

**Youth in artisanal and small-scale mining (ASM) and higher education nexus: Diffusion
of innovations and knowledge transfer**

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Highlights

- We examined (educated) youth in artisanal and small-scale mining (ASM) and their impacts on higher educational and ASM sectors.
- *Youth in higher education and the ASM impact framework* explains the interrelationships of youth involvement in ASM and higher education and its (potential) impacts on the ASM industry.
- Educated youth involvement in ASM results in diffusion of innovation to the ASM sector.
- Knowledge transfers from higher educational settings into ASM can promote safer and cleaner production.
- Industrial placement and internship programmes are important for students to enhance their knowledge about ASM.

Abstract

Research literature has underscored the growing engagement of youth in artisanal and small-scale mining (ASM). However, no published study has explicitly investigated the symbiotic exchanges on how youth in ASM transfer acquired knowledge and practical skills to educational settings and how they in turn transfer their acquired knowledge in higher education institutions to the ASM sector. Based on our inquiry in Ghana, involvement of educated youth in ASM had resulted in a) diffusion of innovations to the ASM sector, b) skills/knowledge transfer on mineral processing, c) knowledge transfer on health and safety in mining, d) provision of equipment repair and maintenance services, and e) transfer of legal knowledge and processes to the sector. With the transfer of mining-related experiences to educational settings, three sub-themes emerged: f) sharing of ASM experience and knowledge with peers and tutors, g) experiential learning and practical understanding of theoretical concepts, and h) enhanced higher education-ASM industry synergies. In relation to these findings, we argue that the future of the ASM sector in Ghana and broadly sub-Saharan Africa concerning cleaner production and environmentally safe mining practices, to a greater degree, relies on educated youth who hold enormous promise to champion innovation and knowledge transfer to the sector.

Keywords: Artisanal and small-scale mining (ASM); Educated Youth; Diffusion of innovations; Higher Education; Cleaner production; Knowledge transfer

1.0 Introduction

Artisanal and small-scale mining (ASM) has been recognised for providing diverse opportunities for employment and income for different groups of people, especially in a context where ASM continues to grow (McQuilken & Hilson, 2016; Moyo et al., 2022; Verbrugge, 2016). It is a highly dynamic and diverse sector with its operation typified by various activities and varying degrees of (in) formality (Maconachie & Conteh, 2021; McQuilken & Hilson, 2016; Ofori & Mdee, 2021). Statistics show that 44.75 million persons across 80 countries seek employment opportunities in the ASM sector (Perks & McQuilken, 2020). Many people across the globe, including women, young men, children, low-skilled individuals, migrants, school dropouts, students, and even former government employees, seek employment opportunities in the sector (Arthur-Holmes et al., 2022a; Hilson et al., 2013; Jönsson & Fold, 2011).

The diversity of working population who operate in the ASM sector depicts the limited barriers to entry and relative sophistication in terms of mine equipment used (Buxton, 2013; Kambani, 2000). In addition to the low barriers to entry, economic reforms implemented throughout the late 1980s in several sub-Saharan African countries are reported to have engendered a swift increase in ASM activities with divergent groups of people seeking employment in the sector (McQuilken & Hilson, 2016; Hilson, 2004; Hilson & Potter, 2005). In this regard, ASM has become a regular and significant source of livelihood for many people, especially those in rural communities (Arthur-Holmes & Abrefa Busia, 2021; Huntington & Marple-Cantrell, 2022; Hilson, 2012; Osei & Yeboah, 2023). The viability of ASM and its importance in enabling a significant number of individuals to earn income to acquire a variety of assets (e.g. residential plots, housing and buildings, transport

service) and to pursue imaginary future projects have been amply described (Arthur-Holmes & Abrefa Busia, 2022a; Arthur-Holmes et al., 2022a; Osei et al., 2021; Hilson & Hu, 2022). In contrast to these dynamics which speak more to informal ASM operations, the formal aspect of ASM provides job security and decent working conditions for many people (Botchwey et al., 2022; Ofosu & Sarpong, 2022; Martinez et al., 2021).

The academic and policy literature gravitate towards the need for reforms, innovation, technology transfer, education, and awareness-raising campaigns as part of measures to improve the knowledge base of ASM workers and thereby reduce the hazards and unsafe practices which have characterised the ASM sector for decades (Aram et al., 2021; Arthur-Holmes et al., 2022b; Hilson & Maconachie, 2020; Kinyondo & Huggins, 2021). In particular, the transfer of knowledge, deployment of environmentally friendly technologies and innovation in the sector can minimise, if not wholly address, the unsafe practices and hazards associated with ASM operations. Amidst calls for ASM formalisation, some scholars have stressed that effective regulation of the ASM sector can also address the widespread illegality in informal ASM spaces (see e.g., Arthur-Holmes & Abrefa Busia, 2022b; Afriyie et al., 2016; Buss et al., 2021; Hilson, 2020; Ofosu & Sarpong, 2022; Teschner, 2012) while allowing individuals operating in the sector to have productive employment, decent work and sustainable livelihoods (Yakovleva et al., 2022; Owusu et al., 2019). In harmony with this perspective, ASM is touted as an important avenue to address youth unemployment and to also give opportunities for African youth to infuse fresh and innovative ideas, skills and practices that can transform the ASM sector (Ackah-Baidoo, 2016; Arthur-Holmes et al., 2022a; Hilson & Osei, 2014).

The broader development and policy literature on the construction of the African youth holds the view that young people are crucial to innovation in both farm and non-farm sectors (Sumberg & Hunt, 2019; AGRA, 2015; International Fund for Agricultural

Development (IFAD), 2011). For example, the Alliance for Green Revolution in Africa (AGRA) sees the African youth as more open to new ideas than older generations. Therefore, their engagement in the non-farm sector (e.g. ASM) is likely to facilitate the transfer of innovation and technology to the industry (AGRA, 2015). IFAD (2011) further posits that today's youth holds a greater capacity for innovation and entrepreneurship than the older workforce, and the FAO, ILO and UNESCO also acknowledge that 'the vitality and creativity of youth are among a country's greatest asset' (FAO et al., 2009, p.8). In effect, developing the youth as an innovative strategy is critical for transformation. As economic theory posits, there is a strong direct link between innovation, productivity, and economic growth (Sumberg & Hunt, 2019).

An emerging body of research literature has underscored the growing involvement of (educated) youth seeking employment in formal and informal ASM spaces (Arthur-Holmes et al., 2022a; Hilson & Osei, 2014; Osei & Yeboah, 2023). Many young graduates are often motivated to build entrepreneurial activities in ASM or seek employment in the sector simply because of the limited employment opportunities in the formal sector after school. Others are inspired by the desire to diversify their income sources or move into ASM as a more lucrative livelihood activity that provides significant income (Arthur-Holmes et al., 2022a; Hilson & Osei, 2014; Osei et al., 2022; Osei et al., 2021). The growing involvement of young university graduates or educated youth provides avenues for the potential transfer of knowledge from educational settings to ASM operations, which can contribute to responsible and safer mining practices. However, the peculiarities of educated youth engagement in ASM and how their engagement contributes to the sector's transformation and sustainability through the introduction and propagation of knowledge about responsible mining practices, safer and cleaner production, and environmentally friendly technologies are poorly understood.

Moreover, the engagement of educated youth in ASM operations allows them to acquire practical skills and knowledge. These are likely to be transferred to educational settings to enhance or facilitate teaching, learning, and understanding of concepts and theories relating to the ASM sector, allowing even peer students and tutors to appreciate discussions better, and learning about mining and environmental sustainability issues. Nevertheless, these ongoing transformations and linkages between higher educational settings and ASM settings have not been systematically documented in the literature. Our research aims to contribute to a greater understanding of the intricate relationship regarding educated youth involvement in ASM and how this contributes to transforming the sector through the application of knowledge, competencies, skills, and innovations acquired at higher educational settings to the ASM sector, which in turn may reduce potential risks and hazards. We further examine how educated youth engagement in the ASM industry allows them to better understand concepts and theories learnt in educational settings and to further transfer practical learning from ASM sites to educational settings.

The paper, therefore, makes a novel contribution to the literature on transforming and sustaining the ASM sector, particularly on mechanisms to address unsafe mining practices and promote cleaner production. The findings point to a symbiotic relationship between youth involvement in the ASM sector and the implicit and explicit role of educated youth in transforming the informal ASM sector through their knowledge transfer from the courses they pursue at the higher education level. The findings are crucial to inform formalisation policies and reforms to transform the sector and ensure its sustainability. The findings suggest the need for policymakers and other relevant stakeholders keen on providing responsible mining, safety practices, cleaner production, and environmentally friendly technologies in the ASM sector to begin fostering long-term collaborations with higher education institutions that offer practical courses relevant to the sector. Such partnerships could provide avenues for

designing action plans and strategies that can help create a knowledge economy within ASM by harnessing the incremental transfer of knowledge, innovations and technologies embedded in educational settings to transform and sustain the operations of ASM. Furthermore, the findings accentuate the need for governments and higher education institutions to think critically about and discuss how mining-related courses and curricula could be revised to include industrial placement and internships for students to fully engage with the ASM industry.

2.0 Towards a knowledge-based economy and innovation within ASM: a conceptual view

Our analysis in this paper draws on the notion of innovation and a knowledge-based economy and how these can be fostered in informal ASM settings. Historically, the ASM sector has been shown to depend on workers' knowledge and know-how in the extraction and processing of gold ore. Nevertheless, the sector currently relies heavily on low-skilled individuals whose production techniques have been reported to have negative environmental consequences (e.g., Arthur-Holmes et al., 2022a; Bansah et al., 2018; Hilson, 2020; Ofori et al., 2020).

The ASM sector has been undergoing technological innovations in some Amazonian countries and in sub-Saharan Africa (see e.g., Kabunga & Geenen, 2022; Massaro & de Theije, 2018; Hilson & Maconachie, 2020). The transformation and sustainability of ASM operations necessitate the creation of a knowledge-based economy built around the gradual but incremental transfer of knowledge, innovation, and smart processing methods. A knowledge-based economy is often described as an economic system in which the production of goods or services relies on knowledge-intensive activities that advance scientific and technical innovation (Godin, 2006; Foray & Lundvall, 2009). The fundamental principle concerning creating a knowledge economy focuses on human capital (educated population) within an economic system (Asongu & Odhiambo, 2020).

It has been argued that the gradual but incremental expansion of knowledge and greater reliance on advanced technology in the twenty-first century is leading to changes in economies that rely more on the skills and intellectual capacities of the skilled labour force (Sum & Jessop, 2013). According to Afuah (1988), innovation refers to new knowledge incorporated in products, processes and services. The innovation process captures the ‘implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations (OECD, 2009, p.6). Thus, innovation has different meanings, but two issues are often pointed out. First, innovation can take divergent forms (process innovation, product innovation, organisational and managerial innovations, and marketing innovations). The differing modes of innovations make a case for their diffusion patterns and impact on a firm or the performance of a sector (Zanello et al., 2016). Second, what could be described as innovation does not necessarily have to be something new. But it could be new to a sector or an activity that has the potential to impact productivity and transform the way production or activity is carried out (Zanello et al., 2016; Massaro & de Theije, 2018).

In this connection, what is considered an innovation in the ASM sector may be simply new methods and knowledge or production techniques that may not necessarily be new to other sectors of the economy. Innovation in a firm’s activity or within an industry (such as ASM) could be demonstrated through inventive output performance and investment in knowledge-building activities, including learning, design and engineering activities, research and development, and mechanisms to improve productivity. The creation, adoption, adaptation, assimilation, and diversification of technologies are all part and parcel of the innovation process (Kim, 1980; Zanello et al., 2016).

Several factors have been identified in the literature as key to influencing the adoption or diffusion of innovation. First, the nature of the innovation itself affects the speed at which the invention will be adopted or not. For example, in contrast to more sophisticated or advanced innovations (e.g., high-technology equipment), some low-tech innovations are likely to be adopted quickly because they may not require preconditional capacity (i.e. capital and skills). Other factors that may influence the adoption or diffusion of innovation include institutional arrangement, the desirability of the innovation to suit local needs, aspirations, and contexts, together with financial resources, skills, and the channels through which the innovation is communicated or transmitted (Zanello et al., 2016).

The World Bank (2013) highlights that the creation of a knowledge-based economy within an economic system (in our case, ASM) requires four fundamental pillar frameworks. The framework highlights the importance of human capital within a production system. First, creating a knowledge-based economy within a production system requires an educated and skilled labour force that can continuously learn and apply their knowledge and skills efficiently (World Bank, 2013). When applied to the ASM sector, this highlights the need for highly skilled, knowledgeable human resources that can use their skills, knowledge, and competencies efficiently to improve ASM operations.

The second pillar highlights the need for a dynamic information infrastructure from radio to the internet to facilitate timely and efficient communication, dissemination, and information processing. Given this condition, effective and efficient modes or platforms allow a knowledgeable and skilled workforce to effectively share, communicate and disseminate new knowledge about producing goods or services within an economic system.

Third, the World Bank's (2013) framework highlights the centrality of creating an effective innovation system to facilitate adoption and keeping pace with new technologies and human intelligence to ensure its application or use within a production system or

economy. In this case, it highlights the need to work with a range of knowledge-production-based institutions such as universities, research centres, community groups, private enterprises and think-tanks to tap into existing and emerging global knowledge to suit local needs and context. As some scholars have noted, universities, in particular, are increasingly becoming a hub for creating new knowledge and innovations for the commercial market and broader benefit of society (Sengupta & Ray, 2017; Sengupta & Rossi, 2023).

Finally, the World Bank's framework emphasises the need for an institutional regime that incentivises entrepreneurship and the application of knowledge (World Bank, 2013). This final pillar calls for mobilisation and efficient allocation of resources to relevant entrepreneurs within the ecosystem to facilitate the use of new methods, knowledge, and innovations within an economic system. Drawing on this understanding, we argue that the creation of a knowledge-based economy within ASM operations as a pathway to enhance transformation and ensure cleaner production and sustainable mining practices requires a highly skilled workforce with the right incentive, support infrastructure, and innovative systems to channel new techniques, innovative practices, and knowledge to enhance sustainable ASM operations.

3.0 Research context and methods

Given how Ghana's ASM sector has been criminalised in the last six years with a military approach to addressing informal gold mining (see e.g. Bansah et al., 2022; Crawford & Botchwey, 2018; Dery Tuokuu et al., 2020; Eduful et al., 2020), conducting face-to-face interviews or field research in the mining zones is dangerous for researchers. In light of this, we employed an innovative qualitative research approach, specifically digital interviewing methods using phone and WhatsApp instant messenger interviews (e.g. Anderdal Bakken, 2022; Kaufmann & Peil, 2020; Gibson, 2022) for our research. App-based text interviews have recently emerged as a potent tool for conducting research on young people and empowering young interviewees by enabling their voices to be heard in diverse settings (see

Arthur-Holmes et al., 2022a; Gibson, 2022). For instance, Arthur-Holmes et al. (2022a) employed WhatsApp and audio phone calls to interview educated youth, especially university students engaged in ASM operations. For this paper, more detailed and rich interview data gathered from twenty-one (21) educated youth interviewees are analysed from a research conducted from 10 September 2022–10 January 2023 on ‘educated youth in ASM, knowledge transfer from the higher educational settings, and diffusion of innovations in the ASM sector in Ghana’. All the educated youth interviewed were males.

For this research, non-probability sampling techniques, particularly purposive and snowballing, and social networks, were adopted to recruit educated youth in ASM for the interviews. The first author began using social networks, where individuals within his networks provided the needed support to identify educated youth who are involved in ASM across different sites in Ghana. This approach proved useful as it allowed us to identify and interview five (5) youths. These youths who were initially identified helped us to reach out to other educated youth for an in-depth interview. Those who agreed to participate in the research were interviewed through phone calls or WhatsApp texting, depending on their choice. Nine (9) interviewees chose phone call interviews because of their work schedule and inability to engage in WhatsApp instant messenger interviews for a long time after work. The phone call interviews were done during the interviewees’ break time. A sequential stimulus-response approach was used to promote interactions (Kaufmann & Peil, 2020). In the case of our research, the questions were asked, and the participants responded sequentially using WhatsApp text messages. Each question had one message. Once the question was answered, another was posted, with the interviewer interacting with the interviewee by asking for additional information, clarifications, or examples where relevant. For phone calls, the questions were also asked one after the other. Previous research has used a similar method

(e.g., Arthur-Holmes et al., 2022a). We encouraged interviewees to seek clarification and ask questions where necessary during the interviews.

A semi-structured interview guide was used for the interviews. The phone calls were not recorded since the questions were few, and also not difficult to write the responses while on the phone. Anonymity concerning the responses provided was ensured. Interviewees with life history and work experience in ASM were essential to advance the arguments of youths acquiring knowledge in ASM before pursuing mining-related courses in university (in this case, BSc Mineral Engineering; BSc Mining Engineering; BSc Geological Engineering).

Manual coding was used to identify reoccurring responses and variations within the responses. This coding approach was used because the questions and number of interviews were not many to handle. The authors, except the third author, began reading the generated transcript and discussed the responses to identify the main themes of the study. The main themes generated were then discussed and agreed upon by all authors. Life histories and extract from responses are used to support key findings. Some key questions asked included; Did you have any prior knowledge or experience in ASM before going to tertiary institutions (e.g. university and polytechnic)? If yes, did you share your knowledge of ASM with fellow students, tutors, lecturers, and laboratory technicians? How were you able to share your knowledge with fellow students, tutors, lecturers, and laboratory technicians? Have you been able to transfer or share your knowledge/skills acquired in the classroom to the ASM sector? If yes, how have you been able to transfer or share with the knowledge or the skills? among others.

Table 1: Main and sub-themes from interviews with educated youth in ASM

Main themes	Sub-themes
1) Diffusion of innovation and transfer of knowledge from educational sector to the ASM sector	a) Diffusion of innovation or ideas from educational settings to the ASM sector. b) Skills/knowledge transfer on mineral processing. c) Transfer of knowledge on health and safety in mining. d) Equipment repair and maintenance services. e) Transfer of legal knowledge by educated youth.
2) Transfer of mining-related knowledge and experiences to educational settings	a) Sharing of ASM experiences and knowledge with peers and tutors. b) Experiential learning and practical understanding of theoretical concepts. c) Enhanced higher education-ASM industry synergies.

4.0 Findings

As presented in Table 1, two main themes emerged from the interviews, namely, 1) diffusion of innovation and transfer of knowledge from educational sector to the ASM sector, and 2) transfer of mining-related knowledge and experiences to educational settings. Under these two (2) main themes, we identified eight (8) sub-themes that capture the symbiotic relationship and benefits across educational and ASM settings for educated youth. Five (5) themes, namely, a) diffusion of innovation or ideas from educational settings to the ASM sector, b) skills/knowledge transfer on mineral processing, c) transfer of knowledge on health

and safety in mining, d) equipment repair and maintenance services, and e) transfer of legal knowledge by educated youth, fall under the first main theme. Under the second main theme, the three (3) sub-themes we generated included: a) Sharing of ASM experiences and knowledge with peers and faculty members, b) experiential learning and practical understanding of theoretical concepts and lastly c) enhanced higher education-ASM industry synergies. These sub-themes are discussed in detail in the subsequent sections.

4.1 Diffusion of innovation or ideas from educational settings to the ASM sector

Some educated youth who engaged in ASM as entrepreneurs (in this case 4 university graduates) utilised their knowledge about large-scale mining learnt in the classroom and made modifications to existing technologies for site-specific needs and operations.

Consequently, they applied the modified technologies (i.e., tailings dams). Most technologies used in the mining sector are for large-scale mining activities. For instance, tailings dams are designed to recycle water/solution during the mining processes. From the findings, uneducated youth in the ASM sector had little or no knowledge of constructing tailings dams. However, four (4) educated youth interviewed mentioned that they transferred the knowledge learnt about tailings dams in the classroom and implemented a different structure of tailings dams, often called tailings ponds in the sector. Where tailings ponds were used in ASM zones, this normally involved one or two tailing ponds. These ponds were deemed unsuitable for holding wastewater for recycling.

Besides, interviewees claimed that many ASM operators channelled their wastewater from gold processing containing mercury and other toxic substances directly into water bodies. This was because informal gold miners did not have structured tailings dams to recycle their wastewater and manage tailings effectively. However, some educated youths developed new tailings dam structures in the sector by constructing tailings ponds that were more appropriate for safer and cleaner ASM production. From our analysis, we found two

forms of tailings dam innovations¹, including five tailings dams, and the three circular ponds. When interviewees were asked about innovations developed and used by educated youth in the sector, a first degree holder in Geological Engineering, who works as a General Director of a licensed small-scale mining company, explained that:

... my knowledge in physical geology enabled me to understand the negative impacts of mining on the environment, especially on water bodies.... The chief in our area of operation told us not to pollute the water bodies as the Chinese have done in the community...Therefore, to ensure safe mining practices and avoid water contamination, we built a five-connected tailings dams for our mining operations. This is something new that we developed from our knowledge of tailings dams used in large-scale mining. The five connected tailings dams were an innovation we introduced into the sector. It makes our mining activities different from others who also operate in the same community. All the dams look like ponds. They are able to hold wastewater and recycle the water later for mineral washing, especially when we are using water from the dam with fresh water. The wastewater starts from the first dirty dam through others to the freshwater dam. It does not leak into the river where we pump water with the six engine cylinder to our first dam, which is 500 meters away. We call the first dam freshwater dam because the water we get is fresh.

From the above extract, the interviewee claimed that a series of tailings dams he referred to did not leak. It is worth noting that it takes advanced technology to detect leakages in tailings dams. However, the interviewee's explanation implies that the leakages of their dams cannot be detected by a mere observation unlike those who do not have such tailings dam structure. Though some educated youths were able to modify existing technologies to suit their site-specific needs, it was stated that building strong and different structures of tailings dams, especially the connected ponds, was expensive. From our interviews, educated youths who were able to construct the tailings ponds secured loans from financial institutions to pursue such innovative ventures. Per the interview account, the implementation of the recyclable tailings ponds by university graduates was found to transform ASM operations in terms of

¹ The tailings dam innovations in this context is the modification of existing tailings dam structures, that were considered inappropriate for recycling wastewater.

reducing surface water pollution and contamination as well as facilitating environmentally-friendly mining practices.

4.2 Skills/knowledge transfer on mineral processing

Some educated youth transferred the skills learnt in classrooms and laboratories into the ASM sector. This was the case of gold grade analysis (assaying) and grade control. As four (4) interviewees emphasised, in the past, ASM miners did not perform gold grade testing to estimate the gold content at a particular level/depth they had mined or dug. These days, some ASM owners hire geologists and metallurgists to perform gold grade testing before commencing their mining operations. It was mentioned that many ASM operators did not adopt such practices hitherto, particularly due to the high cost involved. According to an interviewee who obtained a first degree in BSc Mineral Engineering:

... In the ASM sector...most operators [do] not...[perform]...gold ore analysis (assaying) before starting their operations. Since preliminary metallurgical tests are quite expensive, their activities are only funded by themselves. One of the most striking challenges to this is that the inability to quantify the minerals well leads to poor metal recovery which may cause them to move to another place to mine with the same practice. The truth of the matter is that perhaps gold may not be at the digging level they have reached, and this may only be revealed upon testing, though they sometime test informally with their gravity techniques. What has changed? Some of the ASM miners especially those mining from 'ghettos' and audits have employed this kind of gold grade determination techniques just to save money and also target the gold in the right approach, instead of the rudimentary way. Similarly, ASM miners who are sponsored by gold buying agents are very careful with the money, so they also go with this metallurgical testing methods, especially in tailings business. In the past fair trade of tailings sample was just by eye inspection and mouth to mouth negotiations, but now gold grade testing (assaying) is the ultimate trading criteria among the other methods partly because of the involvement of educated youth in the sector.

Moreover, due to the involvement of some educated youth in ASM, four (4) youths indicated that they had impacted the mineral separation process which most ASM miners hitherto used. These skills transfer from university students, and graduates were linked to their in-depth academic insights on the angle of inclination of the sluice/washing board for better gold

recovery. For instance, a 28- year-old educated youth who hold a BSc Mineral Engineering degree stressed:

The most emerging idea that has transpired in the ASM field over the past few years due to innovation and knowledge transfer from school to the sector is the angle of the sluice board. Mineral separation by sluicing can only be done with considering the angle at which the sluice board is situated or positioned. For you to trap most of the gold on the mat or blanket, the angle should be a factor. Steep-inclined board would bring about a faster separation process where you may end up losing most of the gold. This challenge has been rectified and now most of the miners are doing the right thing, though in an informal way, but better than before.

From the findings, five (5) educated youth taught ASM miners anytime they returned to their communities for ASM-related work to pay their tuition. Also, three educated youths claimed they had taught informal ASM miners to comprehend effective mineral processing and promote safe mining practices through consultancy. Moreover, five (5) interviewees from the engineering field noted that educated youth have transferrable skills that are sometimes utilised to teach non-educated miners how to maximise gold recovery and how to adopt new mining methods.

Furthermore, we found that young people who had acquired knowledge in various academic disciplines that apply to the ASM industry utilised them to teach miners anytime they returned to their communities for ASM-related work to pay for their tuition. Some educated youth, through consultancy, have taught informal ASM operators to comprehend the effective mineral processing and promotion of safe mining practices. Interviewees, especially those from the engineering field, noted that educated youth have transferrable skills that are sometimes utilised to teach non-educated miners on how to maximise gold recovery and use mining methods with minimal impact. For example, one interviewee, a BSc Mineral Engineering degree holder, asserted:

While in the university, I learnt the book knowledge of mineral processing, expanded my understanding of ore processing and recovery, and I have done my best to teach ASM operators. how mineral processing promotes cleaner extraction voluntarily. Through consultancy, I have taught some galamsey operators the right methods for the very bad processing and mining habits that have existed in the past, which they are

practising. For example, the angle at which the sluice board is set for efficient separation. The arrangement of mats or blankets on the sluice board for a good gold trapping mechanism in terms of its nature and morphology. The safe handling of mercury and its control, amalgam processing and how to control and manage its fumes were also explained to galamsey operators and gold dealers as well on some of the sites at Bondaye where I used to work. I also taught them the fair trade of gold, which I learnt in 3rd year in small-scale mining and processing course, which was taught by one of our lecturers, and I contributed locally at the very beginning. Gravity concentration, which was a common processing strategy in ASM, was learnt, felt, and mastered when I was pursuing my minerals engineering degree. For example, the use of the sluice board, gold pan, amalgamation, and smelting are all common terms and processes used in ASM and also learned at the university.

Also, the two geological engineers mentioned that though they did not know about ASM operations before university, their engagement in the formal ASM sector allowed them to apply their mining-related knowledge to conduct gold prospecting or exploration activities. One of them rated his application of geological engineering knowledge in mineral prospecting and exploration as 60%, while the geology of the area forms 40%.

4.3 Transfer of knowledge on health and safety in mining

Data analysis shows that the engagement of educated youth in ASM allows them to transfer their school-based knowledge on the safe use and handling of mercury (amalgamation) to uneducated and semi-literate counterparts. Unsafe mining practices often have several health and safety consequences for many miners within the ASM sector. That notwithstanding, many ASM workers do not adhere to safety regulations and practices at mining sites. Our findings indicate that the involvement of educated youth has stimulated knowledge transfer to less-educated miners who hitherto did not observe any occupational health and safety regulations. As pointed out by this interviewee, a BSc Mineral Engineering degree holder:

Mercury is a toxic and harmful substance and the most vital element. to bond with gold from a recovery perspective. At first, ASM miners were using their bare hands to rub in order to facilitate this kind of physical action and may end up getting affected. Some may eat or urinate with their contaminated hand, which is a bad practice and unhealthy. Through knowledge transfer and innovation from school to the sector, this practice has been reconstructed. Now miners only get direct contact with mercury now except the recalcitrant among them. This technology was obtained during an ASM course I enrolled in at the University of Mines and Technology (UMaT).

Another interviewee reported how he has managed to apply his knowledge and skills to ASM operations.

Yes, very well. As a geography student, I had the opportunity to learn a lot about safe mining and safety in natural resource utilisation. This enlightened my path in the field of ASM. Whenever I went to the ASM site, I tried to discuss with my colleagues the dangers associated with some of the on-site activities and actions. For instance, the channelling of wastewater containing mercury and other harmful substances directly into water bodies. I also shared with those who work directly with mercury how it can affect their kidney and lungs when it gets into their body.

Some educated youth interviewed (n= 11) reported that several ASM miners did not wash their hands properly after handling mercury. Many of them also handled food and ate with their bare hands after ore processing, which involved mercury on-site. This, however, posed serious health and safety concerns for these operators. According to six (6) educated youth, the lack of adherence to precautionary measures regarding the handling of mercury was because these non-educated miners had yet to experience severe health problems such as respiratory diseases. As a result, they continue to use and mishandle mercury. According to an educated youth who is a managing director of a licensed small-scale mining (SSM) operation at Anyinam:

Mercury is a slow killer and does not act quickly. It takes a long time for the health problems of mercury exposure to manifest. Therefore, ASM workers do not take any advice regarding how mercury is to be used before and after gold processing...Some local people I have employed told me; boss, we have been doing this for a long time and have not died from it.

Additionally, interviewees reported that many ASM operators did not wear masks when heating gold amalgam. As seven (7) interviewees mentioned, the burning of the amalgam generated mercury fumes in the air, and miners who inhaled it frequently potentially risked suffering from respiratory diseases. Eight (8) interviewees further indicated that after interacting with some ASM miners they contacted, they made them aware of how to use mercury to extract gold without exposing themselves to severe health risks, especially when misapplying it. Out of the eight (8) interviewees, five (5) also indicated that they offered practical explanations to ASM miners about using and handling mercury in mineral

processing. However, they indicated that most were reluctant to adopt what they had taught them.

That said, those who heeded the vital information on mercury use and knowledge shared by the educated youth made conscious efforts to gradually adopt them to ensure safer and cleaner production within the ASM landscape. Educated university graduates working with international organisations sometimes visit mining sites to introduce and talk to miners about mercury-free processing technologies that reduce mercury emissions and their adverse health impacts. For instance, an interviewee reported that after being made aware of these mercury-free technologies, he bought one and started to use it to process gold ore. However, he admitted the processing procedure was somewhat complicated.

In underground mining, we found that local miners had inadequate knowledge of how to use compressors. As a result, dust and fumes from blasting and drilling ore exposed miners to various health risks. Some of the ASM miners who were responsible for drilling and blasting always inhaled a lot of dust and fumes from the explosives since almost all the audits and ghettos constructed or designed by small-scale ‘underground’ miners did not have good lighting systems to escape these fumes compared to the large-scale mining industries. Two (2) interviewees mentioned that underground miners knew that their exposure to dust could cause respiratory problems. Yet, most had resorted to drinking herbal mixtures to clean their liver to prevent illness. As one of the interviewees indicated:

Underground miners, usually chisellers, drink ‘concoction’ to clean their liver when they are around the compressors in mine workings (underground mine spaces). They know that dust from chiselling and blasting the ore is not good for their health. But they are reluctant to change their ways of mining practices. My friend’s father died of his frequent exposure to dust. (BSc and MSc degree holder in Environmental Science)

4.4 Equipment repair and maintenance services

The involvement of educated youth in the ASM space was found to benefit the sector through the provision of repair and maintenance services. For example, some university graduates

who engaged in small-scale mining used the knowledge they had acquired in school to provide support services to ASM miners who needed technical assistance to repair their equipment. Besides, some educated youth who had established formal ASM operations employed fellow graduates from different fields to work for them. In this case, graduates who worked in such ASM operations utilised their knowledge and skills across various departments of the ASM business, from administration to mechanical and extraction levels. One such group of graduates was those with engineering backgrounds, such as mineral, mining, mechanical and geological engineers, who provided ASM-related support services to licensed small-scale mining companies. As emphasised by a mechanical engineer:

I used my mechanical engineering-related knowledge and technological know-how to fix the mechanical problems of mill hammer machines used in ore processing at some sites I worked for. I was able to repair this equipment because of my engineering education and training at the university.

Four (4) interviewees explained that other educated youth, such as electrical and mechanical engineers, could bring their expertise to repair machines used in the gold recovery process.

As this interviewee indicated:

In the registered ASM sector, some educated, especially those unemployed and finding it challenging to obtain jobs in large-scale mining, take up temporary employment as electricians or mechanical engineers. For example, our company has employed one university graduate who is our mechanic for the excavator (BSc in Geological Engineering graduate).

4.5 Transfer of legal knowledge and processes by educated youth

We found that some educated youth used the legal knowledge acquired at the university to resolve land insecurity issues that are common in the ASM sector. Some educated youth reported forming partnership arrangements based on legal documentation procedures. The partnership arrangement did not have a formal approval from the Ghana Minerals Commission. As the findings show, the educated youth who are lawyers and involved in the ASM sector engaged in legal agreements with their ASM partners in order to avoid land-related conflicts. In most informal ASM settings, operators verbally go into contracts without

any proper documentation, which increases the possibility of conflict between interested parties. According to four (4) educated youth, their ASM partners offered registered concessions for the mining operations. Therefore, the registered concessions became the basis for ore production negotiation and sharing arrangement. For example, a legal practitioner involved in ASM mentioned:

When we started our ASM, we needed a contract agreement with the person who was going to give us the concession for the mining activities, so that we avoid any misunderstandings in future... As the lawyer of the mining group, I represented the group in court with our partner (concession owner) and did the necessary legal documentation and processes required for our operation ... We all agreed on the terms of operation and ore production sharing arrangement... Since the partner is just giving us a licensed concession, we decided to give him 15% of the ore production every week, provided that we worked and extracted gold in the week.

Such contract negotiations have afforded some uneducated ASM miners² the opportunity to also learn and understand legal contracts and the consequences of breaching them. Hitherto, most uneducated ASM miners in the ASM sector acquired land for their operations through informal arrangements with landowners which were usually not backed by any legal documentation or formal processes.

4.6 Sharing of ASM experiences and knowledge with peers and tutors

Our findings show that youth who engaged in ASM, especially informal gold mining, had accumulated substantial knowledge and skills about ASM operations ranging from ore extraction to processing during their Basic, Junior High or Senior high school education.

Besides, these youth who were able to further their education to the tertiary level, especially

² Uneducated ASM miners refer to those who have ASM knowledge and practical experience but have not had formal education. Having a formal education influences the kind of mining practices people engage. This group include people who have acquired secondary education, but their education and knowledge are limited on safe mining practices, business operations, and legal knowledge, and processes, etc. Uneducated ASM miners or uneducated youth are those who not acquired various forms of knowledge acquired at higher educational settings.

university, carried with them mining- related knowledge and skills such as health impacts of unsafe mining practices, ore processing using mercury, ore body tracing and ore sampling. Furthermore, depending on the course they pursued at the university, they applied their experiential knowledge of ASM operations during classroom discussions, which benefitted their colleagues who lacked work experience in the sector.

According to one interviewee, his knowledge and practical skills regarding gold recovery and understanding of value addition through tailings re-processing and mineral identification provided him with the opportunity to explain some mining practices to some ASM lecturers or professors in mineral engineering, particularly how to recover gold by gravity concentration technique like panning and sluicing. This knowledge could only be acquired through years of working in the ASM sector. In addition, issues of mercury use in the mineral engineering class allowed him to share his perspectives. Through his ASM experience, some lecturers or mineral laboratory technicians became knowledgeable and gained expertise in the gold recovery process.

Another interviewee who studied Environmental Science at the university indicated that his exposure to ASM through galamsey before going to the university enabled him to share his practical knowledge regarding the pollutants in ASM and their health implications with his fellow course mates and lecturers during laboratory work sessions.

4.7 Practical application and understanding of key theoretical concepts

Some educated youth with prior ASM knowledge and experience were admitted into academic programmes, including environmental science, mining engineering, mineral engineering, natural sciences, geology, and geography. For instance, a mineral engineering student who had worked in informal ASM for many years used his practical skills or experience to grasp concepts such as gold recovery, tailings processing, and rock formations. According to one interviewee who did BSc in Mineral Engineering, his over ten years of

work experience in informal ASM exposed him to different mineral extraction and processing stages. This helped him perform laboratory work during his undergraduate studies with ease and mastery. In his own words, he narrated his ASM journey:

My interest in BSc minerals engineering came from my exposure to small-scale mining during my childhood and presently since I was born in a typical mining community where ASM is the only prime occupation. During my teens, the only work that I could do was washing loaded blankets or mats. I had a series of transformations and skills in this field from time to time until I started loading the hammer mill machine, which was the most effective and reliable comminution equipment at that time. I graduated from machine loading to sluicing of mineralised material (specifically midlings) to obtain a better concentrate of the mineral (gold), with the aim of promoting the next recovery stage like amalgamation (the gold concentrate would be able to form a compound with mercury). In my opinion, I was learning and working with the idea of attracting glory and a good name for myself, not knowing I was building a career and promoting myself one day. There are also instances that I took full responsibility as a leader to supervise, manage and control the tailings washing plant, which we affectionately called sump washing in my teens.

He further explained how the above ASM experience helped him gain an academic advantage over his colleagues at the university:

... Helped me a lot when I entered the university as a minerals engineering (minerals processing) student because I knew almost all the operation units in ASM, especially the minerals processing aspect. For example, ASM helped me gain a lot of practical knowledge and skills that a significant percentage of my colleagues did not have during my undergraduate. Courses like Minerals Separation Processes, Small-scale Mining and Processing and Pyrometallurgy contain ASM aspects, from grinding, panning, sluicing, amalgamation, heating of amalgam and smelting where different gold ores are treated to recover its valuable metals. I had full hands-on experience in mineral processing in ASM in Prestea some years ago and presently.

Similarly, an interviewee who studied for a bachelor's degree in Geography and Regional Planning at the university used his acquired knowledge and practical skills in ASM to explain environmental problems, comprehend concepts and philosophies in geography, and better grasp key concepts taught in the classroom. In addition, due to his accumulated knowledge of mining and its impacts on the environment, which was gathered mainly through many years of engaging in ASM operations, he developed an interest in geography at the senior high school level and furthered to the university.

...Yes, it did help me a lot as I was able to understand better courses and topics in Geography and Planning that focus on environmental degradation, biodiversity conservation, and natural resources management. In class discussions, I mainly was called upon by my lecturers and colleagues to share my experiences on the activities within the ASM and how they can be related to some of the environmental management and natural resources utilisation concepts and management approaches.

Interviewees who did not have exposure to ASM operations before doing geological engineering but working in the ASM sector suggested that the ASM sector should be pursued as an avenue for university students, especially those in environmental science, mining, mineral, and geological engineering, to undertake internships. According to some interviewees, this approach would provide an important opportunity to learn technologies and mining methods used in the ASM sector. As expressed by some of the interviewees, this line of thought stems from the valuable experiential knowledge that students with ASM work experience have, which inevitably enriches their academic training.

4.8 Enhanced synergies between higher education and ASM sector

Findings from two interviewees show that the University of Mines and Technology (UMAT) provided mining training sessions to ASM operators at their university premises to acquire knowledge in the area of environmentally sound and responsible small-scale mining following the government ban on ASM in 2017. As stated by these interviewees, the government funded the training sessions as part of efforts to sanitise informal mining activities in the country with impunity and promote sustainable mining practices in the ASM sector. Through this medium, the seeds of collaboration between higher education (HE) institutions and the ASM industry were sown.

Following up on the importance of applying their knowledge in the ASM sector, eight interviewees emphasised that the tertiary education authorities should start thinking about how educated youth, particularly university students, can use their knowledge and skills acquired in the educational settings to promote sustainable mining practices and reduce safety

and health risks in the foreseeable future. Universities' collaboration with the key institutions in the mining industry was identified to provide avenues for university students to bring sustainable mining practices, including mercury-free technologies, which are environmentally friendly, into ASM operations.

Moreover, the involvement of university students in ASM has potentially positive implications for formalisation efforts in the sector through their association with higher educational institutions. This is evident from instances where some graduates had ventured into ASM business as entrepreneurs. Also, through the involvement of educated youth in the sector, some small-scale mining companies were noted for employer engagements that sought avenues for students to have practical experiences and internships with them. A 28-year mineral engineering graduate suggested that mining companies, especially those in formalised settings, should see higher education institutions as the first points of call for technical support and training their employees, which will further enhance the synergies between both academic and mining settings.

5.0 Discussion and conclusion

Transforming and sustaining ASM operations across rural sub-Saharan Africa through introducing environmentally-friendly technologies and improving knowledge of local miners and application of smart mining practices should be high on the development agenda of countries where ASM continues to be a viable source of livelihood for many people. In this paper, we examined the nexus of higher education and ASM and how educated youth involvement in these sectors impact each other. Specifically, we explored the symbiotic relationship between the two sectors, emphasising the role of educated youth in promoting cleaner and safer production in the ASM sector. By doing so, we developed a model known as the youth in higher education and the ASM impact framework to explain the

interrelationships of youth involvement in ASM and higher education and its (potential) impacts on the ASM industry (see Fig. 1).

Starting with the youth in the framework (Fig. 1), two youth categories are admitted into higher educational institutions: inexperienced youth and experienced youth. First, as our findings reveal, ASM provides an avenue for youth to engage in the sector. This offers another opportunity for the youth to acquire knowledge and practical skills in the ASM industry. Thus, youth who have gained knowledge about ASM operations and built ASM experience over time constitute the experienced youth. They are also called youth with ASM knowledge. However, inexperienced youth are the youth with little ASM knowledge who lack practical experience about ASM operations. This group of youth might have acquired the ASM knowledge from the classroom (in junior high school or senior high school), the media outlets (such as television, and radio, etc.) and from other people. The ASM knowledge this group of youth have is considered as general knowledge. When these two groups of youth enter university or polytechnic, they are able to acquire knowledge from different disciplines, including mining-related courses, environmental science, geography, business administration and law. Based on the knowledge gained in tertiary institutions, inexperienced youth and experienced youth status change to become educated youth.

In higher educational settings, experienced youth share their ASM knowledge through laboratory work and classroom discussion. This allows tutors and other students who have not engaged in [informal] ASM operations to learn from the experienced youth and to also discuss mining-related topics. Related the framework to our findings, students with ASM experience who gained admission into mining-related courses could grasp and comprehend concepts such as gold recovery, tailings and geological formation of minerals. Such exposure to ASM operations while in university affords experienced youth to show interest in various aspects of ASM (such as safety and health, safe mining practices and clean production) and

subsequently seek employment in the mining industry. In a way, this finding points to one potential pathway to respond to the growing public outcry from scholars, development professionals, and donor partners on the need to make school curriculum practically oriented for today's youth as they transition into the labour market in search of jobs (Sumberg et al., 2017; Yeboah, 2021; Yeboah et al., 2020).

Second, as illustrated through the framework, when educated youth engage in ASM as entrepreneurs or employees, they are able to utilise their knowledge and skills acquired in higher educational settings. For instance, some utilised their knowledge to develop innovations and diffuse ideas or knowledge about mining practices into the sector (as seen from the arrow from new knowledge, innovation, and diffusion of ideas/mining practices (NKIDIMP) box to the ASM Box). Moreover, as the NKIDIMP is applied to ASM, educated youth who engaged in the sector could have (potential) positive impacts on the ASM industry (see the arrow pointing from the ASM box to the impact of NKIDIMP in the ASM box). The educated youth will be able to pay greater attention to responsible, environmentally-friendly mining practices, cleaner production, and add value or transform ASM operations. As shown in the impact of NKIDIMP in the ASM box, educated youth involvement following their knowledge of the mining activities, especially ASM could lead to awareness creation about the proper use of mercury, reduction in mercury emissions through the use of mercury-free processing technologies, reduction in safety and health risks, development of new structures of tailings ponds and increase in ore production through grade determination and proper mounting of sluicing board at a right angle.

To illustrate the above linkages in the framework, it is clear from our findings that many ASM miners, especially, mishandle mercury.

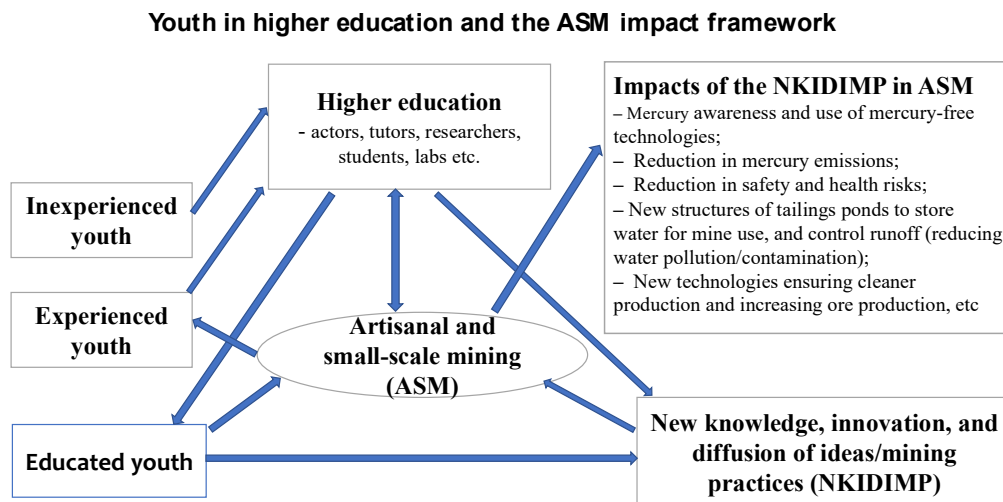


Fig. 1: Youth in higher education and the ASM impact framework

Source: Authors' construct

After exposure, some either fail to wash their hands or wash them improperly. Others even choose to handle food and eat with their hands exposed to mercury. Such careless behaviour poses a threat to miners' health. Earlier studies have highlighted that one major negative externality generated by ASM operations is the use of mercury which causes chemical water pollution (e.g., Arthur-Holmes et al., 2022b; Bansah et al., 2018; Hilson & Pardie, 2006; Smith, 2019; Telmer & Veiga, 2009; Hirons, 2020). While we make no claims of absolute reversal of this situation, our findings suggest that many educated youths know the pollutants used in ASM operations and their impacts on water bodies and human health. Moreover, these youths reported bringing local mine workers' attention or awareness to these pollutants and the negative consequences of their improper handling of mercury. Therefore, more involvement of educated youth in ASM could become a useful avenue to address the improper handling of mercury and other toxic chemicals used in mineral processing and further redress their negative consequences.

Given the negative impacts of mercury use on the environment, educated youth could easily understand the process and use of mercury-free technologies introduced into the sector compared to uneducated ASM miners who mostly occupy the sector. Therefore, through educated youth knowledge transfer from educational settings to the ASM industry, the Minamata Convention on Mercury's agenda to reduce the emission of mercury and its use (e.g. United Nations Environment and Global Mercury Partnership, 2017) could be realised through this distinct group of ASM miners. Relatedly, the mercury amalgamation method of mineral processing could also be reduced in the sector as educated youth make efforts to share their knowledge of mercury and its usage with uneducated ASM miners.

Studies have highlighted that many countries, including Ghana, have developed National Development Plans for reducing mercury emissions in ASM mines and managing health impacts associated with mercury use (Hilson et al., 2018). Thus, in realising these plans, educated youth can play an integral part through their willingness to learn new technologies and knowledge of mining and its negative environmental and health impacts. We argue that educated youth hold the potential to achieve such objectives in the ASM sector, where mercury handling is a major concern, through bringing innovations and transferring their knowledge to the sector. Their involvement can even create avenues for uneducated youth who hitherto have been tagged as unwilling to adopt environmentally sound technologies nor acquire knowledge around mercury handling and emissions to adopt relevant knowledge and new technologies.

As shown in the framework, the knowledge that educated youth obtained in higher educational settings can be used to innovate technologies that promote safe mining practices in the sector. Our findings show that some educated youths are able to develop and use different structures of tailings ponds. The benefits of such innovation (i.e., tailings ponds) are enormous. First, our findings suggest that such innovations are considered to store water for

mine use, and control runoff (reducing water pollution/contamination) and prolonged leakages. Investment in this technology or innovation would likely go a long way to address the challenge confronting rural mining communities that are beleaguered with pollution of their water source for domestic and farm use. Second, tailings pond innovations are key to cleaner production because other miners can adopt this method of managing wastewater from mineral processing. Third, tailings pond innovation is also important in reducing the transfer of heavy metals into the food chain via food crop uptake when mining wastes contaminate farmlands. This is especially when wastewater containing heavy metals does not leak into farmlands with crops. Fourth, the waste materials in the ponds can be processed to generate additional income.

A key finding from this study is worth mentioning in showing the relevance of youth from higher education in ASM. That is, educated youth with legal knowledge and background are making new arrangements for mining partnerships that are ingrained in the legal system. Based on this arrangement, educated youth involved in ASM are more inclined to formalise the sector. Furthermore, in line with the legal documentation of ASM partnerships through the legal systems, educated youth are better positioned to operate legally. Consequently, they can promote safe mining practices. Therefore, educated youth involvement in ASM should be championed in the development and policy agenda of higher education, mining/mineral institutions, and governments in sub-Saharan African countries, including Ghana.

From the framework, higher education actors (such as lecturers, laboratory technicians and researchers) based on their knowledge and skills can develop innovations, and create new mining practices through their research for the transformation and sustainability of the sector. The higher education institutions that are into mining-related courses can interact with the ASM industry with collaborative and training programmes as

well as research conducted in the ASM sector for the development of innovations and knowledge acquisition and understanding of mining practices. In the framework, such interconnection is important due to its synergetic benefits. Linking this explanation to our findings, we saw that educational institutions like the University of Mines and Technology (UMaT) had provided some training sessions for ASM miners to gain knowledge and better understand the negative environmental impact of ASM, following the ban imposed on ASM operations across the country. The training was a Government of Ghana-sponsored programme as part of the community mining scheme. UMaT has a partnership with some registered small-scale mines. Students, especially graduate students, undertake field trips to those mines. Some lecturers also provide consulting services to registered small-scale mines. These essential activities are not done in some other universities in the country.

From the framework, a model of partnership that offers opportunities for the mining industry to meet academia becomes one potential pathway to help make school curriculum more practical and also allow students to acquire knowledge, competencies, and various skills in high demand in the mining industry. In light of this, higher education institutions that offer mining-related courses may need to develop internship programmes or regular interactive sessions where students can have practical internships with licensed ASM operators to exposit and deepen their knowledge about mining practices. This would likely enhance the students' employability after university.

In conclusion, educated youth involvement in ASM has a huge potential to create a knowledge-based economy within the mining industry through youth transfer of skills and knowledge and the diffusion of innovations or ideas. Our findings show that more engagement of educated youth in ASM could help address issues regarding unsafe mining practices, negative environmental impacts, and safety and health concerns of the ASM sector in the future. Therefore, avenues are needed to create a collaborative and mutually beneficial

relationship between ASM actors and academic institutions that offer courses relevant to the ASM sector. Regular interactions and joint programmes are also needed to exploit the knowledge of each sector for mutual gains. As mentioned earlier, higher education institutions may need to design and develop internship programs where students can have practical internships with licenced ASM operators to highlight, share and deepen their knowledge about mining practices. Based on our findings, we also conclude that educated youth involvement in the key aspects of ASM, such as entrepreneurs, management roles, and mineral extraction and processing, could help the sector adopt environmentally sound mining practices to ensure safer and cleaner mineral production in the sector.

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