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Formal Education, Practical Learning and Mining

An analysis of the career paths of mining workers in Norway with formal training from ca. 1860 to 1940

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Abstract

High-quality education is emphasised as key for 'natural resource intensive economies' to overcome problems with underdevelopment. However, our knowledge of how education has benefitted natural resource industries and how skilled workers specialising in natural resources have used their capacities and experience, is scarce. Norway is one of the richest resource natural resource intensive economies in the world with a high performing education system. Natural resource industries have constituted the largest part of the economy, and this remains the case today. This paper explores formal education and practical learning and how they were used in mining development in Norway between the 1860s and 1940, a period when the sector went through a radical technological transformation and productivity increased dramatically. I find that the adoption of new complex equipment, working techniques, systems and power sources

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were followed by an increase in the use of formally trained workers and a diversification in the workers' educational background, notably chemists, construction engineers, mechanical engineers, electro-engineers and economists. They supported the advance of the sector by using, maintaining and organising the new technology. The formal mining instruction was largely used in the making and designing of mines, ore extraction, and management and organisation of mining companies. Yet, mining engineers combined the theoretical and scientific instruction with work experience - both in Norway and abroad - and this practice represented supplementary learning processes to the formal training, which were key to transfer and use technology from abroad.

Introduction

This paper seeks to complement the literature with a historical in-depth analysis of the role of education in mining in Norway, one of the richest natural resource intensive economies in the world. It seeks to further our understanding of the role of education in 'natural resource intensive economies' by exploring formal education and practical learning in the increasingly knowledge-based, innovative and productive mining sector in Norway from the 1860s to 1940; a period in which mining went through a radical technological transformation in terms of finding, removing and processing ore. Trained workers are followed through their formal studies to the labour market, and throughout their career, with the aim of exploring learning processes in school and outside a school setting, and how such knowledges were used.

On the one hand, mineral and metal extraction is a 'natural resource industry', and has been found to be based on – along with other natural resource industries, such as agriculture, timber and fishing - 'medium and low technological activities'. This, in turn, have led to the hypothesis that natural resource industries have created very few qualified jobs.[i] This argument is part of a wider notion that natural resources cause slow growth and retard development. Countries rich in natural resources which exhibit poor economic performance are often understood as being 'cursed' and recommended to shift to industries which are not based on raw materials.[ii]

On the other hand, historical studies, and analyses of recent decades, indicate that there are natural resource industries which have had similar characteristics as manufacture or high-tech industries. Evidence suggests that natural resource-intensive industries in high-income economies have been highly knowledge intensive, dynamic and innovative, they have created linkages to other industries, and they have depended on a number of knowledge specialisations, inputs from other sectors and skilled workers.[iii] A key empirical problem with the 'resource curse' idea is that some of the richest countries in the world, such as Norway, Sweden, Canada and Australia, have developed fast-growing and high-performing economies based on, and much due to, natural resources. What are the underlying factors explaining growth in knowledge-based and dynamic natural resource industries? Education is pointed out to be key for natural resource intensive economies to solve problems with underdevelopment and vital to their development, and is explored here for the mining sector in Norway between 1860s and 1940, a period in which the sector developed radically. Was education used in this transformation? If so, how? Were there any limitations to formal education?

Theoretical framework

According to the economist Thorvaldur Gylfason natural resources have weakened the incentives to invest in human capital. He writes that:

> "...nations that are confident that their natural resources are their most important asset may inadvertently...[...]... neglect the development of their human resources, by devoting inadequate attention and expenditure to education. Their natural wealth may blind them to the need for educating their children."[iv]

Similarly, the authors Elena Suslova and Natalya Volchkova test human capital formation and find that industries which require 'sophisticated human capital inputs' would be in disadvantage in natural resource rich countries.[v] They write that:

> "...resource intense sectors absorb national savings while creating only a few eminently qualified jobs which leads to lower incentive of the society to educate their citizens compared to the societies with lower abundance in natural resources."[vi]

The argument is based on the idea natural resource industries have been founded on medium- and low technological activities, which have led to lower incentive of the society to educate their citizens compared to countries with less natural resources.[vii] However, these assumptions lack of empirical evidence.

Historical studies and analyses of recent decades indicate natural resource industries which have had similar characteristics as manufacture or high-tech industries. They have depended on a number of knowledge specialisations, inputs from other sectors and skilled workers. Paul David and Gavin Wright analyse the underlying institutional foundations for the mining sector in the

United States and show it was highly knowledge-based and created connections to other parts of the economy, including non-resource-based sectors:

> "We find...[...]... that late nineteenth century American mineral expansion embodied many of the features that typify modern knowledge-based economies: positive feedbacks to investments in knowledge, spillover benefits from one mining specialty to another, complementarities between public- and private-sector discoveries, and increasing returns to scale—both to firms and to the country as a whole."[viii]

Olav Wicken and Simon Ville compare two successful natural resource intensive economies, Norway and Australia, from a historical perspective historically, and find that linkages have developed between natural resource-based industries and other sectors, such as capital goods sectors, services and research institutions. New industries based on natural resources have often emerged out of these linkages and been vital for growth in both countries. They conclude that: "...dynamic interactive relationship between natural resource industries and enabling sectors is regarded as the core aspect of the successful economic development of Australia and Norway."[ix] More specifically, in mining, would not the mapping of ore deposits and analyses of minerals and metals require workers with in-depth knowledge in geology, mineral and chemistry? The planning and making of mines, would they not entail some of the most complex constructions that exist? After all, they are normally underground and involve solid tunnels, adits and ventilation systems, which demand precise mathematical calculations and scientific principles to prevent from collapsing.

On the other hand, there is evidence that natural resource industries in African and Latin American countries have performed poorly and affected the wider economy negatively.[x] This leads to the hypothesis that economies specialising in natural resources have managed their natural resources in very different ways. While Latin American and African natural resource intensive economies have generally experienced slow growth, Norway, Sweden, Canada, New Zealand and Australia, have developed highly successful and fast-growing economies based on natural resources. The interesting thing about these cases is that they have developed fast-growing economies instead of experiencing slow growth, stagnation and underdevelopment. Keith Smith points out that:

> "(t)hese small, open economies have rested their development paths on resource-based sectors, and out of them have developed low- and medium-technology industries that have driven growth within these countries. This has been the case not only historically, but in many instances remains the case today."[xi]

How have successful natural resource intensive economies grown? What are the underlying factors explaining high-performing natural resource industries? High-quality education has been emphasised as important and some scholars find 'human capital' as the most important factor which allow resource abundant countries to overcome the problems with underdevelopment.[xii] Petrovsky finds that education, among other factors, may affect natural resource development positively and reduce potential negative economic effects.[xiii] Mike Smart finds a causal chain from diversity of natural resources and educational attainment to democratisation and from democratisation to per capita GDP.[xiv] Recent studies come to similar conclusions. Brooks and Kurtz suggest that human capital resources condition development in oil rich countries, because they "...make possible the management of resources in ways that encourage the absorption of technology and development of new economic sectors." When human capital is absent, however, the resource curse is more likely to present itself.[xv] Ronald Mendoza, Harold McArthur and Anne Ong Lopez argue that "... notably human capital – appear to have transformed the natural resource curse into a boon for development."[xvi]

In some of the high performing natural resource intensive economies, such as the Nordic countries, Australia and Canada, education systems have been well developed.[xvii] In Norway, campaigns to improve the reading and writing skills of the population have roots back to the seventeenth century.[xviii] The Church encouraged reading through religious texts from early on and the first school law in Denmark-Norway was introduced in 1731. The oldest primary school in the Nordic countries opened in Bergen in 1740 and was financed by the Cross Church. During the nineteenth century, the state gradually increased public funds to education.[xix] From 1827, all children in the country between seven and fourteen years old should receive teaching in reading, writing and some calculation for at least three months a year and in 1837, 86, 4 per cent of the children in the appropriate age had formal schooling. In 1860, a law, which established a school system with regular school for all for seven years, was introduced.[xx] Using Norway as a model for other resource-rich countries, Thorvaldson Gylfason underlines the high level of human capital in this country.[xxi] Gøril Bjerkhol Havro and Javier Santiso draw on experiences from Chile and Norway and show that both countries have benefited from natural resources in recent years. They suggest that natural resource wealth is dependent on macro-economic policy, but also capable civil servants, a developed business community and human capital.[xxii]

Analyses on human capital and natural resources are highly nationally-oriented and use quantitative analyses to explore the relationship between natural resources, education and industrial performance, but how we lack in-depth analyses on the direct functions of education on the industry level. There is an agreement that mining education was of growing importance for mining, but we know less about *how* it was used and the type of knowledge it represented historically. There is little knowledge about what mining engineers – and other trained workers relevant for mining – actually learnt and did, and their work and daily tasks. How is education used in natural resource industries? Countries vary greatly, and knowledge bases vary between different types of natural resource industries, which calls for more detailed analyses. Peter William Musgrave has perhaps made the most comprehensive comparative analysis of the role of education and natural resource development. He detected the use of specific skills, which appeared to be important for the British and German iron and steel industries from the mid-nineteenth century to the mid-twentieth century, and related them to particular knowledge domains and qualifications. As an example, he finds that changes in technology from the 1860s were supported by new capabilities and specialisations:

> "The growing stress on science was leading to the employment of chemists in the industry. Here can be seen the beginning of the grade of "technician". Another growing point was associated with the expansion of the counting house, calling for more clerks whose education ranked them in this grade. The export trade would demand some knowledge of foreign language. Such men needed a broad education with specific attention to science and mathematics for potential works chemists."[xxiii]

Norway is one of the richest natural resource intensive economies in the world, much based on the country's oil and gas industry from the 1970s. But the country has a much longer tradition extracting minerals than oil, and metals, notably silver, copper, iron, steel, pyrite and aluminium. The following questions are explored in this paper: was the formal mining education – i.e. the knowledge learnt in school - used, and did it contribute the development of the innovative and increasingly knowledge intensive mining sector in Norway at the turn of the century? Were there any knowledge limitations to the formal instruction? If so, what were they, and was useful knowledge acquired other places, and in other ways, than in a school setting? Did workers with other types of education – other than mining - work in mining? If so, what educational background did they have and why would they be used?

Sources and methodology

Much research has been done on the relationship between technical education and industrial performance, but there is not much empirical evidence on its specific functions and direct impact on technological change, and much less on changes in natural resource industries. Analyses often focus on the supply and demand of education from a quantitative point of view and conclusions are normally based on the assumptions that 'the more skilled workers, the better'. The argument is that rich and developed countries have had a high number of engineers and technicians while poor and underdeveloped countries have had fewer.[xxiv] Yet, we cannot assume the relationship between education and industrial development, and second, we cannot expect engineers and technicians to have had the same functions everywhere and at any time. Robert Locke writes that "(i)t cannot be assumed…[…]…that schools in countries did not differ significantly in curricula, instruction, and in the way they were associated with business and industry…"[xxv] He underlines that cataloguing number of students, rates of growth etc. accounts for only part of the story:

> "To determine comparative educational effectiveness, from the entrepreneurial viewpoint, one needs (aside from data on numbers, size of student body, rates of growth of schools, and background of students)

> information about the conditions of entrepreneurship within an economy and about the extent to which the educational institutions were able to satisfy these conditions. It cannot be assumed...[...]...that schools in countries did not differ significantly in curricula, instruction, and in the way they were associated with business and industry even if each country had the same number of schools and they were of equal size. An investigation into the curricula of competing national systems of higher education ...[...]... is crucial for an analysis of higher education and entrepreneurial performance."[xxvi]

In analyses of education it is important to be aware of the knowledge limitations of formal instruction, and explore its direct applications in daily work, as well as learning processes and work experiences *after* graduation. Following the students from school to the labour market may contribute to further our understanding of the role of engineers, technicians, economists, etc. and how they have impacted industries. To obtain a complete picture of the role of engineers and technicians in innovation processes, empirical analyses of their formal learning through education, careers and practical learning through travelling and work would be required. The argument of Wolfgang König is relevant here:

> "So long as we lack research on the careers of the technical intelligentsia or on the selection processes and recruitment of industrial engineers, the question regarding the relations between technical education and economic performance cannot be answered properly".[xxvii]

'Mining education' is here referred to as formal mining engineering and mining technician study programs provided on a higher and intermediate levels at universities and schools which were aimed towards mining. 'Mining', for its part, is defined broadly as the production of metal ores, non-metallic minerals, stones, or rocks, and energy minerals.[xxviii] More specifically, mining involves the removal of metals and minerals from the earth and the extraction and mixing of ores into pure minerals and metals and alloys. 'The mining sector in Norway' includes all metals and minerals that were produced in Norway, and which were included in the official statistics.[xxix] An outline of the development and technological changes is provided in the first part of the analysis.

Was mining education used? If so, how was it used? These questions are sought answered in the second part of the analysis. First, the relevance and usefulness of the formal instruction is explored by analysing the cognitive and practical content of the study programs in terms of courses, content and teaching forms in relation to technological changes in the sector. Here, a broad and subdivided definition of technology by Bruland and Mowery, who divide it into 'knowledge', 'techniques' and 'organisation', is useful to capture the factors that enabled production. First, (1) knowledge entails the understanding and skills which are necessary for production and involves scientific knowledge and natural laws as well as engineering, know-how and operative skills. In mining, notably, this refers to the knowledge needed to measure, design and build the tunnels, adits, shafts etc. of mines, and to remove, transport and process ore. Second, (2) technology further involves techniques, i.e. the machines, tools and equipment and the instructions and processes required to employ, repair and maintain these. In mining, these were for example steam engines and turbines used for lifting and drainage, mechanical and electric equipment used inside and outside the mines, and crushers, converters and furnaces used in the processing of metal and mineral ores. Third, (3) organisation involves the administration, management and coordination systems through which productions occur. In mining, this includes the administration and management of workers and equipment at the mines, crushing and smelting plants, laboratories, workshops etc. These three aspects of technology are integrated in production processes.[xxx] First, this definition of technology is used to outline technological changes by using official statistics, the Mining Journal and secondary literature. Second, the content of the formal mining instruction at the Mining School, the University and Norwegian Institute of Technology (NIT) are analysed and compared to the technology used in mining. Here I use study plans, programs and descriptions of courses and subjects from the Royal Frederick University, the NIT and Kongsberg Silver Works Elementary Mining School in addition to official statistics and articles published in the press and the Mining Journal.

In the third part, I examine learning processes that happened outside school, notably work experience and 'learning by doing' by examining travels, work and career paths of mining engineers. Information about work and travels is collected of all mining engineer graduates from 1787 to 1940. Did mining engineers and technicians acquire work experience? If so, where and what kind, and how was it used? Limitations to the formal education is explored by considering that learning happens in different ways and in different settings. Nobel Laureate in economics Gary Becker finds that the adequate way of learning depends on the nature of the knowledge:

> "Some type of knowledge can be mastered better if simultaneously related to a practical problem; others require prolonged specialization. That is, there are complementary elements between learning and work and between learning and time. Most training in the construction industry is apparently still best given on the job, while the training of physicists requires a long period of specialized effort. The development of certain skills requires both specialization and experience and can be had partly from firms and partly from schools..."[xxxi]

For instance, words are viewed as a more effective tool when learning algebra than when learning carpentry.[xxxii] It is therefore essential to take into account other arenas for learning than schools and classrooms.

Considering the previous argument, mining activities largely involved physical and practical tasks of planning, designing and making mines, and making pure metal and mineral products, through digging, carrying, transporting, crushing and smelting. This indicates that learning by doing has been central. More generally, Hirsch-Kreisen and colleagues argue that natural resource industries, more than manufacturing industries, have often developed based on learning by doing and trial and error.[xxxiii] Theories in natural sciences, mathematical tools, testing of ore and chemical experiments were key to the successful implementation of mining projects, and was conveniently taught in classrooms and laboratories at schools and universities, but knowledge of how to operate mines and smelting plants, and how to transfer, install, adopt and repair equipment, and how to implement working methods, required practical experience. The physical and practical characteristics of mining suggests that its activities has been largely based 'tacit' knowledge, which is defined by Joel Mokyr as "... implicit skills such as dexterity, hand-eye coordination, and sense of 'what worked'".[xxxiv] This knowledge is best transferred from person to person through practice and observation.[xxxv] For example, to understand how to use a tool, a drill, an engine or a machine, reading about them in a book is not sufficient. They should be used and practiced with, probably multiple times, before operating them with success. Kenneth Arrow, for example, finds that workers solve problems and daily tasks, and become more efficient, through learning by observing and learning by doing.[xxxvi] Following this line of argument, there are some skills, which *must* be learnt in a practical work setting. The aim here is to explore work experience after graduation, both in Norway and abroad, and how such experiences were used for mining purposes in Norway.

Did workers with other types of education work in mining? If so, what educational background did they have? Biographies in so called 'yearbooks', published by the University, the Norwegian Institute of Technology (NIT) and technical schools, between 1855 and 1943 include detailed information of travels, scholarships, study and work abroad, and work positions at companies in Norway of whole cohorts of high school- and technician graduates. The publications were normally made 25 years and/or 50 years after graduation, which allows for a detailed analysis of the graduates' working career. It is therefore possible to analyse all workers with formal education who at some point during their career worked in mining.[xxxvii] Biographies are used in combination with official statistics to analyse changes in employment. The year of recruitment is known, which makes it possible to calculate the number of mining engineers, mining technicians, as well as all trained workers and make an estimation of their share.

An outline of mining in Norway: a technological transformation

Mining has played an important role in Norway since the sixteenth century. Mineral and metals goods traditionally ranged from copper, nickel, iron and silver, but miners had little knowledge of mineralogical features and geological formations in the early days, and ore was found more or less randomly.[xxxviii] Making mines and removing ores was traditionally based on animal and human power and most of the rock underground was extracted manually with picks, crowbars and wedges. Men and animals transported the ore by carrying the load on their backs and pushing or pulling a wheeled tram.[xxxix]

The demand for metals and minerals increased in the eighteenth and nineteenth centuries due to the on-going industrialisation processes that was happening in many countries at the time. The increased demand encouraged new searches for ores. Throughout the eighteenth century new minerals were recognised, described, and classified, and resulted in the discovery of many new elements, such as cobalt, nickel, manganese, tungsten, molybdenum, uranium, and others.[xl] New and more efficient techniques to find ores were developed, and organised and directed efforts led to more ore discoveries.[xli] In Norway - as in other countries – geological surveys, finding ores and mine measurements were gradually carried out in more systematic and organised ways and chemical analyses, microscopes and separation processes were used in ore analyses. From the 1870s, the Geological Survey of Norway used optical mineralogy.[xlii] Equipment and laboratories were increasingly used in geological research and chemical processes made it possible to determine the composition of rocks and minerals, and, to a greater extent than earlier, reveal their inner structure. More precise and detailed geological maps were made. In 1891, the Survey established a publication series, including yearbooks, academic reports and map descriptions of Norwegian geology. By 1920, geological and laboratory work had resulted in overview maps of the country, including Svalbard, detailed maps of mineral deposits and detailed ore analyses.[xliii]

Geological mapping, ore surveys and discoveries of ore deposits enabled increased production of the traditional metal productions of silver, copper, iron and nickel from the late nineteenth century.[xliv] After a recession period in the 1870, due to low prices, a renewal of the iron-, nickel- and copper industries began, large-scale production was initiated, and production increased considerably.[xlv] New metals and minerals were also produced, also on a large scale. Pyrite became an important production and large-scale production of electro-metallurgical products, notably nickel, ferro alloys, steel and aluminium were initiated.[xlvi] Coal production started in Svalbard in the early twentieth century and reached almost 33 000 tons in 1912 and 450 000 tons in 1924.[xlvii] During the Great Depression, production of most metals and minerals declined, but production increased again in the mid-1930s.[xlviii] Most of the metal and mineral products were exported to large markets in European countries and the United States, and the share of mining products increased from 6, 5 percent of exports in 1900 to 29, 2 percent in 1939.[xlix]

Metal and mineral extraction diversified from only a couple of products in the nineteenth century to multiple products in the early twentieth century. In

1866, a total of forty-two mining companies in Norway produced seven different metals and minerals, namely cobalt, copper, iron, nickel, pyrite, silver and zinc.[l] In 1917, a total of 167 mining companies produced around fifteen different minerals and metals, notably copper, molybdenum, iron, nickel, pyrite, silver and zinc.[li] In 1939, a total of ninety companies produced around seventeen different metals and minerals, notably aluminium, coal, copper, feldspar, iron and ferro-alloys, limestone, molybdenum, nickel, rutile, zinc, pyrite and talc.[lii] In 1919, pyrite stood for 76.5 percent of total production, while in 1939 it stood for 7.9 percent, and aluminium and ferro-alloys stood for 19.3 and 19.4 percent respectively.[liii]

The official mining statistics allow us to calculate how much each the average worker produced of mineral and metal ore (removal of ore from mines) and pure metals, minerals and alloys (smelting and refining ore at smelting plants) each year, which indicate productivity. Calculations made of production of selected metal and mineral ores, and metallurgical products, and average number of workers indicate radical productivity increased. Some of the productions showed great variations, notably coal, nickel and iron, but the general tendency, both for mineral and metal ores and metallurgical products, is that the amount of metals and minerals that were produced annually per worker increased over time. There were variances within the sector, but in general terms, the metals and minerals that were produced of each worker were much more after the turn of the century than in the 1870s. The productivity for the whole sector seemed to increase dramatically.[liv]

The company structure varied from company to company, but the number of workers employed in the mining industry increased, except for a couple of years in the 1920s – a recession period - when the number decreased dramatically. Before 1900 the average number of workers was around 2 650, while between 1901 and 1920 it was around 6 580 workers and between 1921 and 1939 the average number of workers was around 8 800.[lv] There were, however, large differences when it came to the size of companies. Large-scale companies often employed hundreds of workers. In 1940, the largest mining companies in were Sulithjelma Mines Ltd. with around 800 workers, Sydvaranger Ltd. with around 950 workers and Sydvaranger Ltd. with 1 441. Other companies varied between a couple of workers to around 300 workers.[lvi]

The dramatic production increase from the turn of the century and the initiation of new metal and mineral projects, led to exhaustion of many of the high-grade easy accessible mineral and metal ore deposits. The increasing demand, and exhaustion of mines, meant that companies were met with new challenges in terms of finding, removing and processing ores. New mineral- and low-grade ores in more isolated places and deeper underground were given attention. Undoubtedly, mining became more complex over time and maintaining profitability in new global settings involved adopting new techniques to locate and find ores, to organise work, and to prospect, remove and process ore and the knowledge that was used in mining was broad and varied.

First, the adoption of large-scale production led to an increased emphasis on mining administration, long term planning, management and business organisation. Perhaps knowledge of administration and economics seemed unnecessary in mining at first sight. The business historian Alfred D. Chandler wrote that administrative challenges in mining in the early twentieth century were minor compared to those of many other industries due to fewer technological changes.[lvii] However, this argument is unconvincing. On the contrary, it seemed to be very important to know how to administrate and manage mining companies, in particular the large-scale mining companies with multiple divisions, infrastructure challenges and hundreds – sometimes thousands – of workers. Knowledge about how to administrate large organisations in a rational way became key. In 1925, the Norwegian Mining Journal published an article saying that the understanding of "...economic, commercial management of a mine" was important - and required - for appointment to managing positions.[lviii]

Second, detailed planning of future production became increasingly important from the late nineteenth century, especially as high-grade ore was running out and mines were exhausted. Part of the future planning and economic forecasting included extensive use of knowledge in mathematics, economics and economic geology. Insight in mining laws and commercial-, civil- and social laws was also vital in this work. One example is Orkla, a Swedish company which took over the operation of Løkken Works in 1904. Before 1904, there was little knowledge of the extension of the ore deposits, even though Løkken Works operated for 250 years. Until then, production depended on the extraction of the highest copper-containing ore and old mining operations were arguably implemented "from hand to mouth."[lix] Røros Copper Works started earlier with such economic planning. In 1872, the mining engineer Jacob Pavel Friis presented a plan to the Directory of Røros Copper Works, which showed future production of two mines, Storwarts and Mugg, for respectively 70 and 30 years.[lx]

Third, after analysing the ore and evaluating economic profit of production, one of the biggest challenges involved the planification of the structure of mines, i.e. map tunnels, adits, shafts, ventilation shafts etc. and organising where they would go relative to each other. Making tunnels and adits meet below the ground surface required accuracy, precision and detailed measuring and constructions and structures beneath the earth were particularly difficult to make, since the mines could easily collapse. Shaft-sinking and vertical excavations from the surface were often made in deeper mines.[lxi] The use of natural scientific methods and detailed and careful examinations of the geological ground were crucial for this type of work and physical and mathematical principles were key to design and make mines. As mining developed, and mines became deeper and bigger, this type of work became increasingly challenging. In-depth knowledge in geometry, geology, mineralogy, mechanics and construction engineering were increasingly used and the mathematics used in operation became even more advanced.

The mine preparation and work in the 1880s of the engineer and sous-director at Vigsnes Copper Works Emil Knudsen are good examples of how mathematics and knowledge of natural sciences were combined with detailed measuring work and calculation. The old maps and observations at the firm were not accurate, and so Knudsen began making an accurate geological map of the oldest mine with a new theodolite (measuring device).[lxii] After systematic analyses of the mineral composition, he found out where the mineral ore developed underground:

> "On the basis of my geological maps of mine, I did surveys and found vein number 1 again at 360 meters' depth, whereas vein number 3 in my theory was not to be found that deep since the cavity with ore formation had been removed from the transversal plateau [...] (A)t 347 meters the ore appeared...[...] However, I found two new smaller ore veins at 260 and 286 meters...[...]... and when we got down to 460 meters I found vein

> number 2A, vein number 5...[...]... and vein number 1. At 160 meters I found an unknown ore vein number 1B, which I also rediscovered at 360 meters."[lxiii]

His work led to "...measurements [which] matched so accurately that there were only five millimetres difference in the lateral direction and 10 centimetres vertically..." A 'room and pillar' technique was used to remove the ore from the mine, in which the mined material was removed across a horizontal plane, creating horizontal arrays of rooms and pillars. Knudsen explained that when using such techniques, the size of the pillars was crucial. Too big pillars would potentially mean loss of ore and too small pillars could give too little support and involve the risk of the mine collapsing.[lxiv] It is evident that such measurements and constructions required in-depth precision, and knowledge of geology, mineralogy as well as mathematics and physics.

Fourth, more powerful machinery and power sources were adopted to facilitate large-scale production. Mechanical and electric power largely replaced steam, animal and manual power. Machines of different types eased the work at the mines, first steam engines, and later turbines, which gave power to lifts, drills, transport vehicles and drainage equipment. During the nineteenth century, new mechanical equipment was gradually adopted. In 1895, 26 out of 90 companies used engines, which included a total of 31 water engines, 32 steam engines, 18 electrical engines and 1 gas engine.[lxv] The adoption of electric power by the turn of the century, revolutionised mining and permitted large-scale production. Large power plants were built and used to provide electric power to equipment at the mines and processing plants. The first big electric power plant for mining in Norway was installed and used at Røros Copper Works in 1896 and included a high voltage network which provided power to lifts, pumps, locomotives, crushing machines and other equipment.[lxvi] Coal companies also used electric power and multiple electric machines, but they used different types of extraction methods, due to the softer mineral, and adopted long wall machines and electric drilling machines in the mines.[lxvii] By 1918, all mining companies used mechanical and electric equipment. This year, a total of 1 654 electric engines were registered at 167 mining companies in Norway. The applied mechanical power was 36 947 horsepower.[lxviii] In 1938, 146 companies used a total of 6 592 electric engines and the total primary power in ore, metal and mineral extraction and processing companies was 98 078 horsepower, in addition to the electricity for smelting, electrolysis etc. which totalled 294 210 kW (around 400 000 horsepower).[lxix]

This increased use of mechanical and electric equipment at the mining companies modified daily tasks for miners and engineers. In 1926, the Norwegian mining engineer Wolmer Marlow stressed the importance of having knowledge of how to operate and repair new machinery:

> "In order to master the increasingly applied mechanical operations at a modern mine and the often necessary large building projects, it must be required of the leader, that he fully knows this very important side of a mining operation. The daily and constant work at a mine is often purely mechanical and structural."[lxx]

11 years later, in 1937, Professor Harald Dahl stressed that the mechanisation influenced the work of the engineer. The faster the mechanisation, the more important it was for engineers to become familiar with the machinery they were operating. He referred to an English mining engineer who stressed that "...the more machinery that gain access to the mines, the higher the requirements of expertise."[lxxi] The installation, use and repair of mechanical equipment and machinery were based on knowledge in engineering, notably mechanical and construction engineering, which had previously not been used in mining. And, as electricity was commonly used from the late nineteenth century, electro-engineering became a new widely used knowledge field.

Fifth, after the ore was crushed and milled, separation- converting- and smelting processes were used on the ore to obtain pure and desirable mineral or metal products. During the nineteenth century, new processing techniques were adopted to extract new types of ore, lower-grade ore, to rationalise operations and to make purer products. The flotation method and the Manhés process were adopted in the late nineteenth and early twentieth centuries to extract copper, and the amalgamation process and sodium cyanide were used to produce silver. These new techniques were found to be very efficient and cost effective.[lxxii] From the turn of the century, electric smelting and electrolysis were for example used in production of aluminium, nickel and steel, and magnetic separation was used in iron production.[lxxiii]

The choice of separation- converting- and smelting techniques depended extensively on the characteristics and composition of the ore. The development of new techniques, and modifications of existing ones, were based on multiple specialisations. Testing, experimentation, creation and use of an increased number of metal and mineral products - and constantly more, better and more efficient techniques to process them - were based on in-depth knowledge of each mineral and metal - their characteristics and treatment – and widespread knowledge of geology, mineralogy, electro-engineering, chemistry and metallurgy. In 1925, the Norwegian mining engineer Fredrik Sebastian Nannestad confirmed that it was important to be aware that, in practice, there were no minerals which were treated equal. Therefore, the knowledge of ore dressing methods, mineral characteristics and processing techniques represented very extensive knowledge.[lxxiv]

These technological changes happened on a broad scale and contributed to a technological transformation of the sector. By the 1920s, all mining companies adopted mechanical and electric power, and some of them were characterised by being some of the most technologically advanced firms in Europe. Orkla Mining Company and Sulithjelma Copper Works were technologically advanced corporations with large-scale productions of copper and pyrite. By the 1920s, Orkla Mining Company was viewed as "...an extremely well managed enterprise, the mine was one of the best in Europe and the mechanical equipment was excellent."[lxxv] The company was called "Europe's most modern and well-equipped and leading pyrite works."[lxxvi] Sulithjelma Copper Works became Norway's second largest company at the beginning of the twentieth century. With the first railway in the northern Norway and one of the first electric smelting ovens, the company was considered "Europe's most modern mining works."[lxxvii] The state-owned company Kongsberg Silver Mines became a "fully modern mining works" in 1914 with the installation of a full electric operation of pumps and lifts.[lxxviii] New power sources and new extraction techniques made the electro-metallurgical industry particularly successful. It is found that "(m)ore than anything else it was this industry which transformed Norway from a rather poor farmland into a prosperous industrialised country."[lxxix] The sector was innovative, productive, it was based on highly complex knowledge and became increasingly knowledge intensive. The question that is explored in the next section is whether the formal mining instruction, the courses in the study programs and the knowledge they represented, was played a role in this development, whether it relevant for mining, and if so, how.

Formal mining instruction

Mining education was one of the first technical training programs aimed to form engineers and technicians to a specific industry. The first mining school in Europe was created in Freiberg, Germany in 1702, and schools of mining and metallurgy were established in Austria, Russia, France, Italy, Norway and Sweden some decades later.[lxxx] In the nineteenth century, there was a growing conviction worldwide that mining engineers and technicians – and education more widely - were important for mining projects to succeed.[lxxxi] This growing conviction should be understood in relation to the radical technological changes that were happening in world mining from the late nineteenth century, in terms of new and more efficient energy sources, new techniques for finding, removing and processing ore, new management systems and large-scale production.[lxxxii] David and Wright find that mining schools in the United States were key to the exceptional development of mineral and metal productions in this country.[lxxxiii] In Germany and Britain iron mining "a broad general academic education with some basic science was essential".[lxxxiv] Especially managers in these industries needed a "...sound basic education which included science."[lxxxv] In Australia and Chile too – countries with a long mining tradition and increased production of metals and minerals in the early twentieth century - mining engineers were understood as crucial.[lxxxvi] In Norway, formal mining education was provided from 1757 at the Mining Seminar in Kongsberg and transferred to the Royal Frederick University in Christiania in 1814. Formal mining education even became mandatory for certain leading positions from early on. In 1818, Røros Copperworks decided that: "As Managing Director at Røros Copperworks must in the future no one be selected, who have not fully studied mining, and passed exams in his theoretical as well as practical skills in mining engineering..."[lxxxvii]

The main purpose of the Kongsberg Mining Seminar was to educate engineers to be employed at mining companies. The aim of the mining engineering program at the University - set to four years in 1814 and later extended to five years - was twofold: to provide (1) capable managers for mining companies and (2) scientists to the University and research centres. The University took a scientific approach and the basis of the mining engineering program was natural science courses, notably mathematics, mechanics, geology and mineralogy, which, as seen, lay the foundation for knowledge of how to design, plan and construct mines.[lxxxviii]

The students received in depth teaching of natural sciences, but also instruction of 'mining' itself. In addition to courses in general natural sciences, the study program included courses which were more directed towards specific tasks in mining. Some of these courses included the instruction of how to use and repair mining machinery, mine structures and constructions, notably 'mining construction', 'mine factory' and 'machine drawing'.[lxxxix] Another mining course was metallurgy. Here, the students were introduced to metal characteristics and extraction methods.[xc] As more metals and minerals were produced, and more processing techniques entered the market, learning about metallurgy – and physical and chemical behaviour of metallic elements - was key for the future work of mining engineering students.

Gradually, more focus was given on mechanical equipment. In 1871, 'study of machines' became a course and object of examination.[xci] This change reflects the increased use of steam engines, lifts, mechanical devices etc. around mid-nineteenth century, and the increased need to know how to use and repair mechanised equipment. Moreover, as a response to the adoption of electric power by the turn of the century, electro-engineering was added as a separate course in 1909.[xcii] Inorganic chemistry was added as a specialised chemistry course in 1910, which included lectures about chemical elements, physical chemistry, electrochemistry and mechanical technology and 'electrometallurgy' was introduced as a separate course in 1913.[xciii] These reforms responded to the new large-scale mineral and metal productions based on ore extraction and the use of electric power.

Changes in the program and adoption of new courses happened normally after new technology had been adopted and spread throughout the sector. For example, new courses in mining machinery were introduced in the program after the widespread use of mechanised equipment and the course in electro-engineering was introduced after the shift to electric power from the late nineteenth century. It is clear that new courses followed the adoption of new technology, which suggests that technological changes influenced the study program. All in all, the mining engineering program covered a broad spectre of natural science and engineering courses and adapted to, and roughly matched, the 'knowledge areas' which were used in mining. This highly suggests that that the mining engineering students were given a solid scientific and theoretic knowledge foundation, which was both relevant and useful for the mining sector (see table 1):

Table 1. Simple overview of knowledge areas used in mining and mining engineering study program in Norway

Scientific knowledge areas used in mining	**New knowledge areas from the late nineteenth century**	**Mining instruction**	
Mathematics Physics/mechanics Geology Mineralogy Chemistry Metallurgy Construction engineering	Electro-engineering Economics Administration	**Continuous courses from 1814:** Mathematics Mechanics Geology Mineralogy Mining construction Mine factory Metallurgy (ore treatment and analyses) Machine drawing	**New courses (first adopted):** Study of machines: 1871 Electro engineering: 1909 House construction: 1911 Social economics and law: 1911

Sources: K. Ranestad, "The mining sectors in Chile and Norway, ca. 1870–1940: the development of a knowledge gap", *Innovation and Development* (2017), 9

The increased diversity, specialisations and complexity of the mining sector were important arguments for a broad mining engineering program. In the late eighteenth century – during the time when the Mining Seminar in Kongsberg provided the formal mining education in Norway - theoretical sciences are found to be less used and more dominated by traditions and craft skills.[xciv] Later, however, in the nineteenth century, scientific knowledge became more important and in 1910 the Norwegian Institute of Technology (NIT) wrote that "(a) large modern mining enterprise is a technically very complicated business and requires among engineers and managers a significant insight in numerous and extensive areas."[xcv]

In 1914, the mining engineering program was transferred to the newly opened Norwegian Institute of Technology (NIT). A Committee - established to discuss the future of the mining engineering program - quickly concluded that it be moved to the NIT, since, the technical courses, such as machine study and construction studies, electro-engineering and surveying were more developed at the NIT than at the University. Teaching facilities were new, and the laboratories were well-equipped.[xcvi]

The mining engineering program maintained the courses in natural sciences after being transferred to Trondheim, but also increased the focus on machinery and construction. By 1914, most mining companies used mechanical and electric constructions, such as drilling, draining, ventilation and transport systems, ore dressing and extraction equipment etc., which explains the increased emphasis in this area.[xcvii] From 1914, during the third and fourth years, the students took courses in social economy and law and bookkeeping. The course 'social economy and law' included topics about the relation between capital, work and nature, increase in value, capital interest and wages, and a separate course for bookkeeping was introduced in 1913 and finance and statistics were introduced as separate courses in the 1920s.[xcviii] These changes are probably explained by the adoption of large-scale mining in the late nineteenth century and the new focus on accounting and long-term economic planning.[xcix]

Increased focus on management and economic planning in mining is also seen in other countries. In Britain, larger units and workforce from the turn of the century required increased skills in business and management.[c] In the United States, mining became increasingly intricate due to new mining methods, new devices, more complex interaction among parts of the system and a growing work force, which led to the use of new managerial and economic skills, as well as technical skills.[ci] In Chile - a country with a huge mining sector and large foreign corporations investing in copper, iron and saltpetre – reforms were made in the mining engineering program at the University of Chile and new courses in project formation and budgets, administrative law, legislation and economy and mining law were added in 1908.[cii]

In response to the diversification of the sector and the new specialisations, the mining program was divided in two in 1931, with one sub-program specialising in 'mining' and another in 'metallurgy'. The two study programs included many of the same courses, but the first one included more teaching of surveys and ore dressing and the second one included more courses in chemistry and metallurgy.[ciii] This reform reinforces the argument that the mining programs adapted to the changes in the mining sector, although it happened rather late considering that the electro-metallurgical industry emerged from the late nineteenth century.[civ]

In 1867, a more practically-oriented mining technician program was established in Kongsberg, the public Kongsberg Silver Works Elementary Mining School.[cv] The intermediate mining technician instruction was organised in a similar manner as the mining engineering programs and included roughly the same natural science courses. The mining courses were accounting, drawing of machinery and constructions and practical assignments in ore surveying. The main difference was that the program was shorter than the mining engineering program (two years – two and a half years from 1870) and excluded in-depth teaching of scientific theories. The instruction focused instead on short introductions to different knowledge domains and hands-on practice and exercises, which were provided during work hours at Kongsberg Silver Works.[cvi] The theoretical teaching increased to 1560 hours in 1899, and new courses in mining construction, chemistry and metallurgy were adopted, but practical exercises and daily work at Kongsberg were still an obligatory part of the program.[cvii]

In the early twentieth century, formal training became mandatory for 'head of mines', which were the position for which the Mining School prepared the students and included managing mines and assisting engineers in their work. Mining technicians were normally not meant to administrate and manage companies, but rather to assist engineers in their work.[cviii] In 1921, the Mining School was closed temporarily, however the industry expressed its wish to reopen the school again. In 1930, a debate emerged, and the strong argument was that the country still needed mining technicians and foremen with theoretical training. In 1936, the School reopened, and new courses were added, notably electrical engineering, ore dressing, construction and civil engineering, mining and ore surveying, and the study of company and work. The introduction of these courses indicates that the Mining School also followed, and adapted the teaching to, the technological changes in the sector.[cix] The technology influenced and shaped the formal mining instruction also here.

Hands-on practice and work experience: abroad and in Norway

Debates about the content of engineering and technical educational programs developed early in many countries, and have continued until today. Often the discussions have been about whether the instruction should be more 'practically-oriented' or 'scientifically' or 'theoretically-oriented', and the underlying question has been about whether engineers have been fully trained from the day of graduation or whether they have needed more practical training. The core of the matter seems to be related to different views about the role of formal technical and engineering education in developing 'capable' technicians and engineers.[cx] In Norway, such a debate began with the Mining Seminar in Kongsberg. Articles were published in journals and newspapers by engineers, professors and company managers, and reflected their different opinions about which courses to include and how they thought the program should be organised.[cxi] An argument that was made in the 1860s was that more practical tasks should be included in the mining engineering program because the graduates were not able to "...climb the mining ladders or not even to hold a mining lamp without burning their fingers."[cxii] Later, in 1910, the director of Sulithjelma Copper Works, Holm Holmsen, wrote that mining engineers graduated from the University had "all felt what it meant to start working with an education that was not of the practical kind."[cxiii]

There seemed to be no consensus with regard to how the mining engineering, and the teaching, should be organised, and the debate continued, but organisers of the University, and later the NIT, were clear in their view. They stated that even though this was a 'profession-oriented' study, graduates were not ready for their work profession at graduation. The mining engineering program was focused on scientific theories, and although it mixed different teaching forms – lectures, practical exercises, laboratory work and several months' work practice - graduates required more experience to perform successfully as mining engineers.[cxiv] The University and the NIT rather aimed to offer teaching which would provide the best possible scientific and theoretic foundation for the engineers in their work.[cxv] In 1937, professor Harald Dahl wrote that: "(w)hen one speaks of the mining engineering education, the majority thinks of the study at the NIT; but it is often ignored that this is just a first step, and that the most important part of education is still ahead." The objective of the formal education was, he wrote, to provide general knowledge, to help developing the students' judgement and to provide them with theoretical and technical insight. They were introduced to critical thinking and how to "reflect on the problems they later need to solve."[cxvi] It was, thus, in the work place, after graduation, that the mining engineers practiced problem-solving and learnt how to use scientific theories in practice. The mining technician program was more practically-oriented than the mining engineering program, but the mining technician graduates still needed more experience to become fully skilled 'mine managers'.[cxvii] Thus, experience-based learning, hands-on practice and learning by doing had to be acquired after graduation.

So, did mining engineers and technicians acquire any practice? What did they do after graduation? 307 of 341 Norwegian mining engineers who graduated between 1787 and 1940 – either in Norway or abroad - obtained internship positions, or lower technical or assistant positions, in mining businesses or at the University or NIT – the year after graduation. The daily tasks of such assistant positions included observing, learning from, and working with, more experienced workers, which would probably prepare them for work positions which included more responsibilities and challenging tasks later on.[cxviii] Perhaps more importantly, and noteworthy, is that 226 mining engineers (around 66 percent) went abroad, often with scholarships, to 1) acquire information about specific techniques, 2) do geological surveys, or 3) work for a period at a foreign company. 148 of these mining engineers travelled abroad to visit mines, metallurgical plants or to study specific mining techniques on behalf of companies, visit industrial exhibitions, or to do practice at a mining plant. Such travels are called 'study trips'.[cxix] 127 mining engineers went abroad to work for a longer period, normally a couple of years. There was a continuous flow of mining engineers going to European countries with important mining industries, notably German, Sweden, France and England, and from the 1880s mining engineers also travelled to the United States. Other popular destination were Chile, Spain and France and some of them went to multiple countries during their trips.

Working experience from abroad was highly appreciated by mining companies in Norway. Professor Johan Herman Lie Vogt was contacted by Skandia Copper Works in January 1907 and asked he could recommend a mining engineer for the manager position at the copper mine at Lillebotten and Narvik. One important criterion was that "(t)he man should have practiced at copper mines, and preferably abroad."[cxx] The general value of foreign practice is confirmed by the preference that was given mining engineers who had been abroad. First of all, only nine of the mining engineers stayed abroad and in thirty-four of the cases it is not known clear whether they came back, which means that most of them returned.[cxxi] Second, of the ones who came back from longer work periods abroad, were mostly recruited to middle-management and management positions in mining after their return.[cxxii]

But why would these study travels, and learning and work abroad be important? To understand all dimensions of technology, its strength and weaknesses, and to capture the 'tacitness' of how to use machinery, equipment, tools, power stations, techniques, working systems, and so on, in-depth and comprehensive knowledge of how they functioned in operation was needed. This required more than reading about them in magazines, books and technical journals and normally it involved hands-on experience and learning by doing on-site. The key to asses, select, transfer and use technology was to observe, and learn from workers and engineers who had experience with it. Norway was a small 'catching-up economy' of the Industrial Revolution and it is found that the country based much of its innovation processes on transfer of technology from abroad, notably from large industrial powers.[cxxiii] This was also the case in mining. New techniques, machinery and equipment often had their origin in Britain, Germany, France and the United States – with some important exceptions - which were countries to which mining engineers normally went.[cxxiv]

The career of the chemist Olav Steen provides an illustrative example of how work experience from other countries was used in the process of selecting a new and more efficient smelting technique at a smelting plant in Norway. After graduation in 1895, he worked at multiple iron and steel companies in Germany and Italy. One of his working tasks was to travel around Europe and study smelting techniques for iron and steel. In 1917, he was recruited as operation manager at Stavanger Electrical Steel Works in Norway. Steen found that the furnace that was currently in use, a Roechling-Rodenhauser induction furnace of four steps, was not safe. It had low durability, long repair time and was expensive to operate. He recommended electric arc smelting instead and se suggested an eight-ten ton Heroult furnace, which he had worked with at an iron works in Northern Italy. This would, according to his assessments, lead to important cost reductions. The oven he recommended was ordered from England and after a couple of years it was installed and used successfully in operation.[cxxv] Steen's practical understanding of steel techniques was of great advantage to Stavanger Electrical Steel Works and represent examples of supplementary knowledge to the formal theoretical mining instruction. The knowledge that was acquired during these trips was different than the knowledge learned in school, but it was not less important. They acquired contacts and hands-on practical experience with new mining techniques, coordination systems and organisational procedures, which seemed to be highly useful – and perhaps key - for the development of the sector.

Considering that the mining engineers acquired 1) a highly useful formal training; and most of them acquired 2) practical experience, many of them both in Norway and abroad, did they draw on this combination of theoretical knowledge and experience in Norwegian mining? Ninety-four per cent of the mining engineers were recruited to mining companies, and other related mining organisations, such as research centres and schools, which highly suggests that they did.[cxxvi] Mining engineers worked in all kinds of metals and minerals, notably copper, pyrite, silver, tin, coal, iron, pyrite, nickel and aluminium, but they also worked with consulting, at Norwegian Geological Survey, academia and mining and technical schools, which were organisations related to mining development in the country. Their main work areas and work positions can be divided into three main categories, namely (1) engineers, middle-managers or managers at mining companies, (2) consultants, (3) or as teachers or researchers. Fifty-three mining engineers worked as consultants at some point during their career; as freelancers, academics or as public servants and seventeen had an academic career and became professors either at the University or the NIT. But most of them worked at mining companies, while some of them began a career in academia and Geological Survey of Norway. Only 15 of the mining engineers who did a career in mining never worked at a mining company. It should be mentioned here that - in addition to provide formal mining education and educate mining engineers – many professors in natural sciences had a close relationship with mining industries. They often provided scientific expertise and gave advice to companies with regard to start-up strategies, surveying or selection of new techniques.[cxxvii]

Norwegian mining engineers were recruited to all sorts of mining companies; big and small, domestic and multinational.[cxxviii] Although some companies - notably Kongsberg Silver Works, Røros Copper Works, Big Norwegian Spitsbergen Coal Company, Bjørkåsen Mines, Falconbridge Nickel Works, Folldal Works, Løkken Works (Orkla) and Sulithjelma Mines - employed more mining engineers than others, they were largely spread around the sector. In 1932, the Mining Journal wrote that ever since the mining engineering instruction transferred to the University in 1814 there were mining engineers at "practically all the mining works."[cxxix]

An estimation of their career length indicates that they increased in numbers. Given that the mining engineers had an average career length of forty years, the available mining engineers – graduated in Norway and abroad - would be forty-eight in 1866 and 221 in 1940. With this estimate, the number of workers per mining engineer varied, but remained relatively low from thirty-five to ninety-two, and mining engineers stood for between 1 and 2.8 per cent of the workforce.[cxxx] Using the same forty years estimate we can compare the number of mining engineers to the number of mining companies and indicate how many they were. Between 1866 and 1870 there were between forty-eight to fifty-two mining engineers, while there were forty-two mining companies. In 1917, the total number of mining companies had increased to 167 and there were 161 mining engineers, which meant just about one mining engineer per company. By 1940, the supply had increased dramatically. In 1939, there were 139 mining companies and 212 mining engineers, i.e. one and a half mining engineers per company.[cxxxi] It does not mean that all companies had employed mining engineers at all time, but it indicates their work potential.

The biographies enable a more detailed analysis of their career paths and work positions. A general observation of their work is that their daily tasks and responsibilities were broad and varied, but there are some traits that stand out. First, (1) engineering work and middle-management positions were the most common. Normal positions at the beginning of a career were assistant engineer positions, mine manager positions, manager positions of smelting and crushing plants, chemists, geologists or operational engineers. 124 mining engineers worked as mine manager, operational engineer or head engineer some time during their career. Forty-seven mining engineers worked at smelting plants as smelting masters, smelting accountants or metallurgists. Second, (2) few mining engineers owned their own mining company. Only eight mining engineers inherited or purchased a mining firm.[cxxxii] The great majority of them were not investors, but rather company administrators and managers of mining companies. Ninety-seven, i.e. around 30 percent, became middle-managers, while 108 became managers or operational managers and eighty-five of them became directors and fifteen became members of Board of Directors at a mining company. In sum, around sixty percent of the mining engineers, 192, acquired a managing or directing position at a mining company or public mining organisation during their profession, normally after several years working. The high recruitment of mining engineers to managing positions, suggests that their knowledge was highly valued by the industry (see table 2 below of the highest position acquired during working career):

Table 2. Highest position acquired by the mining engineers during working career

Director/manager of a mining company/organisation	60 percent
Middle-management position at a company/organisation	30 percent
Unknown	10 percent

This trend seemed to be worldwide. Mining engineers often managed mining companies in the United States, Britain and Germany, and a review of around one third of the Chilean mining engineer graduates between 1850 and 1940 also suggests that they became administrators and directors of mining businesses in Chile.[cxxxiii]

The directing, management, engineering and middle-management positions which were common among mining engineers involved supervising a mining division, or having the overall responsibility of a company, research centre or educational institution. Mining companies were normally divided into multiple divisions, and each division had a supervisor, and assistants, while miners, hewers and day labourers carried out the physical work of building, excavating, removing and transporting the ore. The strategic technical positions, and the middle-management and management positions involved delegation of work, practical engineering tasks, designing mines, coordination work, technical decision-making, supervision, administration and coordination of several hundred workers, economic and strategic technical planning, accounting, scientific ore analyses and maintenance of machinery and equipment.[cxxxiv]

The head engineer, or mine manager, planned and organised the work at the mine and was in charge of the equipment that was used and the miners who removed the ore from the mines. This meant having the responsibility for the daily operation concerning removal and transport of ore, planning and ensuring that the work was performed successfully.[cxxxv] The mine manager normally had an assistant, or several, who helped him in his work and replaced him when he was away, which positions the formally trained mining technicians were meant for.[cxxxvi] Supervisors of crushing plants were responsible for the workers and equipment at the quarries and supervisors of the processing and smelting plants were 'smelting masters', 'smelting accountants' and metallurgists and administered the ore smelting processes. They were in charge of ore testing and analysis and supervised the workers who operated the smelting ovens, converters and furnaces. The smelting accountant, and 'mining accountant' in particular, did bookkeeping and accounting.[cxxxvii] 'Managers' of mining companies normally administered the daily operations and delegated work while the 'directors' (or directories) had the overall responsibility and decision-making of companies and delegated some of this responsibility to middle-managers.[cxxxviii] This administrating and organisation roles of the mining engineers suggest that they were heavily involved in the adoption, coordination and management of new technology that we see took place in the late nineteenth and early twentieth centuries.

Other trained specialists

Mining engineers and technicians only represented a small share of the skills and knowledge specialisations that were used in Norwegian mining. The increased complexity of mining activities, the gradual mechanisation and adoption of complex machinery and equipment led to an increased use of technical manuals, user's guides and instructions, which may indicate that miners, smelters and other low-level workers also needed to calculate, and read and write as part of their daily work. This challenge seemed to be solved in Norway as the share of literate people in the country was very high from early on compared to other European countries. Fritz Hodne finds that in 1873, around eighty-seven per cent were able to write and read and ninety-nine per cent were able to read.[cxxxix]

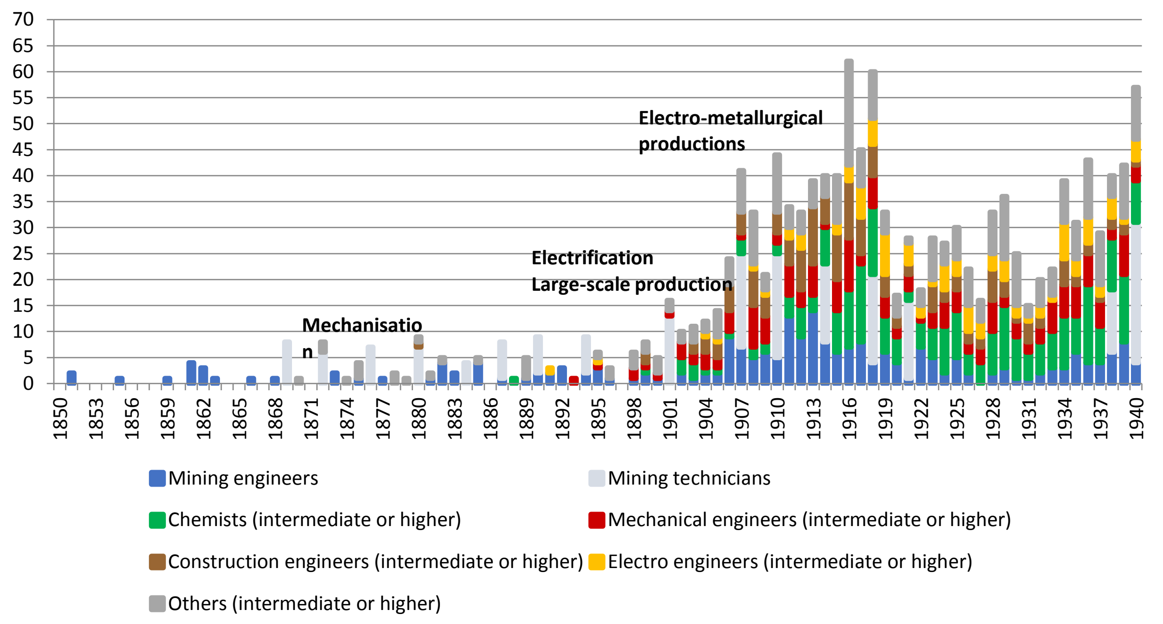
Other sources show that by the 1890s the literacy estimate rate was near a hundred per cent.[cxl] According to Carlo Cipolla, more than seventy per cent of the adult population was literate by 1850 and Norway became one of the countries with highest literacy in Europe.[cxli]

Three intermediate technical schools in Bergen, Trondheim and Oslo were established from the 1870s with different technical programs. Other technical schools and evening schools were founded in multiple towns and near industrial areas, such as Bergen Drawing School of 1772, Horten Technical School of 1855, Skienfjorden Technical School of 1887 and the School of Agriculture of 1854 (Higher School of Agriculture from 1897).[cxlii] The Norwegian Institute of Technology (NIT), much based on the German technical educational system, was founded in 1910 and provided engineering programs on a tertiary level. In addition to the mining engineering program the NIT offered study programs in architecture, electrical engineering, mechanical engineering, construction engineering and shipbuilding.[cxliii] In addition to mining engineers and technicians, the University, the NIT and technical schools – and foreign schools and universities - supplied mining companies with technicians, chemists, construction engineers, mechanical engineers, electricians, economists etc.

Figure 1, based on a review of the student yearbooks from Norway, shows that the workers in mining with formal education became more diversified by the turn of the century. Before the 1890s, a couple of mining engineers were the only formally trained workers, but from the 1890s there was a steady recruitment of workers with training and specialisations in other knowledge areas than mining, notably mechanical engineering, chemistry, electrical engineering, construction engineering. Figure 1 also indicates that changes in recruitment roughly matched technological changes that were taking place in the late nineteenth and early twentieth centuries. The mechanisation process was followed by recruitment of mechanical engineers, and the widespread adoption of electric power as an energy source from the turn of the century was followed by the hiring electricians and electro-engineers:

Figure 1. Composition of formally trained workers recruited to mining in Norway*

Year of employment**



*Include people who finished high shool in Norway; continued their education in Norway or abroad and worked in Norwegian mining.

**In 79 of the cases the exact year of employment in the mining sector is uncertain.

Sources: All student yearbooks (see references).

It should be noted that trained workers were recruited by companies after, or in the process, of transferring, installing and adopting new techniques. For example, most of the electro-engineers were recruited after the turn of the century, by which time electric power was commonly used to provide power to mines and in electrolysis. According to the student yearbooks, the first electro-engineer to be recruited to a mining company was Peter Kjølseth who was employed by Sulithjelma Copper Company in 1891. This was the year that the Directory and the manager decided to build an electrical power station to provide power to equipment at the mines and Kjølseth was hired to manage, and facilitate the installation of, these constructions.[cxliv] A similar pattern seemed to be the case for chemists. The experimentation of new chemical and electro-metallurgical smelting techniques was followed by the recruitment of chemists. The large-scale electro-metallurgical companies - producing aluminium, nickel, iron, steel, and other metals and minerals - that were developing from the turn of the century, recruited most of them. Some years, in the late 1910s and 1920s and 30s, more chemists than mining engineers were recruited to the sector. In 1915, for example, six mining engineers and eight chemists were hired. From the turn of the century, economists, lawyers and business administrators (categorised as 'others intermediate or higher' in Figure 1) were also hired. They were recruited to the large-scale companies to ensure long-term planning and to facilitate rational operation and efficient management.

The recruitment of trained workers to Løkken Works (Orkla Mining Company) illustrates, on company level, the variety of specialists that were used in mining from the turn of the century and how their recruitment coincided with the installation and adoption of new equipment and techniques. Løkken Works started copper mining in 1654 in Meldal near Trondheim and was taken over by the Swedish Orkla Mining Company in 1904. After Orkla took over, major technological changes were carried out, which were needed to rationalise and maintain profit.[cxlv] First of all, the number of workers increased from around 10 to more than 400 in 1906, and to around 670 in 1911.[cxlvi] An electric plant and advanced equipment, notably pumps for drainage, air-driven drilling machines, compressors and pumps were installed. The decision to implement these technological changes, which led to a dramatic increase in production, was then followed by the employment of a variety of trained workers. In the nineteenth century, only a couple of mining engineers were involved in mine organisation and ore surveying, but from the end of the nineteenth century a range of workers with different types of education were hired.[cxlvii] The majority of the trained workers that were recruited were mining engineers, but also several electro-engineers, mechanical engineers, construction engineers, chemists, and other specialists. In 1931, the company set up a new ore processing plant, which explains the recruitment of chemists from the late 1920s (see table 3 below):

Table 3. Recruitment of trained workers to Løkken Works (Orkla from 1904)

Year of employment*

Year	Chemists	Construction engineers	Electro engineers	High school	Lawyers	Mechanical engineers	Military background	Mining engineers	Water, road and bridge engineers	Ship building engineers	Unknown	Total
1895-00						1 ('manager')						**1**
1901-05		1 ('adm. Dir.)				1 ('chief engineer')		2 (1 'Director')				**4**
1906-10		3 (1 'department engineer')				2 (1 'engineer', 1 'assistant')		4 (2 'engineers')			1	**10**
1911-15		3 (2 'engineers')	1 ('engineer')	1 (unknown)			2 (1 'transport manager)	2 ('engineers')				**9**
1916-20		3 (1 'inspector')	4 (1 'electro engineer', 1 'manager of electro')				1 ('accountant')	4 (1 'engineer')	1	1 ('sous chef')		**14**
1921-25			1			1 ('assistant engineer')		2			1	**5**
1926-30	4 (2 'chemists')		3 (1 'engineer', 1 'manager')	2 (1 'secretary', 1 'accountant')				1 ('operational manager')				**10**
1931-35	3 (1 'chemist')		2 (1 'engineer')			6 (1 'manager of mech., 1 'constructor', 3 'drawer')		2 ('operational engineers')			1	**14**
1936-40	2 (unknwon)	1 ('construction manager')	2 (1 'manager', 1 'engineer')	2 (1 'accountant', 1 'correspondent')	2 (1 'lawyer', 1 'secretary')	1		4 (2 'geologists', 1 'manager')	1 ('construction manager')			**15**
Total	**9**	**11**	**13**	**5**	**2**	**12**	**3**	**21**	**2**	**1**	**3**	**82**

* Some of the positions are unknown.

Sources: *Studentene* (Oslo, 1855-1940); G. Brochmann (red.) *Vi fra NTH de første 10 kull: 1910-1919* (Stavanger, 1934); O. Amundsen, *Vi fra NTH de neste 10 kull: 1920-1929* (Oslo, 1950); L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen 1975); B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961); Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954); O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915* (Trondhjem, 1916).

Table 3 also indicates that the trained workers at Orkla, with some important exceptions, acquired work positions which were associated with their formal education. This reflects a general trend of specialists working in their field of study; mechanical engineers were hired as 'mechanics', electrical engineers were employed as 'electricians' and chemists were hired as 'chemists' or 'metallurgists'. Trained workers largely worked in the work area which their formal education indicated, which suggests that their knowledge specialisations were appreciated by mining companies. It may be that 'signalling effect'[cxlviii] played a role in the employment of trained workers, but the correlation here between their educational backgrounds and line of work strongly indicates that mining companies found their formal training to be relevant for, and directly usable in, operation. It is difficult to determine here whether education was a driver for technological change, but it is clear that the workers with varied educational backgrounds supported and facilitated the increasingly complex mining technology of the late nineteenth and twentieth centuries by contributing with specialised knowledge in how to organise mining businesses and how to use and maintain electric and mechanical equipment, mining constructions, converters, furnaces etc. and how to coordinate workers.

An increased diversification of the composition of trained workers is also observed in technologically complex mining projects other places in the world. English and German iron industries used natural scientists, chemists and technicians during the nineteenth century, but in the early twentieth century a broader spectre of skilled workers and natural scientists were used, including accountants, economists, professional businessmen and managers.[cxlix] The North American large-scale copper projects in Chile, which mined some of the largest copper deposits in the world in the early twentieth century, with highly advanced and up to date technology - railway systems, electric power plants, metallurgical plants and huge mines with constructions and mechanical and electric equipment - recruited a wide range of specialists and skilled workers. Correspondence between engineers of Andes Company Company in 1925, in its initial phase, indicates the variety of professionals that they needed. A long list of workers were to be sent from the United States to the many departments; superintendents, office engineers, foremen, field engineers, different types of construction foremen, clerks, construction mechanics, carpenters, electricians, electric constructers, draftsmen, erectors, supervisors, machinists, tank erectors, steel erectors, brick masons, pipers, and others.[cl] With regard to the machinist department, in addition to one general machinist foreman, it was stated that "...we should have at least six experienced machinists to install the great number of machines which go into the complete plant."[cli]

Information about the year the workers with formal education were recruited to the mining sector in Norway allows us to make an estimation of how many they were. An estimation of forty years is used here, although it was possibly an exaggeration for some of them. It was normal for trained workers to switch between sectors, and not work in only one sector during their whole career. The estimation is, thus, used as an approximation of the relationship between total workers and trained workers. With this estimate the share of trained workers increased drastically from 1.2 percent in 1866 to 11.7 percent in 1940, which suggests that the role trained workers played in mining increased significantly.[clii] This drastic increase of trained workers in mining goes against the argument that natural resource industries by definition have created few qualified jobs. On the contrary, mining was based on highly complex knowledge, and included such wide-ranging work activities, that it may seem like an exceptionally broad range of workers with technical and managerial skills and educational backgrounds in natural sciences, all kinds of engineering and technique, as well as economics and administration were used.[cliii]

Concluding remarks

It is widely recognised that education and human capital development have been key for natural resource intensive economies to overcome the problems with underdevelopment, but our knowledge of how education has been used and its direct implication on technological change and development of natural resource sectors is scarce. This paper is an attempt to further our understanding of skilled workers in a dynamic and knowledge-based mining sector by looking to the role of engineers, technicians, and other graduates from the University, the NIT and technical schools in Norway, who worked in mining in Norway. By using study programs from the University and the NIT, engineering reports and graduate biographies the paper has followed graduates from school into the natural resource sector with the aim of capturing the complexity of learning processes both at school and at work. The paper has explored the relevance of mining education, its knowledge limitations, learning processes of mining engineers outside school settings, and the use of trained workers in mining in Norway between ca. 1860 and 1940, a period in which world mining went through radical technological changes.

During the nineteenth century, mining became increasingly challenging in terms of finding, removing and processing of ores. Challenges emerged as the demand for minerals increased, high-grade mineral and metal ore deposits were largely exhausted and new minerals and low-grade ores in more remote places and deeper underground were given attention. In Norway, by the late nineteenth century, mining operations had been rationalised with new mining and smelting techniques, new coordination systems and new equipment, furnaces, converters, power stations etc. and the adoption of large-scale production. Technological experiments and technologically complex mining companies led to an increased need for theoretical and scientific preparation. New multifaceted constructions underground meant that extensive knowledge of natural sciences became particularly important. Knowledge of geology, chemistry and mineralogy were extensively used in the construction of geological maps and ore analyses and mathematical calculations and knowledge of physics and mechanics were used in the design and measuring of mines.

Formal mining instruction - both the broad scientifically-oriented mining engineer program and the more practically-oriented mining technician program - was relevant and highly useful for mining companies, research centres and academia, and the study programs adapted to – and made reforms – according to the technology that was used in mining. Yet, the teaching at school did not seem to be enough for the mining engineer and technician graduates to perform successfully at the workplace. This was first and foremost related to nature of mining activities. Mining activities largely involved physical and practical tasks of planning, designing and making mines and making pure metal and mineral products through digging, carrying, transporting, crushing and smelting. Moreover, the uniqueness of ore deposit and mine, and the transfer, installation and adoption of furnaces, converters, equipment, tools etc. were physical and practical tasks which required long practice to carry out. The physical and practical characteristics of mining suggest that the daily tasks and work were largely based tacit knowledge, which has been best transferred from person to person through practice and through learning by doing. Much learning, thus, happened outside school. To become capable mining engineers and technicians, the graduates combined scientific and theoretical knowledge they learned at school with several years of hands-on practical experience.

Technological change and economic growth in a catching-up country like Norway relied heavily on the acquisition of foreign technology, and more so than on technology developed domestically. Industrialisation was largely based on skills and competences to imitate and *use* foreign techniques and methods and to adapt and modify them to local conditions. Most of the mining engineers from Norway - and engineers and technicians more widely – adapted to these needs and travelled abroad to study, do practice, visit industrial exhibitions and to work. Visits to foreign mining plants, educational establishments and research centres were vital for technology transfers, as they enabled insight into new scientific research and new mechanised equipment, electric power plants, convertors, furnaces etc., and management systems. The knowledge that the mining engineers acquired during these trips was different than the knowledge learned in school, and was key for the development of their practical skills. They acquired contacts and hands-on practical experience with new mining techniques, coordination systems and organisational procedures, and they learnt about how to use, handle and maintain technology in practice, which was essential to carry out their daily tasks at work in Norway.

Most of the mining engineers in Norway, ninety-four percent, made a career in mining, which suggests that they were highly valued by the industry. They mostly worked at companies, but also with consulting, research and teaching. Some mining engineers became mining consultants, researchers or geologists and collaborated closely with mining companies. Others worked as chemists, designers, managers or entrepreneurs. The mining engineers had multiple functions and were involved in multiple aspects of mining development. Yet, most of them acquired middle-management and directing positions, which were key strategic positions involving coordination of workers, direction, operational control, designing and constructing mines, engineering and supervising operational divisions. Hence, they seemed to be largely involved in the transfer, supervision and management of the new technology that was adopted, and the workers who operated it.

Mining engineers and technicians in Norway were increasingly used in mining from the late nineteenth century, and this was in line with the global trend. Yet, a review of the career paths of all the high school graduates from 1855 to 1940 in Norway shows that not only mining engineers and technicians were recruited, but a broad spectre of trained workers. Trained workers as share of the total workforce increased and the educational background of the trained workers diversified dramatically from the turn of the century. The technological transformation that was happening in the sector was based on an increased knowledge base, which was supported by and coincided with an increased use of trained workers with varied educational backgrounds. The recruitment of trained workers and their educational background correlated with technological changes in the sector. Workers with specialised formal training in chemistry, electro-engineering, construction-engineering, economists etc. seemed to be recruited by mining companies in Norway to operate, maintain and repair the increasingly complex equipment, working techniques and systems, which indicate that trained workers were key to manage and organise mining projects, and the new technology that was adopted. Mining companies from Britain, Germany, the United States and multinational mining corporations in Chile show similar trends, which support the notion that the development of knowledge-based natural resource industries is largely based on qualified and skilled workers.

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[i] See T. Gylfason, "Natural Resources, Education and Economic Development", *European Economic Review 45* (2001), 847-859; E. E. Leamer, H. Maul, S. Rodriguez, and P. K. Schott, 'Does Natural Resource Abundance Increase Latin American Income Inequality?', *Journal of Development Economics* 59 (1999); E. Suslova and N. Volchkova, "Human Capital, Industrial Growth and Resource Curse", *New Economic School: Working Paper #* WP2007/075 (2007).

[ii] See for example R. Prebisch, *The Economic Development of Latin America and its Principal Problems* (New York, 1950); J. D. Sachs and A. M. Warner, "Natural resource abundance and economic growth", *NBER Working Paper* No. 5398, (1995); T. L. Karl, *The Paradox of Plenty* (Berkeley, 1997); S. Andrade and J. Morales, "The Role of the Natural Resource Curse in Preventing Development in Politically Unstable Countries: Case Studies of Angola and Bolivia", Institute for Advanced Development Studies, Development Research *Working Paper Series* No. 11 (2007); F. van der Ploeg, "Natural Resources: Curse or Blessing?", CESifo Working Paper No. 3125 (2010).

[iii] See for example P. David, and G. Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997); D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002); O. Wicken and S. Ville, "The dynamics of resource-based economic development: evidence from Australia and Norway", *Industrial and Corporate Change*, volume 22, issue 5, 1 October (2013).

[iv] T. Gylfason, "Natural Resources, Education and Economic Development", *European Economic Review 45* (2001), p. 850

[v] E. Suslova and N. Volchkova, "Human Capital, Industrial Growth and Resource Curse", *State University Higher School of Economics: WP 13/2007/11* CAS Working Paper Series, p. 4

[vi] E. Suslova and N. Volchkova, "Human Capital, Industrial Growth and Resource Curse", *New Economic School: Working Paper #* WP2007/075 (2007), p. 3

[vii] T. Gylfason, "Natural Resources, Education and Economic Development", *European Economic Review 45* (2001), pp. 847-859

[viii] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), pp. 204-205

[ix] S. Ville and O. Wicken, "The Dynamics of Resource-Based Economic Development: Evidence from Australia and Norway", *Industrial and Corporate Change*, Volume 22, Issue 5, (1 October 2013), p. 37

[x] M. Vernengo, "Technology, Finance, and Dependency: Latin American Radical Political Economy in Retrospect", *Review of Radical Political Economics,* Vol. 38, No. 4 (2006), pp. 552-553; R. Prebisch, *The Economic Development of Latin America and its Principal Problems* (New York, 1950); J. D. Sachs and A. M. Warner, "The curse of natural resources", *European Economic Review* 45 (4-6); P. Collier and A. Hoeffler, "Greed and grievance in civil wars", *Oxford Economic Papers*, 56 (2004), pp. 663-695; T. L. Karl, *The Paradox of Plenty* (Berkeley, 1997); S. Andrade and J. Morales, "The Role of the Natural Resource Curse in Preventing Development in Politically Unstable Countries: Case Studies of Angola and Bolivia", Institute for Advanced Development Studies, Development Research *Working Paper Series* No. 11 (2007); F. van der Ploeg, "Natural Resources: Curse or Blessing?", *Journal of Economic Literature*, (2011).

[xi] K. Smith, "Innovation and growth in resource-based economies", in CEDA, *Competing from Australia* (Australia, 2007), p. 53

[xii] Leamer et al. (1999)

[xiii] N. Petrovsky, "Does Natural Resource Wealth Spoil and Corrupt Governments? A New Test of the Resource Curse Thesis", thesis, august 2004; Denton, Texas.

[xiv] M. Smart, "Natural Resource Diversity and Democracy", *The Economic Society of Australia*, vol. 28 (December 2009), pp. 366-375

[xv] S. M. Brooks and M. Kurtz, "Conditioning the "Resource Curse": Globalization, Human Capital, and Growth in Oil-Rich Nations", *Comparative Political Studies,* 44(6), (March 2011).

[xvi] R. U. Mendoza, H. J. McArthor and A. O. Lopez, "Devil's Excrement or Manna from Heaven? A Survey of Strategies in Natural Resource Wealth Management", Asian Institute of Management Working Paper, April 25, 2012), p. 8

[xvii] Gylfason (2001); Stijns (2001); Bravo-Ortega, de Gregorio (2005)

[xviii] K. Bruland, "Kunnskapsinstitusjoner og skandinavisk industrialisering" in *Demokratisk konservatisme,* Engelstad, F and Sejersted, F (eds.) (Oslo, 2006), p. 271

[xix] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), p. 151

[xx] F. Hodne, *Norges økonomiske historie 1815-1970* (Oslo, 1981), pp. 242-244

[xxi] T. Gylfason, Policy conference: competitiveness & diversification: strategic challenges in a petroleum-rich economy, "Resources and Economic Growth:Is Africa (Ghana) Different?" (Accra, 2011)

[xxii] G. B. Havro, and J. Santiso, "Rescuing the Resource Rich: How Can International Development Policy Help Tame the Resource Curse?" *Working Paper Series*, June 2010.

[xxiii] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), p. 27

[xxiv] See G. Ahlström, *Engineers and Industrial Growth* (London & Canberra, 1982); F. Valencia Caicedo and W. F. Maloney, "Engineers, Innovative Capacity and Development in the Americas", *Policy Research working paper*; no. WPS 6814. Washington, DC: World Bank Group (2014).

[xxv] R. R. Locke, *The End of the Practical Man* (London, 1984), 5

[xxvi] R. R. Locke, *The End of the Practical Man* (London, 1984), p. 5

[xxvii] W. Kőnig,"Technical education and industrial performance in Germany: a triumph of heterogeneity", *Education, Technology and Industrial Performance in Europe, 1850-1939,* in R. Fox and A. Guagnini (eds) (Cambridge, 1993), p. 81

[xxviii] Carstens, *...Bygger i Berge: en beretning om norsk bergverksdrift* (Trondheim, 2000), 10

[xxix] Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940)

[xxx] K. Bruland and D. C. Mowery, "Technology and the spread of capitalism", in *Cambridge History of Capitalism, vol. II,* L. O'Neil and J. G. Williamson (Cambridge, 2014), 84

[xxxi] G. S. Becker, *Human Capital* (New York, 1975), 37

[xxxii] R. R. Nelson and S. G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge, 1982), 78

[xxxiii] H. Hirsch-Kreinsen et al., "Low-Tech Industries and the Knowledge Economy: State of the Art and Research Challenges", *PILOT Policy and Innovation in Low-Tech, STEP – Centre for Innovation Research* (Oslo, 2003), 9

[xxxiv] J. Mokyr, *Gifts of Athena*, (Princeton and Oxford, 2005), 73

[xxxv] M. Polanyi, *The Tacit Dimension* (Gloucester, 1983), 13

[xxxvi] K. J. Arrow, "The economic implications of learning by doing", *The Review of Economic Studies*, Vol. 29, No. 3 (1962)

[xxxvii] For detailed descriptions of the sources, see K. Ranestad, "The Mining Sectors in Chile and Norway from Approximately 1870 to 1940: The Development of a Knowledge Gap." PhD diss., (Geneva, 2015).

[xxxviii] F. Habashi, *Schools of Mines* (Quebec, 2003), 61

[xxxix] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds.) (Oxford, 1958), 77

[xl] F. Habashi, *Schools of Mines* (Quebec, 2003), 64

[xli] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds.) (Oxford, 1958), 66-67

[xlii] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), 74

[xliii] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), 29, 96 and 124

[xliv] In the 1860s, annual copper and iron production was on average 14-15 000 tons and 20-21 000 tons respectively: Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940)

[xlv] Copper production increased from around 10 000 tons in 1880 to 47 000 tons in 1900, and 50 000 tons in 1918; silver increased from 885 tons in 1880, to 1600 tons in 1905 and 14 600 tons in 1930. Nickel production increased from 1900 tons in 1900 to more than 31 000 tons in 1939 and iron production increased from 6700 tons in 1880 to 1 400 000 tons in 1939: Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940)

[xlvi] Aluminium production increased from 13 000 tons in 1923 to more than 31 000 tons in 1939.

[xlvii] In 1870, 67 000 tons pyrite were produced, in 1905 it had increased to 162 000 tons, and in 1930 to more than 700 000 tons: Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940)

[xlviii] Coal production in 1939 totalled 611 700 tons: Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940)

[xlix] Statistisk sentralbyrå, *Nasjonalregnskap 1900-1929*; Statistisk sentralbyrå, *Nasjonalregnskap 1930-1939 and 1946-1951*

[l] Departementet for de Indre, Norges officielle statistikk, *Norges bergværksdrift i årene 1866-1870*, 1874

[li] Statistisk sentralbyrå, *Norges Offisielle Statistikk, Norges bergverksdrift 1917* (Kristiania, 1919)

[lii] Statistisk sentralbyrå, *Norges Offisielle Statistikk, Norges bergverksdrift 1939*, (Oslo, 1941)

[liii] Calculations based on statistics from Norges offisielle statistikk, *Norges bergverksdrift 1919 and 1920*; Statistisk sentralbyrå, *Norges bergverksdrift 1939.*

[liv] See K. Ranestad, *Knowledge Based Growth in Natural Resource Intensive Economies*, Palgrave macmillan, *forthcoming.*

[lv] Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940).

[lvi] Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1940).

[lvii] A. Chandler, *Scale and Scope: the dynamics of industrial capitalism* (The United States, 1990)

[lviii] Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1925), 186

[lix] Mining engineer Holm Holmsen became technical director at the company and in 1904, he made a report of the "ore in sight" and its percentage of copper and sulphur: Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), 353-355

[lx] J. P. Friis, *Direktør Jacob Pavel Friis' erindringer* (Oslo, 1944), 169

[lxi] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds) (Oxford, 1958), 69

[lxii] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), 88-89 and 99

[lxiii] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), 88-89

[lxiv] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), 8

[lxv] Statistisk sentralbyrå, *Norges Officielle Statistik, Rigsforsikringsanstaltens Industristatistik for årene 1895-1899* (Kristiania, 1904)

[lxvi] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), 421; G. B. Nissen, *Røros Kobberverk 1644-1974* (Trondheim, 1976), 195-96

[lxvii] Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), 183

[lxviii] Statistisk sentralbyrå, *Norges Officielle Statistik, Industristatistikk for året 1918* (Kristiania, 1921)

[lxix] Statistisk sentralbyrå, *Norges Offisielle Statistikk, Norges Industri Produksjonsstatistikk 1939* (Kristiania, 1941)

[lxx] My translation: Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1926), 31

[lxxi] Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1937), 158

[lxxii] *Beretning angående Røros Verks tilstand fra den i generalforsamling i verket den 29. april 1902 Nedsatte komité* (Trondhjem, 1902), 49-50; H. Pedersen, «Den tekniske høiskole er i kontakt med storindustrien», *Bergens Tidende* (9 of April 1929).

[lxxiii] A. K. Børresen and A. Wale (red.), *Vitenskap og teknologi for samfunnet? Bergfagene som kunnskapsfelt* (Trondheim, 2005).

[lxxiv] Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1925), 215-17

[lxxv] T. Bergh et al. *Brytningstider: Orklas historie 1654-2004,* (Oslo, 2004), 57

[lxxvi] Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1933), 49

[lxxvii] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), 107

[lxxviii] O. A. Helleberg, *Kongsberg sølvverk 1623-1958: kongenes øyesten – rikenes pryd,* (Kongsberg, 2000), 292; B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), 421

[lxxix] H. Carstens, *…Bygger i Berge* (Trondheim, 2000), 32

[lxxx] F. Habashi, *Schools of Mines* (Quebec, 2003), 115-422

[lxxxi] See, A. K. Børresen and J. T. Kobberrød, *Bergingeniørutdanning i Norge* (Trondheim, 2007); Musgrave, *Technical Change* (Oxford, New York, 1967); «The rise of American mining engineers: A case study of the Colorado School of Mines", *Technology and Culture*, Vol. 33, No. 2 (Apr., 1992); P. David and G. Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997)

[lxxxii] L. Hovis and J. Mouat, "Miners, Engineers, and the Transformation of Work in the Western Mining Industry, 1880-1930", *Technology and Culture*, vol. 37, No. 3, July (1996).

[lxxxiii] P. David, and G. Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997).
[lxxxiv] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), 27
[lxxxv] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), 74
[lxxxvi] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002); S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990)
[lxxxvii] *Lov, ang. Røraas Kobberværk* (Trondhjem, 12 September 1818), 17
[lxxxviii] See lists of courses in K. Ranestad, "The Mining Sectors in Chile and Norway from Approximately 1870 to 1940: The Development of a Knowledge Gap." PhD diss., (Geneva, 2015), 444-449
[lxxxix] University of Oslo, *Universitets- og skoleannaler* (Oslo, 1834-35), 215
[xc] A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), 67-68
[xci] University of Oslo, *Det Kongelige Norske Frederiks Universitets Aarsberetning 1872*, 149
[xcii] Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), 134
[xciii] Norges Tekniske Høiskole, *Program for studieåret 1912-1913,* 25 and 41-43
[xciv] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), 314
[xcv] Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), 56
[xcvi] My translation: Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), 56
[xcvii] Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920*, 56
[xcviii] Norges Tekniske Høiskole, *Program for studieåret 1913-1914*, 23, 34-35
[xcix] For study plans, see K. Ranestad, *Knowledge Based Growth in Natural Resource Intensive Economies*, Palgrave macmillan, *forthcoming.*
[c] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), 134-135
[ci] K. H. Ochs, 'The rise of American mining engineers', *Technology and Culture.* Vol. 33, No. 2, (1992), 282-283
[cii] *Anales de la Universidad de Chile* (Santiago, 1908), 360-361
[ciii] Norges Tekniske Høiskole, *Program for studieåret 1931-1932,* 61-62
[civ] 311 mining engineers graduated in Norway – or took some of the formal mining education in Norway – between 1787 and 1940 and 118, 34, 6 per cent, studied in another country. Eighty-three of them studied partly in Norway and partly in another country, while thirty-five went abroad right after high school. There was a steady flow of mining engineer students to Germany. Eighty-seven mining engineers studied there. The most popular mining school was Freiberg Mining Academy, where forty-eight studied. Other popular destinations were Sweden, Switzerland, France, England and the United States. The mining engineers followed a wider trend. Before the Norwegian Institute of Technology (NIT) was established in 1910, the only option for Norwegians to acquire higher technical training - except mining engineering - was abroad. In the 1870s, there were around forty-fifty Norwegian students at technical schools on

the Continent. At the turn of the century, there were more than 200 Norwegian students at German technical schools. Studying abroad had two main functions. Students specialised in subjects or disciplines which did not exist in Norway and they worked in international scientific environments and acquired valuable contacts: G. Stang, "Ble det for mange ingeniører?" 34; T. Brandt and O. Nordal, *Turbulens og Tankekraft Historien om NTNU* (Oslo, 2010), 90

[cv] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), 9

[cvi] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), 10-11 and 14

[cvii] For the study plan, see K. Ranestad, "The Mining Sectors in Chile and Norway from Approximately 1870 to 1940: The Development of a Knowledge Gap." PhD diss., (Geneva, 2015), 264-267

[cviii] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), 8-10 and 20; Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), 154

[cix] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), 42

[cx] See for example J. Harwood, «Engineering Education between Science and Practice: Rethinking the Historiography» in *History and Technology*, vol. 22 No. 1 (2006); A. Donovan, "Education, industry, and the American university» in R. Fox (ed.) *Education, technology, and industrial performance in Europe, 1850-1939* (Cambridge, 1993); E. Crawley (ed.), *Rethinking engineering education: the CDIO approach* (New York, 2007).

[cxi] See T. J. Hanisch and E. Lange, *Vitenskap for industrien NTH – En høyskole i utvikling gjennom 75 år* (Oslo, 1985), 53

[cxii] My translation: G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), 140-142

[cxiii] Den polytekniske forening et al. *Teknisk Ukeblad* (Kristiania, 1910), 632

[cxiv] The program included a total of five months practice at a mining company, normally Kongsberg Silver Works: Den Tekniske Høiskole I Trondhjem, *Program for Studieåret 1911-1912* (Trondhjem, 1912), 14-15

[cxv] T. Brandt and O. Nordal, *Turbulens og Tankekraft Historien om NTNU* (Oslo, 2010), 110

[cxvi] Bergingeniørforening, *Tidsskrift for kemi og bergvæsen* (Oslo, 1937), 157-161

[cxvii] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966)

[cxviii] This section is based on an analysis of all the student yearbooks (see references).

[cxix] Fifty-six went on study trips to Sweden, seventy-eight went to Germany, thirty-one went to Britain, and twenty went to France. Fourteen worked in Sweden, twelve in Germany, six in France and nine in Spain. Thirty went on 'study trip' and forty-six worked in the United States.

[cxx] Letter from Aktieselskabet Skandia Kobberverk til Professor J. H. L. Vogt, Luleå 16. jan. 1907, *Johan Herman Lie Vogt*, Eske 70, Privatarkiv nr. Tek 4, Universitetsbiblioteket (Dora), Trondheim.

[cxxi] The many mining engineers going abroad for study and work purposes were part of a larger Nordic trend of 'outward-looking' engineers and technicians: P-O. Grönberg, *Learning and Returning. Return Migration of Swedish Engineers from the United States, 1880–1940* (Sweden,

2003); G. Stang, "The Dispersion of Scandinavian Engineers 1870-1930 and the Concept of an Atlantic System", STS-Working Paper No 3/89, 1992.

[cxxii] Sixty-two were employed to managing or middle-management managing positions by mining companies, one was employed to by the customs department, one by the University, one by the NIT, one by a technical school, three by the Geological Survey of Norway, three by research centres, one by an insurance company, one by a machine company, one by a power company, one by a railway company and in five of the cases their positions are unknown.

[cxxiii] See K. Bruland, *British technology and European industrialization* (Cambridge, 1989); K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989).

[cxxiv] See the general development of inventions and use of technology in mining in Singer et al., *A History of Technology,* 5 volumes.

[cxxv] *Studentene fra 1890*, 217-218; Oslo tekniske skole, *Skrift ved 50 årsjubileet,* 92-102

[cxxvi] Only twenty-one of them worked in other sectors, and one died young

[cxxvii] Laboratories were often used to carry out experiments and tests for mining companies. Mining engineers Kraft Johanssen and Magne Mortenson carried out experiments with flotation at Professor Harald Pedersen's laboratory in Trondheim which led to a flotation plant being built at Storvarts in Røros in 1927 and another plant was created in 1932 for the King's Mine. Another example is Professor Harald Pedersen, who made a process for smelting of bauxite with limestone and coke to obtain a high-quality sulfur-free pig iron and aluminium-rich slag in electric ovens while he worked at the NIT. Norwegian Aluminium Company based its operation on this process: M. Mortenson, Utviklingslinjer i norsk oppredningsteknikk, *Særtrykk av Tiddskrift for kjemi, bergvesen og metallurgi* 2 (1949). See A. K. Børresen and A. Wale (red.), *Vitenskap og teknologi for samfunnet? Bergfagene som kunnskapsfelt* (Trondheim, 2005); A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann* (Trondheim, 2011); "Harald Pedersen": Det store norske leksikon, snl.no (07 November 2017)

[cxxviii] For a list of mining engineers and recruitment to mining companies in Norway, see K. Ranestad, *Knowledge Based Growth in Natural Resource Intensive Economies*, Palgrave macmillan, *forthcoming*. In 1885, foreigners owned 5 out of 8 large mining works. Between 1875 and 1900, the average foreign ownership in this mining was around 41 per cent. In 1909, 80,3 per cent of investments in large corporations were foreign: A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), 32

[cxxix] Bergingeniørforening, *Tidsskrift for kemi og bergvæsen*, 1932, 135

[cxxx] Calculated on the basis of number of mining engineer graduates and workers: K. Ranestad, "The mining sectors in Chile and Norway, ca. 1870–1940: the development of a knowledge gap", *Innovation and Development* (2017), 11. There was a gradual increase of Norwegian mining engineer graduates and that the number – graduated in Norway and abroad - increased dramatically around the turn of the twentieth century. In the eighteenth century, there were only a of graduates, and until 1900 there were many years with no graduates. From 1906 the number of graduates increased considerably. 1911 and 1912 represented peak years with nineteen and twenty graduates. This dramatic increase of graduates correlated with the

production increase around the turn of the century, and the start-up of the large-scale electro-metallurgical industry. More, and larger, companies needed managers, which may have encouraged the graduation of more mining engineers. In 1920s - during the recession period - there were fewer graduates, and in 1926 and 1927 there were no graduates. From the educational establishments' side, these two correlations indicate a response regarding demand of mining engineers: K. Ranestad, "The Mining Sectors in Chile and Norway from Approximately 1870 to 1940: The Development of a Knowledge Gap." PhD diss., (Geneva, 2015), 279-281.

[cxxxi] Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940).

[cxxxii] Mining projects in Norway were often initiated by local engineers who collaborated with foreign investors: See Bergh et al. *Brytningstider;* Petersen, *Elektrokemisk 1904-54*; Thonstad Sandvik, *Multinationals,* 35-36.

[cxxxiii] K. H. Ochs, 'The rise of American mining engineers', *Technology and Culture.* Vol. 33, No. 2, (1992), 283; P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967); K. Ranestad, "The Mining Sectors in Chile and Norway from Approximately 1870 to 1940: The Development of a Knowledge Gap." PhD diss., (Geneva, 2015).

[cxxxiv] K. Hunstadbråten, *Blaafarveværket* (Drammen, 1997); F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005); S. Imsen and H. Winge, *Norsk historisk leksikon*, 2. edition (Oslo, 1999); Lov, ang. Røraas Kobberværk, 1818.

[cxxxv] K. Hunstadbråten, *Blaafarveværket* (Drammen, 1997), 38

[cxxxvi] S. Imsen and H. Winge, *Norsk historisk leksikon*, 2. edition (Oslo, 1999), 38. The work and career paths of the mining technicians tended to be more specialised and one-sided than the mining engineers. All the 191 mining technician graduates from 1869 to 1940 made careers in mining, mainly in copper, silver, iron and pyrite. Mining technician graduates from all the cohorts became 'mine managers' and were recruited to Kongsberg Silverworks, but also to other large-scale companies with several hundred workers, namely the Swedish Sulitjelma Mining Company, Kjøli Mine, Ulefoss Iron Works and Bossmo Mines.[cxxxvi] The mining technicians thus played a much more specific role than the mining engineers, which was to administrate mines at a few of the largest mining companies. Their specialization may be explained by the fact that companies sent workers to the Mining School in Kongsberg to be trained and return to their old work place after graduation: Statens bergskole, *Bergskolen*, 8-10 and 20

[cxxxvii] S. Imsen and H. Winge, *Norsk historisk leksikon*, 2. edition (Oslo, 1999).

[cxxxviii] S. Imsen and H. Winge, *Norsk historisk leksikon*, 2. edition (Oslo, 1999).

[cxxxix] The survey were carried out in Denmark, but according to Fritz Hodne it is seems likely to believe that the conditions were similar in Norway: F. Hodne, *Norges økonomiske historie 1815-1970* (Oslo, 1981), p. 250

[cxl] O'Rourke and Williamsen, "Education, Globalization and Catch-Up: Scandinavia in the Swedish Mirror" in *Scandinavian Economic History Review*, 43, 1995, p. 299.

[cxli] Denmark, Faroe Islands, Finland, Germany, Holland, Iceland, Scotland, Sweden, Switzerland: C. M. Cipolla, *Literacy and Development in the West* (Baltimore, 1969), p. 113

[cxlii] T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), 52

[cxliii] T. J. Hanisch and E. Lange, *Vitenskap for industrien NTH – En høyskole i utvikling gjennom 75 år* (Oslo, 1985), 23

[cxliv] *Studenterne fra 1885* (Kristiania), 153

[cxlv] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), p. 253

[cxlvi] Bergverkstatistikk, 1906; Bergverksstatistikk, 1911

[cxlvii] Henrick Christian Strøm, mining engineer from the Kongsberg Mining seminar and Freiberg Mining Academy, did surveys at the Løkken mine in the early 19th century, Mathias Wilhelm Sinding, mining engineer from the University of Christiania, contributed to a reorganisation of the production from copper to pyrite-copper in the mid-19th century and August Schønbek Ellefsen, mining engineer from the University of Christiania, was involved in evaluations of the operation in the late 19th century: Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), pp. 115, 120 and 128

[cxlviii] In Spence's approach, education is understood as part of a selection process of capable workers into suitable positions, where certain abilities indicate that the person is appropriate for a work or position. Education 'signals' that the person is likely to work, but not because of the cognitive knowledge acquired through formal training: M. Spence, "Job Market Signaling", *The Quarterly Journal of Economics*, vol. 87, No 3 (1973), 335-374

[cxlix] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), pp. 27-135

[cl] Montana Historical Society Archives, Collection No. 169, *Anaconda Copper Mining Company Records*, subj. file 6.4c, folder no. 78-6, 1925-1928 staff

[cli] Montana Historical Society Archives, Collection No. 169, *Anaconda Copper Mining Company Records,* subj. file 6.4c, folder no. 78-6, 1925-1928 staff

[clii] Calculated based on the student yearbooks and Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940). As seen in figure ?? the recruitment of a large number of trained workers in the years 1900s, and 1910s was followed by a sharp decline in the following decade. In 1917, the Concession Act was ratified, which at first sight may seem to have contributed to this downturn. The Act was the last of the 'Concession laws', which gave preference to domestic citizens and provided the state direct control over private and foreign companies. From 1917, the corporations' seat had to be in Norway, the majority of the boards of directors had to be Norwegian citizens and preference should be given to Norwegian workers. Did this new regulation create negative reactions and lead mining corporations to reduce their intake of local trained workers? Probably not. In the years before the ratification of the Act, companies, both local and multinational companies, recruited local trained workers without being bound to any regulations, which indicates that they valued, and perhaps preferred, them. Foreigners were hired, and they sometimes held managing and directing positions, but they seemed to decrease in numbers by the turn of the century as they were often replaced by Norwegians. Norwegian engineers took over management of mining companies – both domestic

and multinational companies – even before priority to Norwegians was settled by law. Thus, the Act formalised an already established trend. The reason for the decline in recruitment in the 1920s and 30s is probably instead explained by the recession period of the 1920s, and then by the Great Depression, which made mining businesses cut expenses, reprioritise and hereby stop the employment, both of trained and untrained workers: *Lov om erverv av vannfall mv. [industrikonsesjonsloven]* (14 December 1917); See K. Ranestad, "The Mining Sectors in Chile and Norway from Approximately 1870 to 1940: The Development of a Knowledge Gap." PhD diss., (Geneva, 2015), 315-332

[cliii] It should be mentioned that according to official statistics there was a slightly larger increase of the workers' salary than the functionaries' salary between 1926 and 1940 in Norway. The 'functionaries' were middle-managers which were normally the workers with technical and engineering education. This may suggest that there was a large, maybe too large, supply of trained workers. An ongoing debate in newspapers and technical journals developed with regard to whether the educational establishments graduated too many engineers and technicians. Many technicians and engineers went abroad to work, which was an indication that there were enough jobs in Norway. After the creation of the three technical schools in Christiania, Bergen and Trondheim in the 1870s, at least half of the cohorts each year left the country. The peak year was 1924 when more than 150 engineers from Norway went abroad. Statistisk sentralbyrå, *Norges offisielle statistikk, Norges Bergverksdrift* (Oslo, 1866-1940); G. Stang, "Ble det for mange ingeniører?" in *Trondheim Ingeniørhøgskole 1912-1987 Festskrift til jubileumsfeiringen 31. oktober 1987* (Trondheim, 1987),34; G. Stang, "The Dispersion of Scandinavian Engineers 1870-1930 and the Concept of an Atlantic System", STS-Working Paper No 3/89, 1992, 26.