facing unknown challenges, so team members need to rely heavily on each other, necessitating strong teamwork practices. In fact, more practices relating to teamwork were identified in Phase 2, developing and piloting, than in either of the other phases.

Further examination of the practices mapping to the ICEs for each phase of the innovation process also shows some features of use to innovation practitioners. Overall, practices supporting the ICE of new idea implementation featured most prominently in all phases of innovation. Those practices supporting the ICEs of openness to new ideas, opportunity recognition, risk awareness and participation in the innovation ecosystem are most important in Phase 1, with their emphasis declining in Phases 2 and 3, in line with the different nature of Phases 2 and 3 compared with Phase 1. Interestingly, while risk is important throughout the innovation process, our data showed that risk awareness was most supported by practices in Phase 1, decreasing through Phases 2 and 3. The reason could be that the innovation process moves from mostly unknown risks in Phase 1 (due to the novelty of the idea and the solution being explored) to mostly known risks in Phases 2 and 3 (where the solution has been tested and de-risked for implementation).

Overall findings from our research allow us to extend our theorisation of innovation to the level of the individual actions required to support innovation success, which, to our knowledge, has not yet been reported. We suggest that these findings can also be used to guide managerial priorities and resource allocation during each phase of innovation, using our innovation process model for mining as a guide or checklist.

5.4 Limitations and future research

While the model presented is not meant to be prescriptive, it can support project leaders and senior leaders to raise awareness of what is required for successful innovation in mining, as was suggested by participants as part of their feedback. The ICEs we identified can also be used by practitioners as a short checklist to support them as they plan for and execute innovation activities. While it makes significant contributions to theory and practice, the study does have some limitations. First, we deliberately focused on the mining industry, so the findings here may not be generalisable to other industries, though we expect that the findings will be relevant to similar industries. Second, the study was based on a moderate number of interviews due to the practical challenges associated with identifying senior mining personnel willing to participate in a research study. However, each interview was conducted in significant depth, and we reached saturation in the themes that emerged from the data.

Future research could develop a more detailed model for specific parts of the innovation process, such as for a specialised area of mining, or at a specific level of innovation activities, such as innovation ecosystem practices to capture the perspectives of external collaborators and the specific practices that support innovation ecosystem activities. Additional research could examine the different phases of a particular activity in more detail, such as the activities and the stakeholders involved in developing a sound business case in the formation phase of an innovation project. Further research could usefully examine how practitioners successfully assess risk in an innovation project involving an unknown technology. Finally, further research could use the methodology presented here to operationalise a model of innovation for another industry sector.

6. Conclusions

In this study, we present a set of practices for agents and decision-makers undertaking innovation work in the context of mining. The study operationalises and contextualises an existing model of innovation consisting of three phases – ideating and strategising, developing and piloting, and implementing and embedding (Kashan et al., 2022) – to enable ready take-up and use by mining professionals. We enhanced the model by identifying practices that individuals and teams can use to support ideation, development and implementation of innovative solutions. We did so by drawing on data collected from interviews with experienced mining professionals and consulting with mining experts. Furthermore, by drawing from the literature on innovation culture and our empirical data, we abductively identified ICEs and mapped these to the practices for each phase. Our research revealed the need for involving multiple types of stakeholders and proposed specific practices for their involvement in different phases of the innovation process. The identified practices that mapped onto the model of innovation can be directly used to support mining practitioners in their innovation projects.

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