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ORIGINAL PAPER

Mining 4.0 and its effects on work environment, competence, organisation and society – a scoping review

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Abstract

The mining industry is facing a technological shift with Industry 4.0 creating new conditions for mining. This is often referred to as Mining 4.0. To succeed through the technological shift, the industry need to handle several challenges wisely, such as how to utilise the new digital technology to promote sustainable work environments, how to recruit skilled workers to the industry, and how to manage organisational challenges as a result of the technological shift. This scoping literature review examines a large field of literature on how Mining 4.0 might affect the mining industry in areas such as work environment, competences, organisation and society, and what can be done to promote sustainability going forward. The paper also identifies several areas that have not been explored in previous research. These include empirical studies on the effects of the technological shift brought about by Mining 4.0 on work environments, and how to attract younger generations to mining to ensure sustainability in the industry going forward.

Keywords Digitalisation · Mining 4.0 · Work-environment · Competence · Organisation · Society

Introduction

The mining industry is facing a technological shift brought by Industry 4.0 (Kagermann et al. 2013), where digitisation and automation are creating new conditions for future mining production. This is often referred to as Mining 4.0 (Lööw et al. 2019; Bongaerts 2020). To succeed through this transition, mining companies need to be able to deal with several challenges, such as: how to recruit skilled workers that are interested in working in an industry which is not always perceived as attractive; how to utilise the digital technology to promote sustainable work environments based on human factors; and how to handle organisational challenges as a result of Mining 4.0. The concept of Industry 5.0 (see (European Commission 2021) started to gain attention in discussions outside of the mining industry. The difference between Industry 4.0 and Industry 5.0 is that the latter places greater emphasis on human factors, and the integration and interaction between the technological solutions developed during Industry 4.0 and humans. In this study, we investigate the readiness of the mining industry to move towards a Mining 4.0 context that is consistent with the increased attention to human factors that come with a shift towards Industry 5.0.

This paper is an international scoping literature review of how Mining 4.0 might affect the work environment, competences, organisation and society. It investigates what the effects of Mining 4.0 are on the work environment, competences, organisation and society, as well as what can be done to encourage more sustainable development.

The paper examines publications concerning the mining industry and mining companies, their exposure to concepts such as Industry 4.0 and 5.0, digitalisation and automation, and how this exposure affects outcomes such as competences, work organisation and work environment. The paper begins with a description of the methodology and after that we

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present the results. The results section starts with a general introduction and is then divided into four sub-sections. Each sub-section opens with a general introduction to the theme based on previously known literature in order to contextualise the results. The paper then discusses the results, which indicate that there is a knowledge gap about the potential effects of Mining 4.0 on the mining industry. We finally present several areas where future research is needed to fill this gap.

Methods

This scoping literature review is based on a search performed in the academic database Scopus. The search string was constructed according to the PEO approach (population, exposure, outcome) to identify literature on how the mining industry's technological shift may affect the work environment, skills, organisation and society. The PEO approach is a systematic method for constructing search strings. In this case, how the mining industry (population), is exposed to digitalisation and automation (exposure), which has certain effects on competence, work organisation and work environment (outcome). Table 1 summarises the constituent concepts and how they were operationalised into search strings. The final search string was: `(TITLE-ABS-KEY ( "industry 5.0" OR "industry 4.0" OR digitali?ation OR automation ) AND TITLE-ABS-KEY ( "mining industr*" OR "mining compan*" ) AND TITLE-ABS-KEY ( competenc* OR skill* OR abilit* OR aptitud* OR "work environment" OR "work organi?ation" OR ergonomic OR "human factors" ) ).`

The search was conducted on 20 October 2022 and yielded 79 items. These publications were divided up between the four authors who followed the following process. First, a rough screening was made based on the abstract and whether the publication corresponded to the purpose of this paper. Publications that focused on coal mines and the Asian mining industry were excluded. In addition, any publications not written in either English or Swedish were excluded. Those items that remained after the rough thinning were read in full text. The authors then met to discuss the thinning process to ensure that it was done according to the same criteria. Thinning was performed based on relevance to the search string, in particular, the outcome component. For instance, articles that only focused on technology and completely ignored work environment, organisation or competence were excluded. In the end, 24 articles were included in the literature review. Summaries of these articles were written and their results were then sorted into the categories: work environment, competences, organisation and society.

To provide a better contextual understanding, the results section has been supplemented with knowledge from previ-

Table 1 Concepts and search strings per the PEO approach

Population		Exposure		Outcome	
Concept	Search	Concept	Search	Concept	Search
Mining industry	mining industr*, mining compan*	Industry 4/5.0	industry 4.0, industry 5.0	Competence	competenc*, skill*, abilit*, aptitud*
		Digitali- sation	digitali?ation		
		Autom- ation	automation		
				Work organisation	work organi?ation
				Work environment	work environment, ergonomic, human factors

ously known literature from the authors' personal libraries. These contextual articles are not mixed in with the text presenting the findings from the literature search. They instead serve as an introduction to each of the themes identified. Articles that were referenced in the literature search have also been included in these sections.

Results

This section presents the results of the literature review. The results are divided into four different areas: work environment, competences, organisation and society. Each section begins with an overarching contextual understanding based on previously known research. After the initial overview, the results of this literature review are presented.

As mentioned at the beginning, the mining industry is facing extensive technological changes. These technological changes are partly a result of new technology and what is usually referred to as Industry 4.0, and partly due to the new environmental requirements in the Paris Agreement (UNFCCC 2015). Industry 4.0 is a concept that encompasses the entire industrial sector and is largely based on the development of digitalisation and connected systems. When the concept is applied to the mining industry, it is sometimes referred to as Mining 4.0 (Lööw et al. 2019).

Industry 4.0 is considered to have had a major impact on the mining industry and some of the new technologies being developed and implemented in the mining industry are automation, robots, remote control (Holcombe and Kemp 2019) and digitalisation (Young and Rogers 2019). These technological changes are bringing about changes in both mining and work (Holcombe and Kemp 2019) which can have organisational implications, such as moving underground work above ground. Such changes can lead to changes in norms and values, such as an increased number of female employees and a less prominent macho culture (Abrahamsson and Johansson 2021). It is also possible that technological changes can increase inclusion for people with certain disabilities. Technological developments are also changing the nature of the work. In addition to the fact that the mines of the future will need less staffing because of automation and digitalisation, the nature of the work will change for those who remain (Abrahamsson et al. 2009). New roles are likely to emerge with work that is more focused on a maintenance-and-service profession rather than direct production work. Some authors believe that the organisational structure of mining companies will gradually become flatter, and 'multi-skilled' workers will be able to operate in most parts of the organisation (Bassan et al. 2008).

Digital technology is not in itself a new phenomenon for the mining industry. For example, 'information technology' has been discussed as a strategic tool for increased production since the early 1990s (Connell 1993), and much has happened since then. The transformation that we have seen in recent years in Europe, in the form of digitalisation and automation, is only the beginning of the revolution necessary to achieve environmentally, economically and socially sustainable development (Herbert and Hidalgo 2021). Today, we are starting to see the effects of these predictions as the technology slowly begins to be implemented. However, we have not yet seen the work-related effects of these changes.

Work environment

Technological advancements will have a dramatic impact on work and workplace design. There is a broad consensus among researchers that digitalisation and new technology have the potential to create attractive workplaces that can help recruit the skilled labour that the industry needs (Kagermann et al. 2013). However, this will most likely not happen by itself, and continuous work environment management will therefore be needed to steer progress towards a healthy work environment. New technology can bring about improvements in work environments such as reduced physical or cognitive strain for operators (Li et al. 2016; Romero et al. 2016; Rabelo et al. 2018). This is of course a good thing, but some authors (Lööw et al. 2019) argue that the consequences of these changes need to be discussed in a larger context. For example, work containing too little physical and cognitive stimulation is not something to strive for Hägg et al. (2009), and if a work task in a production flow is eliminated, it can lead to consequential effects elsewhere and for someone else in the workflow. From an occupational health and safety perspective, digitalisation and new technologies can be seen as an opportunity to create attractive workplaces and not as an end in themselves.

To understand how new technology can be used to create attractive workplaces, we start by discussing what is generally described as a good work environment and attractive jobs. Knowledge of what characterises a good work environment is both comprehensive and robust and has large elements of interdisciplinarity (see (Karasek and Theorell 2009); Thylefors (2008); Johansson and Abrahamsson (2009)). Abrahamsson and Johansson (2013) have summarised the knowledge as follows:

> *In a good work environment, not only are physical risks and problems eliminated, and equipment and work sites are adapted to suit people's different physical and psychological make-up and designed to make work easier, but employees also enjoy autonomy and a sense of participation and influence in matters both large and small. These involve being able to influence the division of duties and the pace and method of working, in relation to both other people and to the technical system used. In*

a good working environment, work provides physical, intellectual and cultural stimulation, variety, opportunities for social interactions, context, and opportunities for learning and for personal and professional development. Here, workloads, demands, and challenges (both physical and psychological) are balanced at a reasonable level. The workplace is also characterised by gender equality, fairness, respect, trust, democratic leadership, and open communication and offers good opportunities for enjoyment and social support. There should also be good opportunities to combine work with a rich and sustainable life outside of work (Abrahamsson and Johansson, 2013, pp. 2-3).

Technological developments in the mining industry are as old as mining is itself. However, the mining industry has been more conservative in comparison to the engineering industry, and the changes have been slower and more incremental (Backblom et al. 2010) than described in the literature regarding the digital transition (Kagermann et al. 2013; Lasi et al. 2014; Zhou et al. 2015; De Mauro et al. 2016; Liao et al. 2017; Masoni et al. 2017; Xu et al. 2018; Ghobakhloo 2018). The digital transformation of the mining industry can be described as a gradual modernisation of technical systems, where various work tasks are automated, mechanised and robotised in combination with increased opportunities for monitoring and control of the production process.

Human factors in technology development for improved work environments

Our literature search found nine articles that deal with the work environment in the mining industry, see Table 2. We summarise these below.

Mining is seen as dirty and dangerous work, often in a male-dominated environment in remote locations (Johansson et al. 2018; Johansson and Johansson 2014). However, technological advances can have positive effects on the work environment (Lööw et al. 2019). The working environment in the modern mining industry has improved (Johansson et al. 2018). However, work in mining is still characterised by many monotonous tasks in dark environments for long periods of time. Mines are also expected to become deeper and more remote in the future. Deeper mines entail new challenges that can affect the work environment, for example in the form of higher temperatures, increased rock stresses and longer transportation (Johansson and Johansson 2014).

There are several health problems are associated with mining. Ranjan and Zhao (2020) show that work-related musculoskeletal workloads are among the most common problems in U.S. mining companies. The parts of the body that are most commonly affected are the back, followed by the knees and shoulders. Furthermore, it is mainly older underground workers who develop musculoskeletal problems, although some young people are also affected. Bauerle et al. (2022) show that fatigue is another common health problem and refer to research that shows that improvements in light conditions are important factors to counteract fatigue. In a knowledge overview, Smith and Sepasgozar (2022) write that mental illness is a major problem in the Australian mining industry. This problem should be considered in the context of Mining 4.0. As pointed out by Johansson et al. (2018), contractors are a common element of the mining industry and previous research shows that a greater proportion of contractors increases the risk of accidents. In addition to contractors, sub-contractors are also common, which can complicate communication and create a 'we-them' culture that could have a negative impact on safety.

Digitalisation and automation are common themes in mining. Pukkila and Särkkä (2000) report an early Finnish attempt called 'The Intelligent Mine Technology Program' that started back in 1992. The program was visionary and used new communication and information technology to compute planning and control of mining. The program also focused on automation of production to achieve increased productivity and safety. The program was ground-breaking but could not be realised in a single mine alone and was therefore tested in parts of different mines. The program was never implemented in its entirety but in a subsequent study, Pukkila (1999) shows that motivated operators have a lower risk of accidents. Johansson et al. (2018) argue that technological development has led to increased safety and a reduction in the number of accidents by distancing miners from the physical work in the mine to monitoring in control rooms. Mechanisation, automation and work in control rooms can also lead to fewer musculoskeletal injuries and greater opportunities for recovery periods.

The mining industry has an aging workforce and simultaneously has difficulties in recruiting younger people who are not usually interested in working in the mining industry (Johansson et al. 2018). Mines are often located in remote locations, which makes recruitment more difficult. The supply of new staff in the area is limited and potential employees often lack the qualifications required to work with the new technology (Johansson and Johansson 2014). To address this problem, Johansson et al. (2018) advocate a holistic perspective whereby people, technology and the organisation interact in better ways to foster attractive workplaces that also attract younger people to work in the mining industry. This perspective is supported by Campbell (2016) who emphasises the importance of including human factors in the design of modern control rooms for mining. Campbell argues that as technology becomes more advanced, the focus on each technological element operating at maximum efficiency tends to shift to a holistic perspective, which takes the role of humans into consideration.

Table 2 Overview of articles identified under the work environment theme

Author	Title
Bauerle et al. (2022)	The human factors of mineworker fatigue: An overview on prevalence, mitigation, and what's next
Campbell (2016)	ABB a Modern Control Room - Human Factors and Their Impact on Plant Safety and Optimization
Johansson and Johansson (2014)	'The new attractive mine': 36 research areas for attractive workplaces in future deep metal mining
Johansson et al. (2018)	Attracting young people to the mining industry: six recommendations
Lööw et al. (2019)	Mining 4.0–the Impact of New Technology from a Work Place Perspective
Pukkila (1999)	Implementation of Mine Automation: The Importance of Work Safety and Motivation
Pukkila and Särkkä (2000)	Intelligent mine technology program and its implementation
Ranjan and Zhao (2020)	Prevalence of Musculoskeletal Disorders and its Impact on Lost Production Days among Industrial Workers: A Data Analytics Approach
Smith and Sepasgozar (2022)	Governance, Standards and Regulation: What Construction and Mining Need to Commit to Industry 4.0

Lööw et al. (2019) expand on this by adding that while a mine must make a profit if it is to survive amongst international competition, the economic result must also be weighed against other success criteria, such as social factors. This can be done by creating a flat organisation based on socio-technology, which according to the authors, promotes employee creativity and empowerment. Campbell (2016) clarifies that factors such as distraction, fatigue, stress, situational awareness and reaction times can have an adverse effect on production and the work environment and should therefore be considered when designing control rooms in particular. Campbell believes that a including human factors in the design of the control rooms could attract the younger 'gaming' generation. This generation has grown up with digital technology, which is positive from the perspective of production. A work environment that is designed according to these factors could encourage the younger generation to stay in the mining industry.

Johansson et al. (2018) draw attention to the fact that employees want to feel proud of their work and their employer. Mining companies must therefore establish a vision and core values that can strengthen the employees' sense of pride. Furthermore, mining companies need to change negative workplace cultures, such as the macho-masculine image that sometimes characterises the mining industry. This could help attract women to the mining industry. Johansson et al. (2018) add that a poor psychosocial work environment can lead to impaired quality of life, commitment and stamina. The positive impact of technological development on the work environment is often cited as an argument to justify large investments in technology. Johansson et al. (2018) stress that new technology has the potential to solve many problems, but not all of them.

There is great variety in the visions and predictions about the future of the mining industry. In conclusion, previous research indicates that technological progress should be combined with social and human perspectives to create an attractive, healthy and safe working environment for all professionals in the mining industry, regardless of age and gender (Johansson et al. 2018; Campbell 2016; Lööw et al. 2019).

Competences

Which skills does tomorrow's mining industry require? This issue has been widely discussed in research and the question has often been whether the competence requirements are increasing or decreasing. In the 1960s, the general perception was that the demand for skilled labour was constantly on the rise, and the job was becoming more and more skilled (Blauner 1977). During the latter part of the 1970s, the discussion shifted so dramatically that the up-qualification theory was largely replaced by a theory of general de-qualification. James (Bright 1958) was the first to assert this, but it was not until Harry (Braverman 1974) published his book 'Work and Monopoly Capital' that the de-qualification theory was seriously discussed in the European debate.

A more nuanced view of technological development was found in the German research on industrial sociology by Kern and Schumann (1974), which showed a risk of polarisation, with some employees benefiting from technological progress while others were given simpler assisting tasks. This issue is still very relevant today, with the emphasis often being on the right to skills development, and that no one should be left behind because of technological progress (Hernandez-de Menendez et al. 2020). However, these general research results say little about the skills and competence requirements for working in mining. There is a dividing line between the need for generic qualifications (that are generally applicable across a wide range of production sites) and the need for plant-specific skills (linked to a particular production unit). The general perception is that there will be a demand for more general skills, such as computers know-how, creative problem-solving, entrepreneurial thinking and interpersonal skills (Yoo et al. 2021; Erol et al. 2016; Jerman et al. 2018; Hernandez-de Menendez et al. 2020; Sima et al. 2020) which must then be continually complemented and developed through on-the-job learning (Ashkenas et al. 2002; Argyris and Schön 1996) to bring about a learning organisation (Senge 2006).

Competence based on lifelong learning and multidisciplinary teams

Based on the above general description of competence research, we can conclude that none of the references mentioned specifically with the mining industry and its skills requirements. Our literature search found 11 articles that discuss competence and skills in the mining industry, see Table 3 below.

Vogt and Hattingh (2016) studied South African mines with a low degree of mechanisation and found that an increased level of mechanisation and automation decreased the need for operators, while the need for qualified personnel for indirect roles such as mine planning and ventilation, increased. Operators will need to demonstrate greater flexibility and decision-making abilities, and they will subsequently need more opportunities to use these skills. Mills (2010) studied automation in the mining industry and cited Schneider Electric's national director of mining, Paul Cooper, who said that there are four main trends driving the development of automation. These are the shortage of skilled workers, the demand for single-sourced solutions, open standards and connectivity. Mills argues that the shortage of skills has driven simplified automation that facilitates remote connectivity, providing an ability to perform diagnostics and troubleshooting remotely. In Australia there are many examples of remote operations where the control rooms are located in the larger cities (Holcombe and Kemp 2019), which also means that there are fewer employees at the mining site. Automation frees people from the production area to work in control rooms that are separate from the mining area. This leads to an improved physical work environment and that mining work is starting to resemble an office work (Abrahamsson and Johansson 2021).

Digital and autonomous technologies are becoming increasingly dominant in mining workplaces. Technological developments are helping to accelerate the pace of change. This in turn leads to a change in demands and requirements for work (Abrahamsson and Johansson 2021; Herbert and Hidalgo 2021). According to Young and Rogers (2019), in the future, digital development will require a skilled workforce that can compile and analyse large amounts of data, which in addition to computer skills, also requires knowledge of mining, metallurgy and geology. Young and Rogers state that it is rare for one person to possess all these required attributes. They therefore advocate multidisciplinary teams and new recruitment methods, such as 'hackathons' where participants meet for a limited time to solve a problem jointly, as a possible solution to the challenge of recruitment and more diverse requirements. Herbert and Hidalgo (2021) put forward the need for competences such as creativity, ingenuity, entrepreneurship, technical competence and knowledge of computer security as important skills for future work in mining. According to Johansson et al. (2010), this could lead to an increased need for qualities such as openness, the ability to collaborate and acceptance of differences between colleagues. In addition, some authors have emphasised that qualities such as flexibility, independence, responsibility and the ability to make strategic decisions about production may rise in importance (Johansson et al. 2010). Herbert and Hidalgo (2021) add lifelong learning and the ability to cope with rapid changes in work to the above list.

The mining industry has an aging workforce (Johansson et al. 2018; Young and Rogers 2019), it is therefore important to improve knowledge on how older people adapt to new technology. It is also important for the mining industry to take advantage of older miners' knowledge through knowledge transfer between more experienced and newer miners. This can be done through mentoring programs or with virtual reality (VR) (Johansson et al. 2010; Johansson and Johansson 2014). VR-enabled training has existed as a training method in the mining industry since the early 2000. It is now considered as a viable solution because the learning takes place in a safe environment, where mistakes and errors lead to increased learning instead of accidents, damaged equipment or downtime (Asbjörnsson et al. 2013). Technological advancement leads to professional knowledge, so-called 'tacit knowledge', becoming embedded into machines and control systems (Johansson et al. 2010). Ultimately, this form of knowledge will be expressed using algorithms in the future. The tacit knowledge that miners previously possessed was gained through physical contact

Table 3 Overview of articles identified under the competence theme

Author	Title
Abrahamsson and Johansson (2021)	Can new technology challenge macho- masculinities? The case of the mining industry
Asbjörnsson et al. (2013)	An On-Line Training Simulator Built on Dynamic Simulations of Crushing Plants
Herbert and Hidalgo (2021)	Improving The Engineering Education In The Raw Materials Sector In An Advanced, Decarbonised, and Digital European Society
Holcombe and Kemp (2019)	Indigenous peoples and mine automation: An issues paper
Johansson and Johansson (2014)	'The new attractive mine': 36 research areas for attractive workplaces in future deep metal mining
Johansson et al. (2010)	Attractive workplaces in the mine of the future: 26 statements
Johansson et al. (2018)	Attracting young people to the mining industry: six recommendations
Mills (2010)	Opportunities abound for mining technology
Smith and Sepasgozar (2022)	Governance, Standards and Regulation: What Construction and Mining Need to Commit to Industry 4.0
Vogt and Hattingh (2016)	The importance of people in the process of converting a narrow tabular hard-rock mine to mechanization
Young and Rogers (2019)	A Review of Digital Transformation in Mining

with the rock and was largely tactile and sensual. The new technology, on the other hand, is based on theoretical and logical competences and skills aimed at understanding the entire production flow.

The results of the literature review indicate that more continuous development, or 'lifelong learning' as it is sometimes described, will be essential for dealing with the rapid technological developments in the future of mining systems. Smith and Sepasgozar (2022) highlight that knowledge in analytical skills, artificial intelligence and mechatronics will become increasingly important. Young and Rogers (2019) add the need for training in data management and digital literacy, and point to the fact that long-term success will ultimately depend on the level of digital literacy of the workforce. The authors describe digital literacy as the ability to understand and use information in multiple formats, from multiple sources. Unlike literacy, digital literacy is not just about understanding the content, it also involves the ability to use and dynamically interact with the content, enabled by a computer. This type of skill is usually found in computer scientists, a role that the mining industry typically has great difficulty recruiting. At the same time, computer scientists need to have knowledge of mining, metallurgy and geology, which is unusual. Hence, the best solution is probably to use multidisciplinary teams consisting of several workers, each with specific knowledge and skills. Most researchers believe that most of the responsibility regarding how to meet the changing requirements lies within education systems, which must adapt to the new needs for knowledge (Young and Rogers 2019; Smith and Sepasgozar 2022; Herbert and Hidalgo 2021).

Organisation

When it is not possible to create attractive and safe workplaces with new technology, organisational solutions are required instead. Research on what constitutes good organisation of work is extensive (Johansson and Abrahamsson 2009) and usually originates in socio-technology, a tradition that focuses on the interaction between people and technology (Trist and Bamforth 1951; Mumford 2006). The most common components of good work organisation are a flat organisation based on principles that empower employees (Kazancoglu and Ozkan-Ozen 2018) and encourage their creativity (Kagermann et al. 2013). This in turn enables a more productive organisation that promotes a culture that is based on gender equality (Abrahamsson and Johansson 2021). Organisational culture should also support new ideas and their implementation, including experimentation, testing, learning, adaptation and development as key leitmotifs (Gorecky et al. 2014).

Almost all models related to organisational solutions have a common theoretical basis originating in some variant of the classic demand-control model, sometimes called the demand-resource model, for measuring work-related psychosocial stress (Karasek and Theorell 2009). Gadinger et al. (2012) illustrate the different dimensions of the model and identify five different types of conditions that must be managed: quantitative (work pace, time pressure), physical (load, noise, temperature and/or chemical substances), emotional (emotional problems), technological (new technologies, IT) and cognitive (complex analyses and operations). The organisational solutions discussed are autonomy, competence variation and in some models a third dimension has been added, social support (Karasek and Theorell 2009).

Learning organisations based on socio-technical principles

The mining industry has traditionally been an interesting object of study for work organisation research. The entire socio-technical research tradition is based on studies in English coal mines in the 1940s and 1950s (Trist and Bamforth 1951). In modern organisational research though, the mining industry is more inconspicuous. Our literature search found 11 articles that deal with the organisation of work, see Table 4.

Vogt and Hattingh (2016) take a historical perspective and describe how mines have become larger as technology has been refined. Control of production has shifted to mining engineers and metallurgists while skilled miners have decreased in number yet the work of those that are still in the mines has intensified. The authors point out the fact that many mining companies have employed low-skilled workers in large organisations controlled by experts. This, in turn, has led to many workers lacking understanding of the entire mining process. Vogt and Hattingh go on to describe that as work becomes automated, so too do workers. A group of support staff emerges for every autonomous machine, and the worker thereby gains a greater degree of freedom in their work. Another aspect is that previous professional knowledge (tacit knowledge) is codified and stored in data-integrated systems. When automation is developed and implemented, many aspects of the tacit knowledge are forgotten, and the workers find it more difficult to understand how and why different parts of the mining process are carried out.

A future scenario along these lines could involve autonomous mining processes where most employees work with the control, maintenance or planning of the mining operations (Vogt and Hattingh 2016). This should be interwoven with the principles of good work in which the position of workers is strengthened such that they are trained and included in the technological transition. At the same time, there are risks associated with the codification of knowledge, such as reduced control over the production process. This could entail situations in which creativity is discouraged in the organisation.

According to Herbert and Hidalgo (2021), future mining will largely be robotised and managed remotely. In some cases, the control room may be located several miles away from the mine (Holcombe and Kemp 2019). For instance, in a study regarding the crushing of debris at dump shafts using a remotely controlled hydraulic hammer, Pawel et al. (2017) found that remote control significantly improves the physical working environment as the operator is relocated to a safe and comfortable central control room. However, workload might grow due to additional tasks. Herbert and Hidalgo (2021) point to the fact that process optimisation could be moved from the mines to office environments where experts analyse data through different models to optimise the mining process. It is difficult to know whether most mining operations will be carried out over long distances or near the production area in the future. Matters regarding the content and structure of the work thus become essential to the quality of work, compared to the geographical locations of work and compared to the production area.

In a study by Moore et al. (2021), adaptive, mobile and modularised technical solutions known as the switch on-switch off (SOSO) mining method, were tested at sites in the western Balkans. The system is primarily intended for the extraction of small, high-value deposits in mines that can be quickly started and closed depending on market demand. Production is relatively labour-intensive, i.e., the number of employees per production volume is higher than in conventional, large-scale mining operations, and the employment period is shorter compared to large-scale mining. Moore et al. (2021) argue that employment can still be important in places where there are few alternative employers. A SOSO-based mine can help to strengthen and diversify the local economy. The rapid establishment involving short start-up times should be handled by a multi-skilled workforce that can quickly adapt to new working conditions. An interesting observation is that the SOSO method requires some of the old physical and tacit knowledge and skills to be retained by the workforce. This is often considered obsolete in large modern mines where much of the knowledge is codified. A multi-skilled workforce leads to a more mature health and safety culture in the workplace (Moore et al. 2021).

Mining investments are expensive and are therefore usually long-term investments. Johansson and Johansson (2014) emphasise the importance of planning the design of the mine as early as possible to avoid embedding problems that later become expensive to remove. It is therefore of the utmost

Table 4 Overview of articles identified under the organisation theme

Author	Title
Herbert and Hidalgo (2021)	Improving The Engineering Education In The Raw Materials Sector In An Advanced, Decarbonised, and Digital European Society
Holcombe and Kemp (2019)	Indigenous peoples and mine automation: An issues paper
Johansson and Johansson (2014)	'The new attractive mine': 36 research areas for attractive workplaces in future deep metal mining
Johansson et al. (2010)	Attractive workplaces in the mine of the future: 26 statements
Johansson et al. (2018)	Attracting young people to the mining industry: six recommendations
Lööw et al. (2019)	Mining 4.0-the Impact of New Technology from a Work Place Perspective
Moore et al. (2021)	Sustainability of switch on-switch off (SOSO) mining: Human resource development tailored to technological solutions
Paraszczak and Planeta (2004)	Man-Less Underground Mining
Pawel et al. (2017)	Development of Test Rig for Robotization of Mining Technological Processes - Oversized Rock Breaking Process Case
Uys and Webber-Youngman (2019)	A 4.0D leadership model postulation for the Fourth Industrial Revolution relating to the South African mining industry
Vogt and Hattingh (2016)	The importance of people in the process of converting a narrow tabular hard-rock mine to mechanization

importance that decisions regarding production and the purchase of new technology are based on long-term planning. At the same time, taking a long-term perspective can be difficult when new technologies and solutions are emerging all the time. According to Paraszczak and Planeta (2004), one of the biggest obstacles is that the new, autonomous technology must be implemented in functioning production systems. The autonomous systems have to be adapted to the surrounding components in the flow of production, otherwise there is an increased risk of disruptions and overheads.

Consistent with Herbert and Hidalgo (2021), Lööw et al. (2019) argue that new technology requires new organisational solutions which support new ideas and their implementation, as well as new ways of doing business where experimentation, testing, learning, adaptation and development are central leitmotifs. Johansson et al. (2010) add that a culture that rewards factors such as lifelong learning, a learning organisation, general knowledge, broad job roles and a holistic understanding of mining production, are crucial factors for attractive and successful mining. Vogt and Hattingh (2016) agree with the view that for mining companies to successfully manage the technological transition, they need to become learning organisations. One way to approach a learning organisational structure is to use technology implementation as a research process that also includes organisational issues. This implies that the mines must produce both ore and new knowledge.

For socially-based problems to be given adequate consideration, in accordance with the basic principles of sociotechnology, Vogt and Hattingh (2016) recommend that experts in human factors be included in these technology implementations to foster the development of new knowledge and organisational learning. The modern learning organisation also needs to be adapted to the human physiological, psychological, social and cultural conditions in accordance with the different dimensions of the demand-control model (Johansson and Johansson 2014). Autonomous production teams and the decentralisation of authority and responsibility are important motivational factors in encouraging increased safety and production as well as achieving lifelong learning at work (Johansson et al. 2010).

All mines compete in a global market (Johansson and Johansson 2014). As such, cost control is crucial and greatly influences the choice of new technology, new organisational solutions and an increasing focus on environmental considerations. Many mining companies tend to deal with these challenges with the help of sub-contractors for financial and flexibility reasons. Johansson et al. (2018) emphasise that mining companies and sub-contractors need to cooperate on issues regarding the physical and social work environment to promote healthy organisational behaviour. Uys and Webber-Youngman (2019) argue that digitalisation will lead to a demand for mining-industry supervisors to acquire new skills. The traditional 'command and control' leadership must be replaced, but at present there is a lack of leadership models that are adapted to the mining industry of the future. Leadership occurs at many levels in an organisation. Johansson et al. (2010) have also emphasised the importance of a good balance between requirements and self-management for work groups and individuals. Flexible schedules and working hours based on social conditions are key factors to the attractiveness of work.

New technological development could impact the division of labour in the mining industry of the future. According to Johansson et al. (2010), the proportion of low-skilled workers is decreasing as mines become more technologically advanced. On the other hand, those who remain will have higher salaries, education levels and skills. Furthermore, highlighting under-represented groups and promoting a workplace culture based on gender equality is stressed as being necessary for healthy organisations. Finally, in a study from Australia and Canada, Holcombe and Kemp (2019) conclude that indigenous people are affected most by new autonomous technology because they usually perform the simple and monotonous tasks that the new autonomous technology is primarily designed to perform.

Society

The mining industry's relationship with the surrounding society can be problematic. The first phase of a mine's permit is exploration, which is a process that can encounter resistance from many stakeholder groups in society. The business will then be subject to an environmental assessment, which can take quite a long time. If a permit is granted, the mine has to be be established, which means that new infrastructure has to be constructed, and sometimes it also means that a new community is built. Production starts thereafter and continues until either the ore runs out or extraction is no longer profitable, which can be a time span varying from a few years to several hundred years. When production stops, the mine and sometimes the community must be decommissioned. After decommissioning, the mining area will be restored and decontaminated. What remains in the form of residual products will be monitored from an environmental point of view for a very long time thereafter. In our study, which focuses on the work environment and new technology, we have mainly concentrated on the production phase and how technological changes affect the relationship with the surrounding society. Our literature search found six articles, see Table 5, all of which deal with effects on employment.

Reinvesting in mining societies for long-term sustainability

According to Lööw et al. (2019), changes in the mine can affect large parts of the surrounding society. It is therefore important to place all structural changes in the societal context. One key question is how automation affect employment in the mining area. Few doubt that automation leads to fewer people employed per unit of production and the effects of this can be tangible. For example, an increased degree of automation in labour-intensive mining often leads to extensive staff reductions. Leeuw and Mtegha (2018) and Modimogale et al. (2021) describe the importance of programs to retrain miners who are made redundant due to automation in African mines. In an early study regarding future unmanned underground mines, Paraszczak and Planeta (2004) found that automation could function as a solution that in the long-run strengthens production and thus secures jobs in the surrounding community. It is also known that automation of loading in open-pit mining leads to lower costs of personnel, while increasing operational productivity (Bellamy and Pravica 2011). Such productivity growth may mean that mines that were previously considered uneconomic may in the future become profitable, which is an example of automation helping to create more jobs rather than the opposite.

However, automation can also reduce the number of jobs that require lower levels of qualifications (Bellamy and Pravica 2011), which raises the issue of social responsibility. One effect is subsequently that the population of the communities surrounding the mines shrink. To recruit workers to these shrinking mining communities, mining companies often switch their employment strategies to fly-in/fly-out solutions and remote control from control centres located in larger and more attractive communities. Another development in the same direction is the replacement of permanent employees with contractors (Johansson et al. 2010). The long-term effects of this development are significant from a sustainability perspective. Bellamy and Pravica (2011) therefore argue for the reinvesting some of the profits generated by mining into the nearby community.

According to Paraszczak and Planeta (2004), there is also a great risk that the new technology will face resistance from the mining staff. This resistance also risks spreading beyond the mining company's borders to the surrounding community. To counteract this, significant efforts need to be devoted to providing information to all workers of the company in order to ensure successful implementation and a positive attitude towards the new technology from both workers and the surrounding community (Paraszczak and Planeta 2004).

Discussion

This literature review has investigated the effects of Mining 4.0 on the work environment, skills, organisation and society in the mining industry. The paper also examines how the effects can be made more sustainable.

To begin with, there is a broad consensus among researchers that digitalisation and automation will affect the mining industry dramatically (Abrahamsson et al. 2009; Holcombe and Kemp 2019; Young and Rogers 2019). However, the effects of Mining 4.0 on the work environment are still largely unknown (Lööw et al. 2019). There is consensus across the publications that new technology will improve the work environments in mining by increasing safety through

Table 5 Overview of articles identified under the society theme

Author	Title
Bellamy and Pravica (2011)	Assessing the impact of driverless haul trucks in Australian surface mining
Johansson et al. (2010)	Attractive workplaces in the mine of the future: 26 statements
Leeuw and Mtegha (2018)	The significance of mining backward and forward linkages in reskilling redundant mine workers in South Africa
Lööw et al. (2019)	Mining 4.0-the Impact of New Technology from a Work Place Perspective
Modimogale et al. (2021)	Amending Dynamic Capability Theory for Information Systems Research on the Reskilling of Coal Min- ers in an AI-Driven Era
Paraszczak and Planeta (2004)	Man-Less Underground Mining

the automation of dangerous work tasks, which relocates the workers from dangerous areas to safe environments such as control rooms. Although increased safety is desired by all involved parties, there is still not much analysis of the likely changes in work environments that will result from the technological shift of Mining 4.0. Aspects such as quality of work, attractiveness and job satisfaction are seldom discussed in the literature, nor are these questions only of concern for the mining companies during implementation of new technologies. They should dealt with in the early phases of developing Mining 4.0 technology.

It is unclear from the literature whether we are on the right path when designing and developing these technologies. Is the technology being designed today leading to sustainable work environments in the future? Impacts on the work environments typically lag behind implementation such that it takes some years to see the effects that a technological system has on the work environment. However, from this literature review we see a shortage of studies that examine the actual effects on the work environment following the implementation of digitalisation and automation technologies in mining contexts. Previous research cannot therefore give any clear suggestions about the effects that Mining 4.0 might have on work environment beyond increased safety, which while it is the most important aspect for good and healthy work environments, it is not the only aspect of importance.

A central theme of the literature found in this study is the growing need for skilled labour following Mining 4.0. Globally, the mining industry has an aging workforce at the same time as new technologies are requiring new skills and qualifications. There is a relatively large amount of research describing the type of labour that will be required. However, there is not much knowledge on how to make the most of and develop the skills of the workforce that mining companies already have. Some researchers have emphasised the importance of taking advantage of older miners' knowledge, both as a resource in technology development and for knowledge transfer to newer miners (Johansson et al. 2010; Johansson and Johansson 2014; Young and Rogers 2019). However, we cannot find any research that describes how this transfer of knowledge should take place.

When it comes to the types of knowledge needed, most of the researchers agree that the mine of the future will require more generic knowledge and skills such as creativity, analytical skills, entrepreneurship, flexibility, independence, responsibility, openness, teamwork and general skills for handling computers and technical equipment (Young and Rogers 2019; Herbert and Hidalgo 2021). At the same time, specific mining skills such as how to read the rock, metallurgy and geology are often emphasised as a key requisite for the industry. It can be a challenge to design educational initiatives that combine these requirements, so the industry must therefore identify organisational level solutions instead. A flat organisational structure based on multidisciplinary teams and socio-technical principles could strengthen the position of employees and encourage their creativity, which in turn could lead to a more productive and healthier organisation. Furthermore, several authors have stressed the importance of an organisational culture based on gender equality that supports new ideas and their implementation, where experimentation, testing, learning, adaptation and development are central aspects of successful and healthy organisations (Herbert and Hidalgo 2021; Abrahamsson and Johansson 2021).

The challenges in recruiting skilled labour and the low attractiveness of mining work is relatively obscure in research. Despite hopes that the new technology will improve the working environment, mining is still perceived as dirty and dangerous work in a male-dominated environment. A holistic commitment to work environment issues that considers the interaction between people, technology and the organisation is necessary for this image to change for the better (Lööw et al. 2019). Human factors must be considered from the outset and in the design of new technologies and workplaces. Furthermore, mining companies need to make efforts to change the macho-masculine image that characterises the mining industry (Abrahamsson and Johansson

2021). Employees must feel proud of their work and their employer, and mining companies need to work with their visions and values to succeed in creating such pride.

There is a consensus in the literature review that Mining 4.0 will have a dramatic effect on organisational matters. Most mining companies will most likely handle these challenges differently. We see divergent organisational effects base on the literature review. On the one hand, there are those that suggest that Mining 4.0 will shift control of production towards mining engineers and metallurgists at the expense of skilled workers (Vogt and Hattingh 2016). Others suggest that the workers' positions should be reinforced with the flattening of organisational structures (Kazancoglu and Ozkan-Ozen 2018) and organisational models based on socio-technical principles (Trist and Bamforth 1951) to promote organisational learning (Johansson et al. 2010). Mining 4.0 may also exacerbate conflicting organisational interests. The interests of the mining companies to use the Mining 4.0 technology to increase productivity and reduce costs may conflict with the workers' interests of good working conditions. Most researchers agree that all workers should be included in the design, development and implementation of technological systems. However, there is little research that examines how the organisational challenges following the technological shift of Mining 4.0 can be handled by the mining companies.

The manner in which the mining companies handle challenges following the technological transformation will also eventually affect the surrounding societies. Although there is consensus in the literature that digitalisation and automation will reduce the number of employees in future mining operations (Leeuw and Mtegha 2018; Modimogale et al. 2021), there is nothing that suggests that mining will be handled completely autonomously or tele-remotely without any people on site. Automation has the potential to counter-balance the challenge of the aging workforce that the industry struggles with globally. Future generations will nevertheless still be required at mine sites. To attract the younger generations to mining communities and to keep them there, some of the mining companies' profits should be reinvested in the surrounding mining communities to enhance the overall quality of life and to secure sustainable long-term mining operations (Bellamy and Pravica 2011).

To summarise, based on our literature review, we see that more empirical research is needed on the effects of Mining 4.0 on work environments in mining. There are few studies looking at how the implementation of digitalisation and automation technologies in mining affects aspects such as quality of work, attractiveness and job satisfaction. There is also a need for new approaches that promote healthy work environments in in early stages of technology development. Research on how to make the most of and develop the competences that the mining companies already have, as well as how to handle knowledge transfer to the younger generation, is also needed. Furthermore, there is a gap in knowledge about how to handle organisational challenges following Mining 4.0. For instance, how can the mining companies become the learning organisations that are necessary to promote a smooth transition between the generations of experienced and novice miners? Research is also needed on adequate methods for integrating contractors and sub-contractors into regular mining operations. Finally, more research is needed regarding what factors determine whether mining work is perceived as attractive or not by the younger generation, to better manage staffing in the technological shift that accompanies initiatives such as digitalisation, automation and Industry 4.0 (Kagermann et al. 2013) and 5.0 (European Commission 2021).

This scoping review has summarised an extensive body of research that shows that modern technology can solve many occupational health and safety problems, but not all of them. Technological development must be combined with social and human perspectives to create a sustainable, attractive, healthy and safe working environment for all professionals in the mining industry, regardless of age and gender.

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