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Understanding the Industry Perspective on the Current U.S. Hardrock Mining Engineering Education

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ABSTRACT: Mining industry receives an increasing attention in green energy transition technologies in the U.S. However, little information is available regarding how the U.S. mining engineering education, particularly hard rock mining, is prepared to meet with the industry needs. This study summarizes a survey with an aim to understand the industry perspectives. The survey consisted of both closed- and open-ended questions. The survey results showed that the industry is concerned with a shortage of qualified graduates from the current U.S. hard rock mining engineering education system. The qualifications of the current education system need to be improved include engineering sciences underlying mining methods, mining design experience, mining feasibility study, the connection between theory and practice, and understanding the overall mining operation. The future desired qualifications were also suggested. Notably, the most desired ones in the next five years include an ability to acquire and apply new knowledge as needed and sufficient field experience. The survey participants, regardless of the nature of their affiliated mining companies, unanimously recommended that the collaborations between the industry and academia in the U.S. should be enhanced. Based on the survey results, the study concluded with four recommendations: (1) involve more multiple stakeholders in reforming mining education programs, (2) reinforce field experience as a key part of mining engineering programs, (3) enhance a closer collaboration between academia and industry, and (4) integrate emerging technologies (e.g., artificial intelligence/virtual reality) guided by pedagogical theories into new mining engineering curriculums.

INTRODUCTION

The mining industry producing all non-plant-based resources plays a critical role in maintaining the wellbeing of people on Earth. The statistics from the U.S. Minerals Education Coalition (2020) indicate that the industry produces approximately 3.19 million pounds of minerals, metals, and fuels on average that an American will need during their lifetime (Fox 2020). The recent green energy transition further strengths the need for critical minerals which is drastic and unprecedented. To tackle this challenge, a collaborative effort among multiple stakeholders, including mining companies, government agencies, and higher education institutions, is required (The World Bank 2017).

The shortage of qualified workforce is one of the most significant challenges faced by the mining industry (Adach-Pawelus 2020; Gleason 2021; Hayes 2019; Knights 2020; Swann 2020). The problem not only reassembles the criticality on the quantity but also the quality. In the U.S., the quantity seems to be more serious because there are only about 200–300 students per year graduated from all the mining schools combined (U.S. Energy Information 2011). In addition, the quality also presents some challenges because topics related to critical minerals (e.g., lithium, rare earth minerals) are not part of the typical mining engineering curriculum. The shortage of qualified workforce impedes the U.S. domestic production of critical minerals which consequently delays the society transition to green energy sector. To improve the current education situation, the first step is to understand the industry needs, which is the focus of this study.

This paper summarizes the results from a survey which seeks to understand the industry perspectives on the U.S. hard rock mining engineering education. The paper first presents the survey purpose statement and research questions. The data collection, participants, survey question development, and strategies for data analysis were described next. After the presentation of the survey findings, the paper finally concludes with the recommendations on how to improve the future U.S. hard rock mining engineering education.

PURPOSE OF THE STUDY AND RESEARCH QUESTIONS

The purpose of this study was to understand the industry expectations on the future U.S hard rock mining engineering graduates. Specifically, the study aims to address the following four research questions: (1) What are the required qualifications a mining engineering graduate should have to be hired by the mining industry? (2) What are the areas for improvement in the current mining engineering education at higher education institutions? (3) What are the recommendations proposed by industry for improving mining engineering education? (4) Do different sectors in the mining industry have different perspectives on the required qualifications that a mining engineering graduate should have?

METHOD

Data Collection

This study was determined as not required for human research protection oversight by the Institutional Review Board. The survey was distributed by the members of the two advisory boards of authors' university. The members further distributed the survey within their professional networks. The members of the advisory boards and participants not only serve for the authors' institution but other U.S. universities offering mining programs. The survey was designed with a focus on hard rock mining engineering related questions. The survey asked the participants to provide their comments on the U.S. mining engineering graduates without being specific to those graduated from the authors' institution. Therefore, the survey findings can potentially represent the general situation of the other U.S. universities' education on hard rock mining. The survey took approximately 10 minutes to complete.

To estimate the minimum sample size required for our study, we conducted a priori power analysis in G*Power 3.1.9.7 (Faul et al., 2007; Faul et al., 2009). We used alpha = 0.05, statistical power = 0.8, and equal sample sizes for the respondents' affiliated companies. When the effect size of d is 0.5, 0.8, 1, and 1.2, the minimum sample size required for an independent sample t-test is 64, 26, 17, and 12, respectively (Cohen 2013).

Participants

A total of 31 individuals responded to the survey. Three participants responded to two or fewer questions, and 28 participants responded to all the Likert-type questions. Reponses provided by the 28 participants were used in the study. Sixteen of the 28 participants further provided their responses to the open-ended questions.

Among the 28 participants, there were 4 (14.3%) junior mining engineers, 1 (3.6%) intermediate mining engineer, 9 (32.1%) senior mining engineers, 4 (14.3%) engineering managers/supervisors, 6 (21.4%) executive/senior managers, 1 (3.6%) environment specialist, 2 (7.1%) geologists, and 1 (3.6%) consulting engineer. When the 28 participants were asked about the nature of their company, 15 (53.6%) reported mining/metallurgical operation, 5 (17.9%) mining/metallurgical equipment supplier, 5 (17.9%) mining/metallurgical consulting, 2 (7.1%) engineering procurement, construction, and management (EPCM), and 1 (3.6%) research and development (R & D).

Survey Development

The final survey consists of 22 Likert-type close-ended and five open-ended questions which can be found in the full length paper published in the Journal of Mining, Metallurgy and Exploration (Chen et al., 2023). This conference paper summarizes some of the high level key findings. The Likert-type question target areas including knowledge, skills, and qualifications of the current graduates, the application of new technologies (e.g., artificial intelligence/virtual reality) in teaching and training, mining workforce shortage, and collaboration between academia and industry. Seven response options are provided for each Likert-type question, including 1 = strongly disagree, 2 = disagree, 3 = somewhat disagree, 4 = neither agree nor disagree, 5 = somewhat agree, 6 = agree, and 7 = strongly agree. The five open-ended questions asked participants to comment on:

(1) areas which include any missing qualifications of the current graduates, (2) the required knowledge and skills in the next five years, (3) any challenges that currently cannot be tackled but will be by new technologies in the future, (4) the preferred software packages for training and operation, and (5) recommendations for universities to improve their mining education.

Data Analysis

To analyze data from the Likert-type questions, the mean score of each question along with its 95% confidence interval (CI) were calculated. For a question related to knowledge, skills, and qualifications of mining engineering graduates, we deemed an attention is required when the lower limit of the 95% CI was below 4 (i.e., neither agree nor disagree). For the rest of questions (e.g., the application of artificial intelligence/virtual reality can be used to enhance mining teaching and learning experience), we considered the participants agree if the lower limit of the 95% CI was higher than 4.

Because participants' responses may relate to the nature of their companies, we divided the nature of participants' companies into two groups (i.e., affiliated with or not affiliated with a mining/metallurgical operation company) and examined if there were significant differences between the two groups on their responses to general qualifications of graduates. There were 15 participants who were affiliated with a mining/metallurgical operation company and 13 participants who were not affiliated with a mining/metallurgical operation company. Therefore, if the population effect size of d is at least 1.2, we met the minimum sample size requirement to achieve a statistical power of 0.8. The questions related to general qualifications of graduates were derived from the overall curriculums. The four questions that the survey asked in this area include: "Current graduates have demonstrated a reasonable grasp on the connection between theory and practice." "Current graduates have sufficient communication skills for their first professional careers." "Mining/metallurgical engineering students should have a good understanding of the overall mining operation, e.g., the mine-to-mill approach." "Current mining/metallurgical engineering graduates have demonstrated sufficient understanding of the overall mining operation."

For open-ended questions, we matched the survey responses with seven criteria designed for evaluating the student leaning outcome. The number of times that survey responses can be matched with each of the seven student outcomes was counted. One respondent's response can only be counted once for one student outcome. Yet one respondent's response may be matched to multiple outcomes, depended on the fit of the response to the outcomes. A higher number implies that participants perceived a need to strengthen that specific outcome. For the responses that cannot be matched with any of the areas, we listed those separately. When participants from multiple types of mining companies all mentioned something related to a specific student outcome/area, it also indicates a need to strengthen that specific outcome/area, regardless of participants affiliated companies. Therefore, we color coded the responses by participants' companies.

RESULTS

Results from Likert-Type Questions

Knowledge of Mining Engineering Upon First Employment

Figure 1 shows the survey responses to the qualifications of mining engineering graduates upon their first professional employment. The results indicate that the participants generally agreed that the mining engineering graduates are equipped with qualifications in the areas of mining methods (4.86 ± 0.55, error bar stands for the 95% CI) and mine design in both underground and surface mines (4.79 ± 0.49). For engineering underlying sciences (4.50 ± 0.57), mining design experience (4.29 ± 0.54), and mining feasibility study (4.25 ± 0.56), the results reflect a somewhat neutral viewpoint and the lower limits of the three were below 4. We consider these three areas can be improved and marked them in orange in Figure 1.

General Qualifications of Graduates Derived from the Overall Curriculum

Responses related to the qualifications of graduates derived from the overall curriculums are presented in Figure 2. Participants did not agree that the current curriculum prepare students to bridge the gap between theory and real-world practice, i.e., 4.11 ± 0.61. It is marked in orange in Figure 2. The responses indicate the expectation of the industry that students graduated with the current curriculum should attain a good understanding of the overall mining operation (6.11 ± 0.41). However, this expectation had not been met as the responses suggested (4.21 ± 0.55), marked in orange in Figure 2. In terms of the communication skills, the responses suggest that the industry in general was satisfied with the current curriculum (5.04 ± 0.60).

Graduate Awareness of Challenges Faced by Industry

The survey also asked the industry to comment whether the graduates aware of the challenges faced by the mining

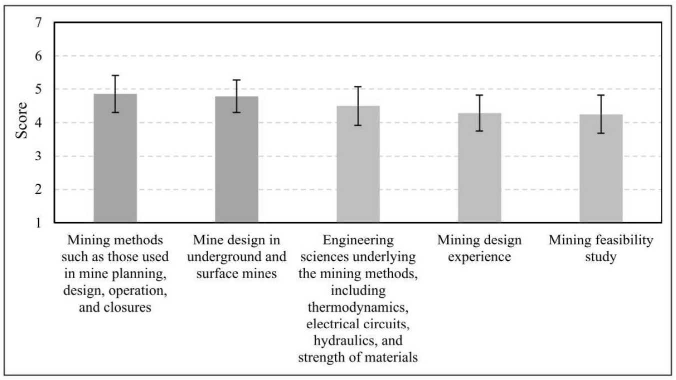

Figure 1. Qualifications of mining engineering graduates upon their first professional employment. Scores of 1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree. Error bars show the 95% CIs. Orange bars have the lower limits lower than 4, which indicate areas require improvement

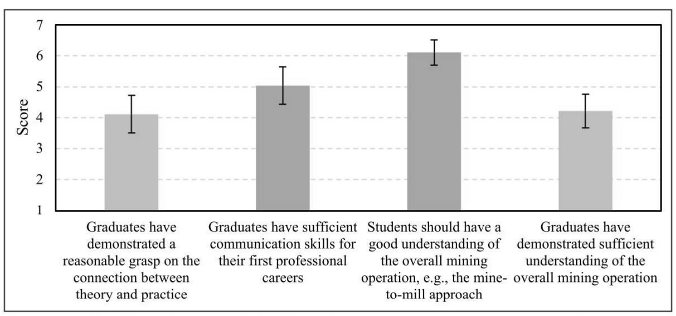

Figure 2. Qualifications of graduates derived from the overall program. Scores of 1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree. Error bars show the 95% CIs. Error bars show the 95% CIs. Orange bars have the lower limit lower than 4, which indicate areas require improvement

industry. Three major challenges, including decreased ore grade complicating the mining operation, growing challenges for tailing management, and increasing responsibilities for sustainability and environment are included in the survey. The survey results imply that the current curriculums made the graduate aware of challenges faced by the mining and metallurgical industry, i.e., 4.79 ± 0.58, 4.75 ± 0.64, and 4.96 ± 0.59 for the respective challenges.

Applying AI/VR, Shortage of Workforces, and Collaboration Between Academia and Industry

In exploring new potential methodology to improve mining engineering education, one question asks the industry whether they think the emerging technologies, such as artificial intelligence and virtual reality (AI/VR), can be effective tools. The responses signal an encouraging attitude, i.e., 5.14 ± 0.50. Additionally, the industry seems to be willing to adapt these technologies into their own training program, i.e., question 9 with a score of 4.75 ± 0.54.

Three questions concern the challenges related to the workforce for the mining sector. The industry agreed (5.82 ± 0.46) that there is a widespread workforce shortage for the industry. The response also indicated that the industry is very willing to collaborate with the higher institutions to better understand the challenges in the workforce (question 11, 6.36 ± 0.34) so to develop potential solutions (question 12, 6.29 ± 0.35). Responses of these questions are presented in Figure 3. It should be noted that these two questions related to collaboration between universities and industry yielded the highest scores and narrowest CIs across the 17 Likert-type questions analysed in the present study. This implies that the participants unanimously agreed the importance of collaboration between academia and industry.

Comparing Ratings of Qualifications of Graduates from the Overall Curriculums Between Participants Who Affiliated with Mining/Metallurgical Operation Companies and Their Counterpart

We perform an independent samples *t*-test to examine the mean difference between participants who were and were not affiliated with a mining/metallurgical operation company on each of the four questions related to general qualifications of graduates derived from the overall curriculums. A significance level of .05 is used. Results reveals that respondents affiliated with the mining/metallurgical operation companies tended to give lower ratings (n = 15, M = 3.67, SD = 1.29) on the question "Current mining engineering graduates have demonstrated sufficient understanding of the overall mining operation" than their counterparts (n = 13, M = 4.85, SD = 1.35), t (26) = −2.37, p = .026, d = −0.90. Significant differences are not found on the rest of the three questions (Table 1).

Results from Open-Ended Questions

Missing Qualifications of the Current Mining Engineering Graduates

Figure 4 shows frequencies of missing qualifications that were matched with seven criteria designed to reflect the student learning outcome. The frequencies of matched missing qualifications range from 2 to 5. Five missing qualifications mentioned by respondents can be addressed under criterion (2). One of the five respondents wrote "Overall understanding of mining/metallurgy related equipment or extraction technologies." Four missing qualifications can be addressed under criterion (1) and (6). One respondent wrote the missing qualification under criterion (1) as "Understanding of metallurgical processes. Too many

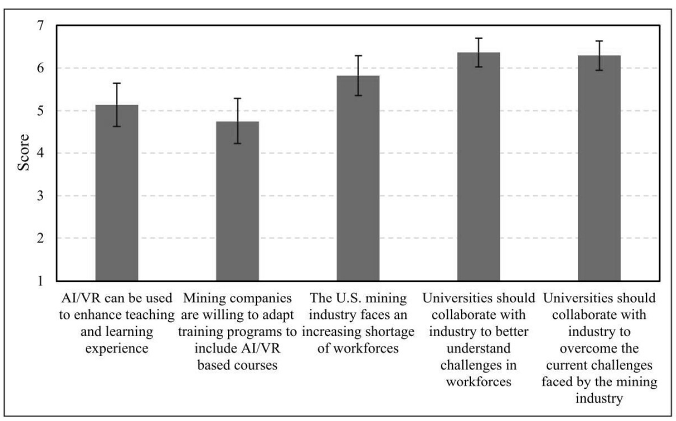

Figure 3. Possibilities of applying artificial intelligence/virtual reality (AI/VR), shortage of workforces, and collaboration between universities and industry. Scores of 1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree. Error bars show the 95% confidence intervals

Table 1. Independent samples *t*-tests for qualifications of graduates derived from the overall curriculums

Question	Affiliated with an Operation Co.	*M*	*SD*	*t*	*df*	*p*	*d*
Current graduates have demonstrated a reasonable grasp on the connection between theory and practice.	Yes (n = 15) No (n = 13)	3.87 4.38	1.64 1.50	−0.87	26	0.395	−0.33
Current graduates have sufficient communication skills for their first professional careers.	Yes (n = 15) No (n = 13)	5.07 5.00	1.49 1.68	0.11	26	0.912	0.04
Mining/metallurgical engineering students should have a good understanding of the overall mining operation, e.g., the mine-to-mill approach.	Yes (n = 15) No (n = 13)	6.20 6.00	1.01 1.16	0.49	26	0.630	0.19
Current mining and metallurgical engineering graduates have demonstrated sufficient understanding of the overall mining operation.	Yes (n = 15) No (n = 13)	3.67 4.85	1.29 1.35	−2.37	26	0.013	−0.90

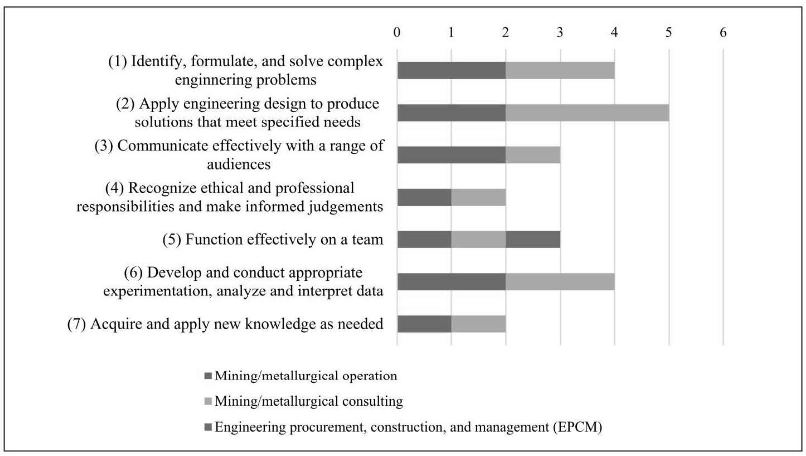

Figure 4. Frequencies of missing qualifications

mining engineers view the mill/downstream processes as a 'black box'." An example of missing qualifications wrote by respondents that can be addressed under criterion (6) was "It seems the ability to apply comminution science is weak, and in some cases misunderstood."

All the missing qualifications that were matched with the criteria were provided by respondents who worked either in a mining/metallurgical operation company or a mining/metallurgical consulting company. One exception occurred under criterion (5). The missing qualifications within criterion (5) were provided by respondents who worked in a mining/metallurgical operation company, a mining/metallurgical consulting company, and an engineering, procurement and construction management (EPCM) company.

Figure 5 presents frequencies of missing qualifications that are under other categories. These missing qualifications were further grouped into three areas: sufficient experience in the field, develop skills and knowledge in general areas, and build confidence and interest. Frequencies of missing qualifications mentioned by respondents within these three areas ranges from 2 to 5. Five missing qualifications were categorized as "sufficient experience in the field," two were

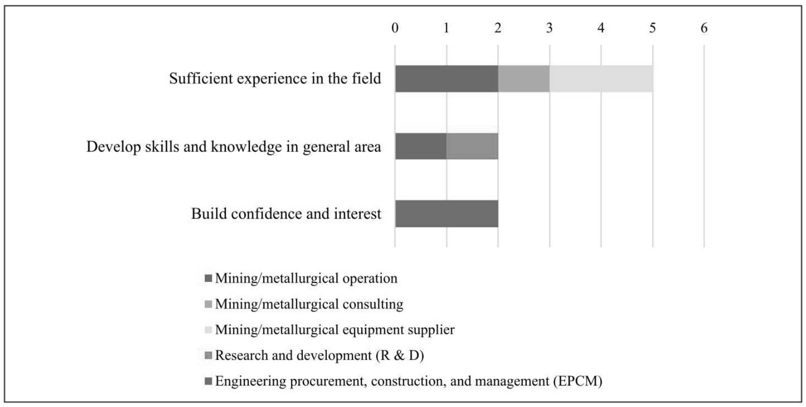

Figure 5. Frequencies of missing qualifications under other categories

"develop skills and knowledge in general areas," and two were categorized as "build confidence and interest." One missing qualification under the area of "sufficient experience in the field" was written as "They are all book smart but cannot implement in the field." One respondent identified a missing qualification in "develop skills and knowledge in general areas" as "Computing skills, mathematical and physical literacy." One of the missing qualifications under the area of "build confidence and interest" was stated as "They should have strong pride in where they came from and who they are."

The five missing qualifications under "sufficient experience in the field" were identified by respondents who worked in a mining/metallurgical operation company, a mining/metallurgical consulting company, or a mining/metallurgical equipment supplier company. The two missing qualifications under "develop skills and knowledge in general areas" were identified by respondents who worked in a mining/metallurgical operation company and a R & D company. The two missing qualifications under "build confidence and interest" were identified by respondents who both worked in an EPCM company.

Desired Qualifications in the Next Five Years

Figure 6 shows frequencies of desired qualifications in the next five years. Frequencies of matched qualifications ranges from 1 to 6. Six desired qualifications can be addressed under criterion (7)—"acquire and apply new knowledge as needed." One example was "AI, Machine Learning, Big data utilization." Four desired qualifications can be addressed under criterion (2). An example of this was "The graduates are getting the basics now. In the next five years we would expect they are getting direction on where the mining industry is headed with regard to automation, digitalization, software development for autonomous mining, carbon footprint measurement and reduction, sustainability and circularity." Three desired qualifications can be addressed under criterion (3)—"an ability to communicate effectively with a range of audiences." An example of this was written as "you need to move away from the typical university technical writing and learn how to write for decision makers, regulators and the general public. Since that is not something typically understood well in academia, you need to reach out to the industry to find and teach this skillset to the students." None of the desired qualifications mentioned by the respondents can be matched to criterion (4) and (5).

The desired qualifications under criterion (2) and (7) were both identified by respondents who worked in a mining/metallurgical operation company, a mining/metallurgical consulting company, or a mining/metallurgical equipment supplier company. The desired qualifications under criterion (1) were identified by respondents who worked in a mining/metallurgical operation company and an EPCM company. The desired qualifications under criterion (3) were identified by respondents who worked in

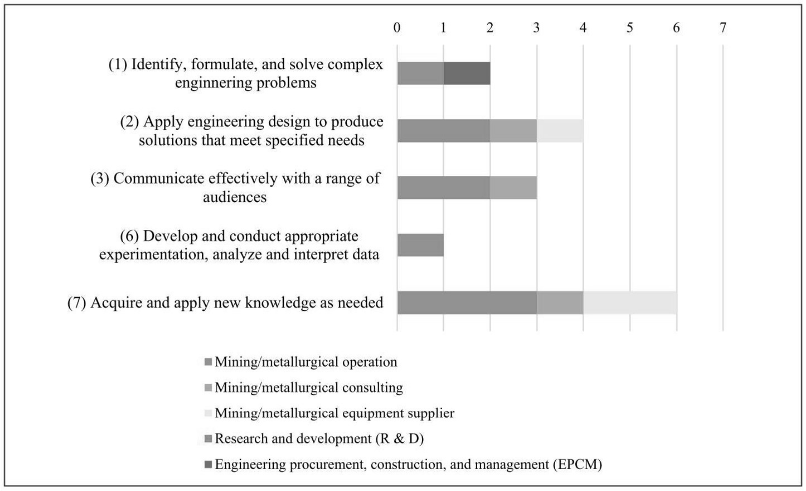

Figure 6. Frequencies of desired qualifications in the next five years

a mining/metallurgical operation company or a consulting company. The desired qualification under criterion (6) was identified by a respondent who worked in a mining/metallurgical operation company.

Figure 7 presents frequencies of desired qualifications in the next five years that cannot be matched with the seven criteria in Figure 7. These desired qualifications were further grouped into three areas: sufficient experience in the field, connect with industry to understand research partnership and job opportunities, and other. The number of desired qualifications within these three areas ranges from 1 to 5. Five desired qualifications were categorized as "sufficient experience in the field," two were categorized as "other," and one was categorized as "connect with industry to understand research partnership and job opportunities." One of the desired qualifications under the area of "sufficient experience in the field" was written as "Critical minerals processing experience. Critical minerals are those that are essential to the economy and whose supply may be disrupted." One respondent identified a desired qualification in the area of "other" as "Very useful would be: advanced excel skills (macros, etc), programming." The desired qualification under the area of "connect with industry to understand research partnership and job opportunities" was stated as "Better connected to the local, regional, national mining industry to more fully understand available research partnerships, job opportunities."

The five desired qualifications under "sufficient experience in the field" were identified by respondents who worked in a mining/metallurgical operation company, mining/metallurgical consulting company, or mining/metallurgical equipment supplier company. The two desired qualification under "other" were identified by respondents who worked in a mining/metallurgical operation company and a R & D company. The missing qualification under "Connect with industry to understand research partnership and job opportunities" was identified by a respondent who worked in an EPCM company.

Based on our analyses of desired qualifications in the next five years, we suggested the projected emphases on criteria (1), (2), (3), (6), and (7). Because the question asked respondents to identify the desired qualifications in the next five years, it is not surprising that the greatest number of the desired qualifications was under (7)—"an ability to acquire and apply new knowledge as needed, using appropriate learning strategies." Similar to our findings on missing qualifications, respondents from multiple types of

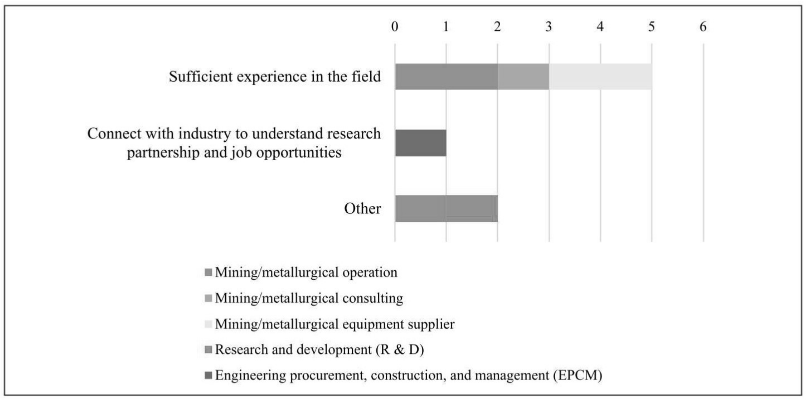

Figure 7. Frequencies of desired qualifications in the next five years under other categories

companies pointed out a need of sufficient experience in the field.

Recommendations to Enhance Future Mining Education

Figure 8 shows recommendations suggested by industry to enhance mining education. The recommendations were grouped into four areas: faculty hire and the focus of the school of mining, collaboration between industry and academia, a need of diversity, and more funding. The number of recommendations within these four areas ranges from 1 to 9. Nine recommendations were categorized as "collaboration between industry and academia," four were "faculty hire and the focus of the mining school," one was "a need of diversity," and one was "more funding." One of the recommendations under the area of "collaboration between industry and academia" was written as "More industry academia collaborations to bring out relevant solutions for the industry." One respondent suggested in the area of "faculty hire and the focus of the mining school" as "When hiring faculty to teach engineers, the emphasis should not be on research or other academic pursuits, but on practical engineering experience. Also, on choosing personalities that like to interact with students." The recommendation of "a need of diversity" was stated as "I think creating diversity of the mining/metallurgy education is important as it is a very broad topic with many commodities involved." The recommendation of "more funding" was written as "More funding for mining education."

The nine recommendations under "collaboration between industry and academia" were identified by respondents who worked in all kinds of companies included in the study. The four recommendations under "faculty hire and the focus of the mining school" were identified by respondents who worked in a mining/metallurgical operation company, a mining/metallurgical equipment supplier company, and an EPCM company. The recommendation under "a need of diversity" was identified by a respondent who worked in a mining/metallurgical consulting company. The recommendation under "more funding" was identified by a respondent who worked in a mining/metallurgical equipment supplier company.

Challenges That May Be Tackled by New Technologies

Several respondents provided their feedback on forthcoming industrial challenges that have the potential to be tackled by new technologies in the coming years. Table 2 presents these comments by respondents' companies.

CONCLUSIONS

Based on the progress made in other countries and findings from our survey, we provide the four additional recommendations to the existing certification mechanism for improving the U.S. metal mining education programs: (1) involving more stakeholders, such as students, faculty

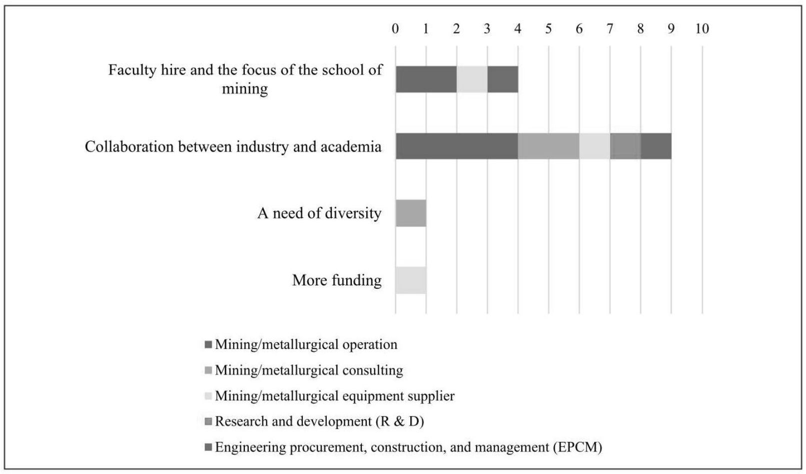

Figure 8. Frequencies of recommendations for enhancing mining education in each area

Table 2. Challenges that may be tackled by new technologies in the coming years

Respondents' Company	Comment
Mining/metallurgical operation	• Big data management, modelling and simulations. • Environmental remediation/water treatment to continue to operate within permit conditions. Declining ore grades require continuous optimization to maintain economic viability. New technologies that address this challenge are always welcome. • Standard mining operations in extreme adverse environments e.g., High Rock temperatures, extreme climactic cold, depth >2 km • Arsenic locked preg robbing low grade ores.
Mining/metallurgical equipment supplier	• New technologies for economically processing various low grade ores and tailings, such as copper ore, phosphate and rare earth, etc.
ECPM	• The industry is faced with challenges and is in 'constant' adaptation mode. A better relationship with the NV-based industry would help to drive research partnerships. Challenges include: identifying resources (AI and other tech); metallurgy and extraction; closure and sustainability; changing reporting formats (ESG and beyond).
R&D	• Sorting small particles.

members, staff in mining related research institutions, and industry, in reforming mining education programs; (2) Reinforcing more or mandatory field experiences as a key part of mining engineering education programs; (3) developing a much closer collaboration between academia and industry; (4) integrating emerging technologies, guided by pedagogical theories e.g., Community of Inquiry, (Garrison and Arbaugh 2007) to prepare for future mining workforce.

A close collaboration between academia and industry should allow industry to inform universities the current trends and needs in industry. Strategies for mining students to acquire more field experiences and build confidence and interest should be developed through collaboration. At the same time, industry may play a role in co-determining the focus and new faculty hire in the mining department/schools.

Potentials for using emerging technologies (e.g., AI/VR) in enhancing mining education are acknowledged by industry. Yet to effectively integrate these technologies in teaching and training, educators have to design learning tasks according to intended learning outcomes and learning theories. For instance, the community of inquiry (CoI) framework was proposed to illustrate that a successful e-learning experience in the 21st century occurs through the interaction of cognitive presence, social presence and teaching presence (Garrison, Anderson, and Archer 1999). When the CoI framework is used to design a VR learning environment, educators need to design an environment that promotes the three presences and helps learners to learn through active participation and shared meaning-making. Specifically, cognitive presence is the extent to which learners are able to construct and confirm meaning through sustained reflection and discourse (Garrison, Anderson, and Archer 2001). Social presence refers to the ability of learners to project their personal characteristics into the learning community, thereby presenting themselves as 'real people' (Rourke et al., 1999). Teaching presence is "the design, facilitation, and direction of cognitive and social processes for the purpose of realizing personally meaningful and educationally worthwhile learning outcomes" (Anderson et al., 2001). We emphasize that a successful technology integration requires a critical examination of the affordances of the technology and strategical utilization its affordances to optimize learning outcomes in a specific learning context.

DISCLAIMER

This paper is a shortened version of the paper published in the journal of Mining, Metallurgy & Exploration (Chen et al., 2023).

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