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UDC 378

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INTERNATIONALISATION OF MINING EDUCATION AND RESEARCH – A RECURRING PROCESS RUNNING THROUGH THE CENTURIES

International cooperation and mobility are buzzwords of today's research and innovation clusters all over the world. These are however not new concepts. The understanding that research and innovation can only thrive in an international and open environment has been in place for at least 300 years in Sweden. All interested and knowledgeable scientists and business developers have been welcomed to push the front of knowledge and the industry forward. The international contacts of Swedish mining education, research and innovation prove that with an open mind and a persistent, long term effort results will come.

The roots of mining education and research in Sweden dates back to the 17th century. Initially the focus was on applied research rather than education, but the early efforts also slowly led to important purely scientific results. Swedish metallurgists/chemists have discovered more elements than scientists from any other nation. Over 150 years, from the early 18th century to the end of the 19th century, 20 elements - and among them many industrially important metals — were isolated and described.

The ancient Falu copper mine was the logical choice for location of one of the first technical schools in Sweden: "Falu Bergskola" (Falu Mining School), which was set up in 1822. Its first director was precisely one of the chemical scientists engaged in the discovery of new elements. This Mining school was later merged with other existing institutions offering some technical training into "Tekniska Institutet" (the Technical Insitute). This was in 1876 transformed into a technical high school along German models. The Association of Swedish Iron and Steel industry (Jernkontoret in Swedish) was a key supporter and funder of these developments. The new school was called Kungliga Tekniska Högskolan (KTH) in translation Royal Institute of Technology. KTH had 5 departments, including a school of mining science.

In 1972 the education of mining engineers was transferred to the newly established Luleå Technical College close to the Arctic Circle. The College was later expanded and in 1997 renamed Luleå University of Technology (LTU).

LTU has become one of the leading mining universities in Europe, to a large extent due to the fact that it is situated in the centre of one of Europe's remaining mining regions. Around 2/3 of all university trained staff employed by Swedish mining has been trained at LTU. But LTU has also had its focus on the mining sector for a long time and in its internal program Mines of the Future it has relentlessly pushed the importance of mining and minerals and demonstrated its ambition to be a leading actor in this area. LTU has been appointed by Swedish government to lead the national education and research in mining. The recent decision by the EU to locate one EIT Raw Materials CLC (Co-location Centre) to Luleå means that the university has been given a similar role also on the EU level. LTU has actively built international links and supported cooperation with other universities within Europe and around the world. The bold and officially stated aim is to become one of the globally leading mining universities.

Key words: *Swedish mining education, international cooperation, industry*
DOI: *10.17580/em.2018.02.11*

History

The roots of mining education and research in Sweden dates back to the 17th century. Initially the focus was more on applied research than education, but the early efforts also slowly led to important purely scientific results. Swedish metallurgists/chemists have discovered more elements than scientists from any other nation. Over 150 years, from the early 18th century to the end of the 19th century, 20 elements were isolated and described [1]. Some of these are:

Element	Name	Year of discovery
Cobalt	Brandt	1735
Nickel	Cronstedt	1751
Manganese	Gahn	1774
Molybdenum	Hjelm	1781
Yttrium	Gadolin	1794
Tantalum	Ekeberg	1802
Cerium	Berzelius	1803
Selenium	Berzelius	1817
Lithium	Arfvedson	1817
Silicon	Berzelius	1828
Thorium	Berzelius	1829
Vanadium	Sefström	1830
Lanthanum	Mosander	1839
Erbium	Mosander	1843
Terbium	Mosander	1843
Scandium	Nilsson	1879

How was this possible? What made a small country in the periphery of Europe reach such a top position among the much larger and wealthier countries such as Russia, France, England and Germany (although at that time not united into one yet)?

Part of the answer is surprisingly bureaucratisation, or the creation of an administrative institution called Bergskollegium in Swedish or Bureau of Mines in English. Another part is the need of improved processes and better recoveries in Swedish mines, which played such a vital role in Swedish economy during this period. The Bureau was set up in1634. Already from its start the Bureau was instructed to run a *chamber of assaying* to investigate minerals from the various mines in the Kingdom of Sweden. In 1686 a fully equipped laboratory, Laboratorium Chymicum was finally inaugurated [2].

During the first phases of the Bureau's existence spirits and supernatural forces were still accepted and played an important role in the explanation of nature and matter. The transmutative chymistry practised by the traditional *alchemists* was however abandoned as it was not useful in solving the problems of the mining industry. A *chemist* only accepted the existence of matter which could be isolated and handled in the laboratory. Towards the end of the 17th century the Bureau was instrumental in the early stages of this transformation not only in Sweden but also in Europe by gradually turning its attention away from transformational *chymistry*, and focusing on what at the time was called mechanical chemistry i.e. early stage modern *chemistry*. The systematic and gradual building of a European network and creating of a national cadre of knowledgeable persons were perhaps the most important ingredients of this process. The international exchange allowed influences to flow in both directions not only into Sweden but also sending ideas and experiences into central Europe. This was not a linear development but over one hundred years and in spite of many problems of various kinds there was progress.

These sustained long term efforts resulted among other things in the establishment of the first Swedish mining education unit in a more modern sense in the early 19th century. As the mining industry was one of the most important off takers of "technically educated men" technical education was initially synonymous with mining education. Only men were in those days trained and educated. It was only in the late 19th and early 20th century that women in Sweden were given equal rights with men to study engineering whether mining or other fields. The demand for problem solving and productivity improvements was particularly strong at the Falu copper mine in central Sweden. This mine had been one of the key factors behind the growth in economic and military power of Sweden in the 17th century when it produced 90,000 tonne ore and 3,000 t copper annually [4]. This equated to 2/3 of European demands in some years. Together with Japanese copper exports Falun dominated the copper supply of the world [6].

Although its domination declined during the 18th century the Falu mine was still important enough to be the logical choice for location of one of the first technical schools in Sweden: "Falu Bergskola" (Falu Mining School), which was set up in 1822. Its first director was precisely one of the chemical scientists engaged in the discovery of new elements, N.G. Sefström. The school was also influenced by J.J. Berzelius the chemist/metallurgist of European or even world renown, who advocated a combination of practical and theoretical training. To find the right balance between science and applied, originally very basic skills, was a constant problem and it was only in the second half of the century that the scientific basis of engineering was fully accepted and appreciated. Even today KTH has as its motto: *Vetenskap och konst* or in English *Science and art*. Art is here not used in the sense the word is usually today: fine arts. A more fitting word would possibly be technology in modern language. Christoffer Polhem was in the early 18th century in charge of all machines, mainly to transport water and ore out of the pit, in the Falu mine. He was called "*konstmästare*" in Swedish, literally Engine master. Today the title would be Chief Engineer or with an even more modern word Chief Technology Officer.

Another of the early schools for technical training in Sweden, which was called "Tekniska Institutet" (Institute of Technology), also had strong links to the Falu mine. This school included the collection of mechanical models, which had originally been constructed by Falun's konstmästare. These two establishments, Tekniska Institutet and Bergskolan, were merged in 1868 and the Institute of Technology was started with its building (no campus in those early days) in central Stockholm. It was modelled and inspired by the German type of technical college (technische Hochschule), which were being set up in the mid-19th century. This meant that the training and education of engineers was formalised, in contrast to the British model of apprenticeships, which was predominant in the UK as long as towards the end of the century.

Tekniska Institutet was in 1876 transformed into a technical high school with 5 departments including a school of mining science. It is interesting to note that mining was

the only department, which expressly had science incorporated into its formal name. The new school was called Kungliga Tekniska Högskolan (KTH) in translation Royal Institute of Technology. The first year the number of students was 273 in total, of which a handful studied mining and metallurgy. Courses ran over 3 or 4 years. First year intake varied considerably according the number of applicants (until the early 20th century all qualified applicants could start an education) and was initially between 25–50 for all departments taken together. It was only towards the end of the century that the number of first year students reached 100. From 1910 the degree given for mining students was called "bergsingenjör" (mining engineer) in contrast to the "civilingenjör" (MSc, irrespective of field of study) exam given by the other departments of the school. The mining department remained at KTH in Stockholm until 1972 when the education of mining engineers was transferred to the newly established Luleå Technical College. The College was later expanded and in 1997 renamed Luleå University of Technology (LTU). From 1996 the special mining engineering exam was abandoned and the engineers with a mining focus were called "civilingenjörer" like all the other graduate engineers [3, 7].

Like in most European countries Swedish mining industry faced a long and persistent down period in the end of the 20th century and early 2000s. This was also reflected in the number of students and even in the name of the training program and the syllabus at LTU. It was no longer called mining but Natural Resources Engineering. Just as the night is at its darkest just before dawn the down period ended abruptly in 2005. LTU experienced a period of quick growth and ever expanding research programs to a large degree funded by three local companies: LKAB (iron ore) and Boliden (non-ferrous metals) in mining and SSAB with blast furnace based steel works in Luleå. The European Union also slowly started to get interested in mining again. This development gave a strong boost to the internationalisation of LTU, both its undergraduate and advanced education and its research activities.

EU initiatives

The boom years in the early 21st century clearly demonstrated how important a reliable and unhindered supply of raw materials is to the EU economy and its industry. In the member countries, there are at least 30 million jobs depending on a steady flow of raw materials at reasonable prices. The European Commission's actions to ensure a sustainable supply of metals and minerals evolve from two main initiatives:

- The Raw Materials Initiative (RMI)
- The European Innovation Partnership on Raw Materials (EIP RM)

These are specific for the raw materials sectors but are generic to the EU in that there are other sectors of the economy and society in Europe which is targeted with Innovation Partnerships and Initiatives using similar methods and approaches. All initiatives further have as a common denominator to create new networks and increase cooperation among all EU's 28 member countries and also other neighbouring and associated countries including non-European ones.

The Raw Materials Initiative

The RMI was first adopted in 2008. It sets out a strategy for tackling the issue of access to raw materials for the EU. This strategy has three pillars, which aim to ensure:

- Fair and sustainable supply of raw materials from global markets;
- Sustainable supply of raw materials within the EU;
- Resource efficiency and supply of "secondary raw materials" through recycling.

The strategy covers all raw materials used by European industry excluding agricultural materials and energy materials. Focus is on minerals although also for example rubber and forestry products are included. The Commission considers that ensuring sustainable access to these raw materials is crucial to the competitiveness and growth of the EU economy and to the objectives of the Europe 2020 industrial strategy: to increase the share of industry in EU GDP to 20 per cent.

The European Innovation Partnership (EIP) on Raw Materials

The EIP Raw Materials is the main EU initiative implementing the RMI and brings together EU countries, companies, researchers, and NGOs to promote innovation in the raw materials sector. According to the Commission EIPs should be challenge-driven, focusing on societal benefits and a rapid modernisation of the associated sectors and markets. EIPs should act across the whole research and innovation chain, and aims at bringing together all relevant actors at EU, national and regional levels in order to:

- step up research and development efforts;
- coordinate investments in demonstration and pilots;
- anticipate and fast-track any necessary regulation and standards; and
- mobilise 'demand' in particular through better coordinated public procurement to ensure that any breakthroughs are quickly brought to market.

Rather than each member country taking the above steps independently, as was previously the case, the aim of the EIPs is to concentrate its efforts across the member countries and to design and implement them in parallel to cut lead times. The overall objective of the EIP on Raw Materials is to contribute to the 2020 objectives of the EU's Industrial Policy and the objectives of the flagship initiatives 'Innovation Union' and 'Resource Efficient Europe', by ensuring the sustainable supply of raw materials to the European economy, whilst increasing benefits for society as a whole.

The Commission hopes to achieve these goals by:

- Reducing import dependency and promoting production and exports by improving supply conditions from EU, diversifying raw materials sourcing and improving resource efficiency (including recycling) and finding alternative raw materials.
- Putting Europe at the forefront in raw materials sectors and mitigating the related negative environmental, social and health impacts.

In 2011/12 the EIP RM developed its Strategic Implementation Plan (SIP) through a long process with broad participation from all types of stakeholders from most member countries. This process resulted in 95 actions to foster innovative solutions. These may be technological or non-technological. Specific actions include research and development,

addressing policy framework conditions, disseminating best practices, building a knowledge base, and fostering international cooperation. Staff from LTU was deeply involved in this process.

KIC Raw Materials

In December 2014 the European Institute of Innovation and Technology (EIT, an independent body of the EU based in Budapest) launched the EIT Knowledge and Innovation Community (KIC) Raw Materials. This is considered a milestone in achieving the objectives of the European Innovation Partnership (EIP) on Raw Materials. One of the key targets of the EIP is indeed to set up a network of research, education and training centres on sustainable raw materials management organised as a KIC, another generic EU organisation to promote R&D across the Union. The KIC Raw Materials will address sustainable exploration, extraction, processing, recycling and substitution and the impact it will generate.

EIT Raw Materials has the very ambitious vision of turning the challenge of raw materials dependence into a strategic strength for Europe. Its mission is to boost the competitiveness, growth and attractiveness of the European raw materials sector via radical innovation and entrepreneurship. This KIC aims at integrating multiple disciplines, diversity and complementarity including business, education and research across the whole raw materials value chain. LTU was one of first and most active participants in the long process leading up the formation of this KIC.

EIT KIC Raw Materials is said to become the strongest consortium ever created in the world in the raw materials field. It has 115 partners from 22 countries. The approach will pay particular attention to systemic thinking and de-siloing across the value chain. Focus will be on growth and job creation by boosting start-ups, Small and Medium-sized Enterprises (SMEs), radical innovation and education. The KIC Raw Materials is organised as 6 Co-location Centres (CLC) and a main coordination Center in Berlin. One of the CLCs is located in at LTU in Luleå in the middle of the Nordic metal mining and smelting cluster. This is the first CLC outside any major European city ever. Partners in the Northern CLC are based in Denmark, Ireland and Sweden. It will no doubt further boost LTU's status as a world leading mining university.

EIT Raw Materials hopes to generate significant impact on European competitiveness and employment. This is planned to be realised through the introduction of innovative and sustainable products, processes and services and well-educated people that will deliver increased economic, environmental and social sustainability to European society. This might all sound a bit vague but there are concrete goals set as well: By 2022, the KIC is aiming to create, among others, 64 start-ups and 5 new primary/secondary sources of critical raw materials (CRM).

Luleå University of Technology today

In an optimistic tone Luleå University of Technology claims that: Great ideas grow better below zero" making a point out of the fact that it is the northernmost technical university in the EU. If this statement is correct might be contested, but LTU had 7,659 full time students (15,122 individuals registered) in 2015 and a staff of 1,777. Measured on the total number of students, 85% finish their studies according to schedule. The gender composition has improved since the times when women were not even allowed to enter the technical educations, but progress is slow and the process not yet completed. Still the balance male/female is not equal, but for both students and staff only 44% are female. Among full professors the imbalance is worse, of a total of 236 persons only 39 or 22% are women. LTU offers a range of programs in addition to mining related ones and operates on five campuses. Mining is taught on the main campus in Luleå and in Filipstad in southern Sweden where programs on Bachelor level are offered. This school named "Bergskolan", like the predecessor of KTH and LTU, has been in operation since 1830. It became part of LTU in 2012 [5].

LTU has become one of the leading mining universities in Europe, to a large extent due to the fact that it is situated in the centre of one of Europe's remaining mining regions. Around 2/3 of all university trained staff in Swedish mining has for example been trained at LTU. But LTU has also had its focus on the mining sector for a long time and in its internal program Mines of the Future it has relentlessly pushed the importance of mining and minerals and demonstrated its ambition to be a leading actor in this area. LTU has been appointed by Swedish government to lead the national education and research in mining. The recent decision by the EU to locate the EIT Raw Materials CLC to Luleå means that the university has been given a similar role also on the EU level. LTU has also actively built international links and supported cooperation with other universities within Europe and around the world. The bold and officially stated aim is to become one of the globally leading mining universities.

LTU is the university in Sweden which has the highest share of its total research funding coming from outside sources such as industry and research foundations, 62 per cent. These close relations with industry give the applied research a boost and supports not only mining research but also other disciplines. The university has an important exchange program with foreign universities. There are cooperation agreements signed with universities in 49 countries from all over the world but a focus on Europe: 29 countries are within Europe. Most of this exchange activity is within multilateral programs such as Erasmus, Nordplus, Linneaus-Palme and ISEP. The number of incoming exchange students has decreased in recent years after Swedish government introduced fees for foreign students. Previously university education was free for all, national and foreign students. In 2015 347 foreign students were attending courses in Luleå while 161 of its students were abroad. The number of local students going abroad has been constant as it has not been affected by the introduction of a fee for foreign students in Sweden. It is the opinion of LTU that more of its students should go abroad for at least part of their education. These figures include all students not only those studying mining and metallurgy. The departments engaged in mining received 53 exchange students from 14 countries during 2015. On the PhD level there were in total at all departments 8 incoming and 10 outgoing students in 2015.

The Department of civil, environmental and natural resources engineering is home to the students and researchers directly involved in mining. Within the department there are two divisions: Division of mining and geotechnical engineering and

Division of geosciences and environmental engineering. There are in total 117 students in Luleå and 103 in Filipstad. The gender balance is 44% female students in Luleå but only 17% in Filipstad where the education is much more applied. There are also other departments which are working in areas related to mining such as economics, history of technology, law and work environment.

But one example of LTU's international offering is the masters programme Emerald, Georesources engineering operated as an Erasmus Mundus program. This is an EU funded cooperation and mobility program. Emerald is a 2-years master course and one semester can be spent at anyone of the four universities cooperating: Université de Liège Belgium, Université de Lorraine France, Helmholtz Institute Freiberg for Resource Technology Germany or LTU.

Another international initiative in which LTU is active is the Nordic Mining School. To enhance the innovative environment LTU and Oulo University in nearby Oulo in Finland jointly set up this Nordic competence centre for exploration, mining, minerals processing and metallurgical education. The School aims at students at masters level and to stimulate contacts, remove borders and increase mobility. Further it is important to develop new business partnerships in the region and highlight Northern Fennoscandia as a significant science region in the areas covered [10].

In addition to the Northern CLC of the EU, as discussed above, there are three additional hubs, one Nordic and two national focusing on exploration, mining and metallurgy which are located to LTU:

NordMin. This is a Nordic (Greenland, the Faeroes, Iceland, Denmark, Norway, Sweden and Finland) initiative funded by the Nordic Council of Ministers to create a Nordic network of expertise for a sustainable mining and mineral industry. The program will seek to involve itself in other national and international initiatives related to mining and minerals industries. NordMin was started in 2012 and at present has funding till the end of 2016 [11].

Centre of Advanced Mining and Metallurgy (CAMM). The Centre is responsible for the coordination and execution of work in the national strategic research area Sustainable use of natural resources: mining and minerals. Funds are provided by Swedish government and cover the complete value chain from exploration, mining, mineral processing, metallurgy and environment. The Centre has been operating since 2011 [9].

Strategic innovation program for the Swedish mining and metal producing industry (STRIM). STRIM has its origins in a research agenda that was completed in 2012 as a result of the international cooperative efforts in the project Sustainable mining and innovation for the future (SMIFU) with participation from industry and academia in Sweden, Poland and Finland. This project was supported by a group of Swedish research funding agencies. The first STRIM program runs during the time period 2013-2016. In a second period the program is extended to 2020 while also defining the applied research agenda for the medium term until 2024 and beyond until 2030. It has the overall aim of contributing to sustainable growth and strengthen the Swedish mining and metal extraction industry. LTU is coordinating also this program. The program has nine focus areas:

- Exploration
- Resource characterisation
- Mining
- Mineral processing
- Recycling & metallurgy
- Reclamation & environmental performance
- Attractive workplaces
- Gender & diversity in mining
- Social license to operate

Compared to the previous STRIM agenda more emphasis is put on non-technical issues such as gender and social aspects of mining which signals a broader range of innovations will be supported [8].

Conclusion

International cooperation and mobility are buzzwords of today's research and innovation clusters all over the world. These are however not new concepts. The understanding that international exchange is necessary for research and innovations to thrive has been understood in Sweden for hundreds of years. It is only an open environment, which welcomes all interested and knowledgeable scientists and business developers, which can bring a mining industry, regardless of country, to become a global frontrunner. Swedish international contacts whether in mining education or in research and innovation prove that with an open mind and a persistent, long term effort results will come.

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