Engineering Education 5.0: Model Curriculum for a Postgraduate Master on Circular Economy

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Abstract

The necessary focus on sustainability issues, especially concerning tertiary engineering education at universities, has increased massively in recent years. On the one hand, the European Commission aims at a long-term examination of sustainability concepts and concrete implementation measures (e.g., Agenda 2030) with concrete initiatives (e.g., Green Deal. On the other hand, there is also a need for reform in the education system to equip the engineers of tomorrow with the necessary competencies for the use and implementation of these measures. This paper presents a model curriculum for a postgraduate master's programme on circular economy in the extractive industry based on a curriculum search and primary data collection in the extractive industry.

Keywords
Engineering Education, Circular Economy, Model Curriculum, Realignment and Engineering Competences.

1. Introduction
Since 2011, many initiatives have been undertaken that helped shape policy and activities for the "European Circular Economy Action Plan" (CEAP) [1]. Under the direction of the Von der Leyen Commission in 2019, they revealed the "European Green Deal", an ambitious plan to help turn the EU economy into a more sustainable and fairer one. In March 2020, the new CEAP was launched as a major contributing keystone of the European Green Deal [2]. The need for transformation derives from the necessity to rely less on imported and virgin raw materials, reduce global market price dependencies, and stimulate new business opportunities and innovation. The action plan supported transformation by engaging policymakers throughout Europe for the promotion of systematic change.

Higher Education Institutes (HEIs) play a vital role in systematic change as they are a contributing factor to the understanding and dissemination of sustainable development through the production and diffusion of competencies, i.e. knowledge, skills, and attitude [3]. For a true greener economy, all disciplines in higher education need to understand their role in helping the EU to reach and sustain policy initiatives [4,5]. The importance of engineering addressing sustainable development (SD) has been pointed out by international organizations, such as the World Federation of Engineering Organizations [6,7]the International Federation of Consulting Engineers [8], and the UNESCO Engineering Initiative [9].

Bearing in mind the roles HEIs in the engineering education field can play towards embedding systematic change for a greener economy, the gap between current education offers and industry requirements needs to be examined to meet the demands set down by policies for the circular economy and to equip graduates with state-of-the-art competencies to achieve and contribute to a more sustainable and fairer European economy.

In this context, a project called – "Strategic partnership for fostering circular economy approach in extractive industry related study programmes" (CIRCEXTIN) – funded by the Erasmus+ KA 203 Strategic Partnerships for higher education was successfully applied for in the 2020 call round. This project aims to create a strategic partnership between Universities and companies developing a comprehensive training platform that will help to modify existing study programmes related to extractive industry, and also knowledge of proper waste management incorporating a circular economy approach. The programme will strengthen the strategic and structured cooperation between higher education institutions through: a) support for various types of cooperation models, including the most ambitious ones such as the European Universities; b) contributing to removing obstacles to mobility by implementing automatic mutual recognition of qualifications and learning outcomes, and by embedding mobility in curricula; c) support for higher education institutions to implement the Bologna principles and tools to enhance mobility for all and to develop a successful multilingual European Education Area by 2025.

The CIRCEXTIN project comprises a consortium of 5 HEIs and two industry entities and is led by the Silesian University of Technology in Poland. The other 4 HEI consortium partners are, Universidad Politécnica de Madrid (UPM) in Spain, TalTec in Estonia, Technical University Delft in The Netherlands, and the Montanuniversität Leoben in Austria. Both industrial companies are from Poland, JSW Innowacje S.A., part of the JSW Group, and Cobant Group S.A.

The main objectives of the project involve the following aspects:

- Exchange of education experience related to extractive industry in various countries and regions
- Identifying similarities and differences in curricula related to extractive industry in the Project partners` countries (for various raw materials)
- Determination of similarities and differences in the requirements of the mining industry of various raw materials
- Determining to what extent the existing education at the Project partners' Universities considers the requirements of a circular economy
- Identifying key qualifications and skills for the education of "future engineers" in the mining industry according to the idea of a circular economy and cleaner production
- Building a common benchmark for educating the "ideal future engineer" of the European mining industry in a sustainable economy
- Preparation of an international platform for building education programmes and courses
- Designing a model curriculum related to the circular economy approach in subjects taught at universities where extractive industry-related studies are conducted
- Building an e-platform for the exchange of experience in the education of "mining engineers" following the preservation and improvement of the environment and climate
- Development of a short postgraduate course curriculum for graduate students
- Development of a Massive Online Open Course (MOOC)
- Establishing a regulatory framework that allows an objective evaluation of the degree of compliance with this indicator [10].

This paper will serve to demonstrate specifically one of the project outputs related to the development of a model curriculum for the circular economy in the extraction industry, which was led by the Montanuniversität Leoben.

1.1 Objectives

The objective of this research was to:

- Conduct a survey among higher education faculty, students, and other professionals across Europe: to collect requirements and preferences of courses and to find differences between the training currently provided in the various extractive industry-related study programmes,
- Data collection of parameters influencing the training requirements in the different countries: to assess the state-of-the-art referring to the use of functional evaluation methodologies and technologies,
- To perform a qualitative and quantified analysis: to identify differences in training needs among countries
- Based on the research and analysis, a model curriculum will be developed

The following chapters will address the conducted research and results of this task as one of the specific contributions to the CIRCEXTIN project.

2. Literature Review

In preparation, the authors conducted a curriculum search at the five participating university partners as a state-of-the-art overview of already implemented study contents at Circular economy in the extractive industry-related study programmes. As an example, the curricula in Mining and Geology were used to ensure benchmarking. As displayed in table 1 the following curricula are currently offered by the respective universities:

Table 1. Overview study programmes

Country	**University**	**Programme**	**Language**	**CE content**
Austria	MUL	Bachelor in Applied Geosciences	German	
		Bachelor in Mining Engineering	German	
		Master in Applied Geosciences	English	Partly
		Master in Raw material extraction and tunnel construction	German	Partly
		International Master in Sustainable Materials (Double Degree Programme) -SUMA EIT Raw Materials	English	Partly
		Joint Master of Science in Advanced Mineral Resources (AMRD)	English	Partly
Netherlands	TU Delft	European Mining Course (S1 Aalto University, S2 RWTH Aachen University, S3 TU Delft, S4 Thesis)	English	x
		Bachelor in Applied Earth Sciences	English	
Poland	SUT	Master in Mining and Geology	English	x
Spain	UPM	MÁSTER UNIVERSITARIO EN INGENIERÍA DE MINAS	Spanish + English	Partly
		Joint Master of Science in Advanced Mineral Resources (AMRD), Sustainable Mining	Spanish + English	Partly
		Bachelor Programmes in Mining and Geology	Spanish	
Estland	TalTech	Georesources (Bachelor and Master)	Estonian + English	x

As can be seen from figure 1 above, the five universities offer a total of 14 university programmes in the Mining and Geology discipline, consisting of bachelor, master, joint master, and international master programmes and courses. Circular economy-related content is almost everywhere partly or fully incorporated, except for the Bachelor programmes “Applied Geoscience”, “Mining Engineering”, “Applied Earth Science”, and “Mining and Geology”.

3. Methods

The tasks leading to the model curriculum are three-fold and are displayed in figure 1.

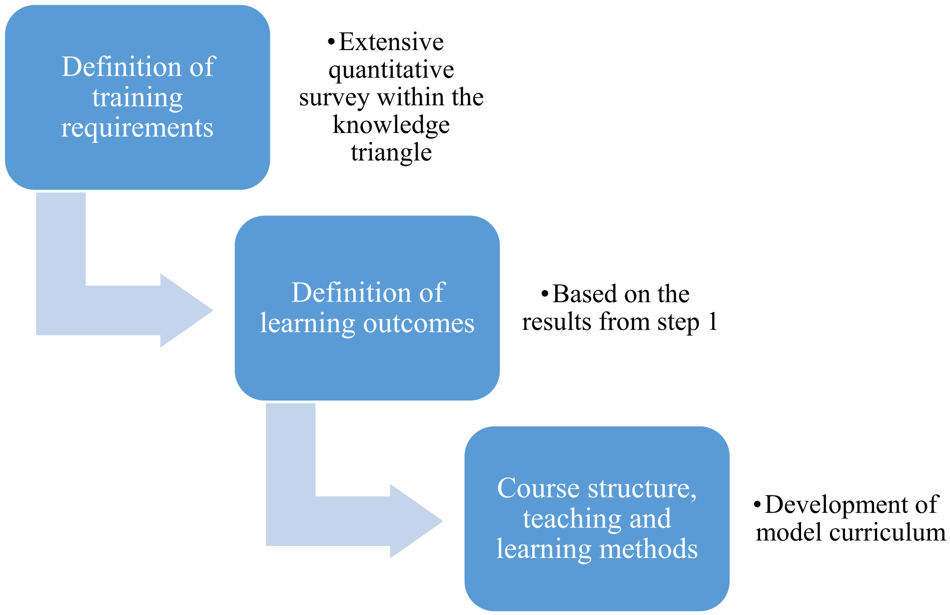

Figure 1. Methodological approach

Based on the curricula review explained in the previous section, the subsequent methodological approach with its three steps will ensure the sound development of a model curriculum for the postgraduate master's programme on circular economy for the extractive industry-related future professionals.

<u>Step 1: Definition of the training requirements:</u>
The objectives of this activity are the extraction, gathering, specification, and analysis of the formative needs. Each CIRCEXTIN project partner distributed the survey among the corresponding target users in their respective countries to collect the training requirements of the postgraduate study programme. The information has been collected in several ways:

- Survey among high education teachers, students, and other professionals across Europe: To collect requirements and preferences of the course and to find differences between the training imparted currently in the various extractive industry-related study programmes this survey has been established. The survey aims to obtain information from a large sample of European countries. The main countries of the project partners are represented (Poland, Spain, Estonia, and Austria).
- Data retrieved from the previous tasks have been gathered and analyzed: Qualitative and quantified analysis will be performed such as SWOT, descriptive and statistical analysis. Data will be exploited both at EU level and by country to identify significant differences in training needs among countries.

<u>Step 2: Definition of the learning outcomes:</u>
Within this task, the partners defined the learning outcomes (i.e. knowledge, skills and competences to be acquired) meeting the formative needs detected and gathered in step 1. Outcomes will be specific, achievable, realistic, measurable, and timed for the selected targets. Learning outcomes defined have been approved by all consortium members.

<u>Step 3: Course structure, teaching and learning methods:</u>
Based on the information gathered on the previous tasks, the teaching and learning methods and the content of the course have been developed and the structure has been defined. This task defined the structure of the entire programme scope into modules that are subsequently split down into sessions and established the course scheduling and training

milestones. As a teaching and learning method, a systems-theoretical-constructivist learning approach has been used. The content structure defined has been approved by all partners.

4. Data Collection

To identify the requirements of the mining industry, key qualifications and skills for the education of “future engineers” in the mining industry, the extent of the existing education at the project partners' Universities according to the idea of circular economy and cleaner production an online survey was conducted. As stakeholders, we identified students, academic staff, professionals related to the raw materials industry, and professionals working in the extractive industry. During November and December 2021, questionnaires adapted to the individual stakeholder groups were developed, and after the approval of all partner organizations the link to the online survey was distributed in each partner network end of January. For the online questionnaire, the tool Lime Survey was used. A total of 55 different questions out of 7 categories were asked. During the period 20th January – 30th April 126 questionnaires were fully completed by the respective stakeholders. The survey results were analyzed quantitatively and qualitatively using IBM SPSS. We achieved in a total of 126 complete responses. Out of this 68 (54 %) can be assigned to students, 34 (27 %) to academic staff, 6 (4.8 %) to professionals, and 28 (14.3 %) to the industry. The KPI of 100 participants was thus achieved. In the survey, the main countries of the project partners are represented, except Estonia. Unfortunately, we did not receive any surveys completed by Estonian stakeholders. A great number of questionnaires are fulfilled from Polish stakeholders (36,9%). Austrians had the second highest response quote with 21,5%. Also, Spanish (9,2%) and Dutch (8,5) stakeholders completed a high percentage of questionnaires as they are part of the consortium. 15,4% of the survey were fulfilled by other nationalities.

5. Results

The following section gives more insights into the survey results and is clustered according to thematic areas.

Statements on circular economy (CE)

Within the online questionnaire participant groups – students, academic staff, and industry representatives – were asked to rank CE-related statements according to their agreement or disagreement.

Students (n=64):

- 65.2% stated, that CE is the answer to current challenges
- 27.5% stated, that they neither agree nor disagree that the principles of CE are incorporated in the study courses
- 57.4% agreed or totally agreed, that the lack of knowledge about CE is a serious threat to the industry
- 66.7% agreed or totally agreed, that CE concepts assist students in better understanding practical concepts or challenges
- 86.6% agreed or totally agreed, that the incorporation of CE into curricula would bring added value to the entire extractive industry sector

Academic staff (n=35):

- 82.1% agreed or totally agreed, that the CE principles help to develop students´ competences through constant interaction and evolvement
- 62.1% totally agreed that the CE concept inspires students to create solutions for the future
- 85.7% agreed or totally agreed, that the incorporation of CE principles could bring added value to the entire extractive industry sector

Industry representatives (n=17):

- 60% agreed or totally agreed, that the lack of knowledge regarding CE is a serious threat to the extractive industry
- 65% agreed or totally agreed, that the incorporation of CE could bring added value to the extractive industry sector
- 13 persons from the industry agreed or totally agreed, that CE concepts help students in the development of competences

Competences

All participants were asked to rank the contribution of the study programme to the listed competences toward the acquisition of CE on a scale from 1 "not at all" to 5 "very much". The results are summarized in table 2.

Table 2. Comparative overview of competences

	Students	**Academic staff**	**Industry representatives**
1	Problem-solving skills, 4.43	Teamwork, 4.07	Practical skills, 4.38
2	Theoretical skills, 4.33	Problem-solving skills, 4.07	Problem-solving skills, 4.38
3	Technical skill, 4.09	Technical skills, 4.03	Creativity, .38
4	Continuous training and development, 4.05	Methodological competence, 3.96	Openness for new approaches, 4.19
5	Special competences, 4.02	Openness for new approaches, 3.90	Continuous training and development, 4.19
6	Openness for new approaches, 4.00	Communication skills, 3.86	Technical skills, 4.00
7	Teamwork, 3.97	Creativity, 3.86	Communication skills, 4.00
8	Ability to quickly analyze and adapt to new situations, 3.95	Practical skills, 3.83	Ability to quickly analyze and adapt to new situations, 4.00
9	Practical skills, 3.89	Self-management, 3.79	Special competences, 3.81

Satisfaction with CE-related content in curricula

Students

The students were asked to what extent they are satisfied with the knowledge about CE provided during their studies. Using a 4-part scale ranging from "No, I am not satisfied with the amount of information" to "Yes, I am fully satisfied with the amount of information provided during my studies", students were able to give their assessments. Figure 2 displays the distribution of the results regarding the student satisfaction.

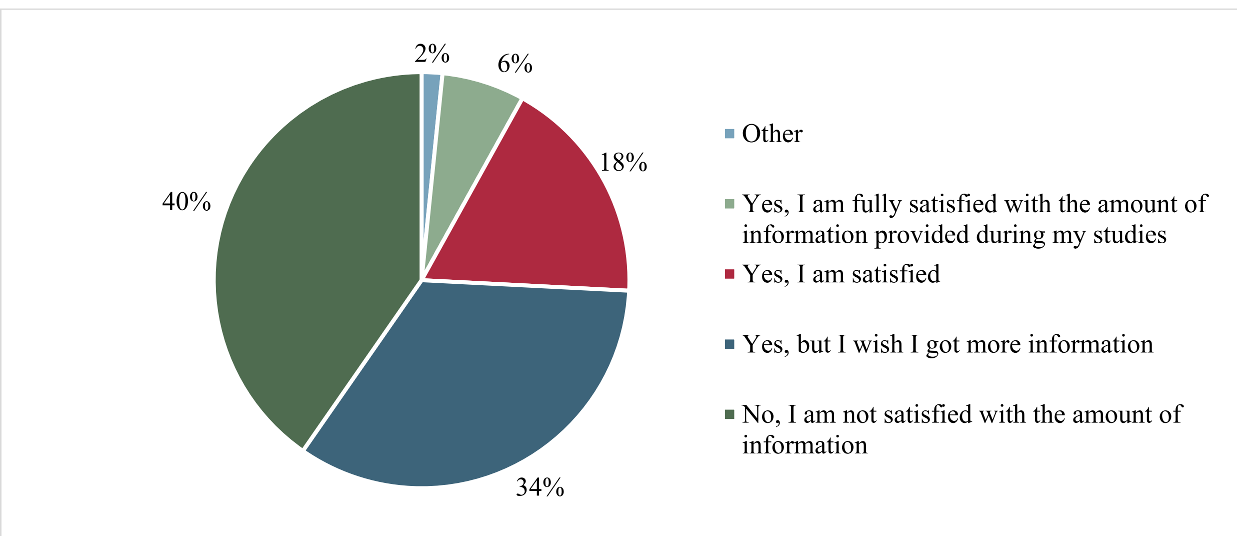

Figure 2. Student satisfaction

Academic staff

Based on a 4-part scale ranging from "No, I am not satisfied with the amount of information" to "Yes, I am fully satisfied with the amount of information provided during my studies", academic staff were asked to what extent they were satisfied with the CE knowledge acquired by students during their studies. The results are summarized in figure 3.

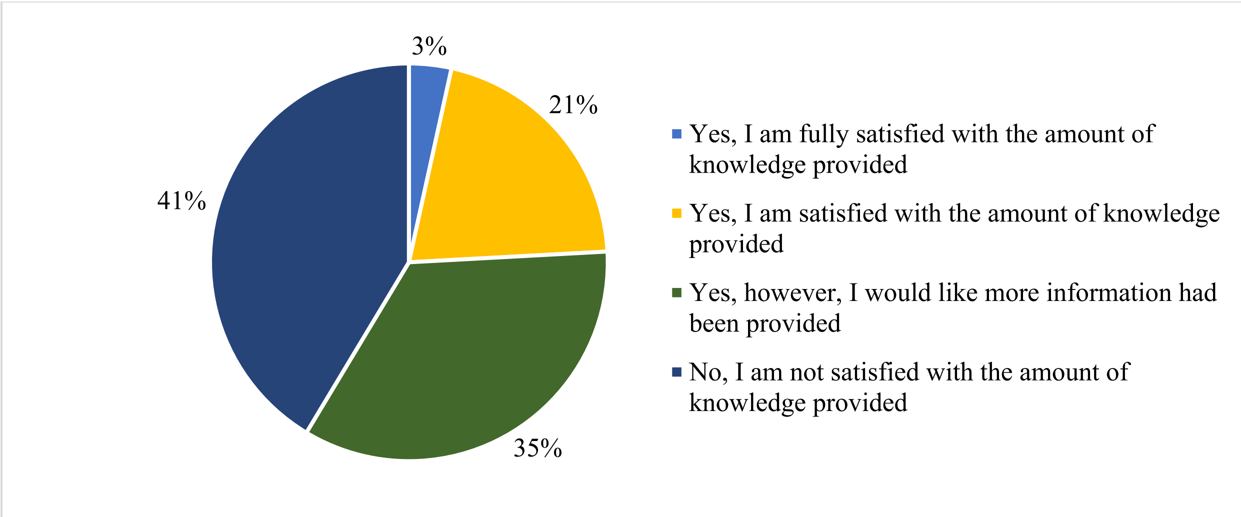

Figure 3. Academic staff satisfaction

<u>Methods to enhance skills towards implementation of CE</u>
The academic staff was asked which, in their opinion, are the most important teaching and learning methods for conveying CE-relevant information. Here, the participants could give multiple answers from a list of pedagogical methods and tools. The results are displayed in figure 4.

Figure 4. Overview of methods to enhance skills

<u>Teaching and learning methods</u>
Students were also asked about their opinion of the essential teaching and learning methods for teaching CE content using multiple responses.

The following methods are the most important ones:
- Cooperation with industry
- Interdisciplinary working groups
- Case studies
- Estimation of economical, societal, and ecological consequences of a project
- Laboratories and exercises with the focus on own results
- Projects

- Seminars
- Best practice examples
- Tools to assess the environmental impacts of the different circularity options. Examples of circular economy in industry
- Internships

6. Model curriculum of the Postgraduate MSc programme "Circular economy in the extractive industry"

Many natural resources are and need to be used in a smarter, more sustainable way. The European Commission's Circular Economy Action Plan sets many ways how to "close the loop" of product lifecycles. The extractive industry is the industry where large volumes of waste are generated. This includes not only solid waste from mine extraction but also liquid waste in the oil and gas industry and gaseous waste (e.g. greenhouse gas emissions from mines). The Circular economy act published by the EU puts a major emphasis on finding new, innovative means to move away from a "take-make-dispose" culture and to develop new methods, technologies, and also approaches to recycle and re-use products. In this context extractive industry and higher education programmes related to it such as mining, mineral engineering, raw materials, and applied earth sciences need to emphasize this context and include this concept in the existing curricula and/or create new study programmes or short courses that will include circular economy approach. The objective is to create a strategic partnership between universities and companies to develop a comprehensive training platform that will help to modify existing study programmes related to extractive industry also knowledge of proper waste management incorporating a circular economy approach. Extraction of raw materials in the world is the base for the development of national and global economies. Raw materials are important for many areas of the industry. However, the mining industry has a very negative impact on the environment and climate change. On the one hand, we have an important branch of industry, on the other, we have to protect the environment. Therefore, the education of future specialists has a vital role in a sustainable and clean economy. In each European country, different threats are identified for different raw resources. However, the Bologna education system needs the training of specialists for an integrated European common market. A student educated in Poland or Spain should know the same principles and be able to build mining processes based on the same circular economy assumptions. Only such an education programme will ensure a common labor market and compatible qualifications. Environmental and climate protection is the only way for the development of economies to ensure the safety and well-being of citizens.

6.1 Need and relevance of the study for science and the labor market

This programme aims at helping to modify existing study programmes related to the extractive industry with up-to-date, practical, and applicable knowledge of proper waste management in the extractive industry incorporating a circular economy approach. The postgraduate master´s programme will contribute to completing the training provided nowadays in the schools in this field, endowing the new graduates with skills suitable to face the needs related to Europeans' Circular Economy Action Plan in the next years. The programme will also support the testing of innovative practices to prepare learners, staff, and students to become true factors of change (e.g. sustainable use of resources and energy, reduction of raw materials consumption, how to compensate for carbon footprint emissions, opt for sustainable food and mobility choices, etc.).

6.2 Qualification profile and competences

After successful completion of this master's programme, the participants are able to:

- Link societal challenges for the development of economic opportunities using new business models
- Integrate new management methods and technologies related to circular economy into daily practices
- Assess the use and application of secondary raw materials and innovative substitution technologies

6.3 Duration and structure of the study programme

The master's programme with a workload of 90 ECTS credits comprises four semesters and is structured in modules. Figure 5 displays the structure of the model curriculum.

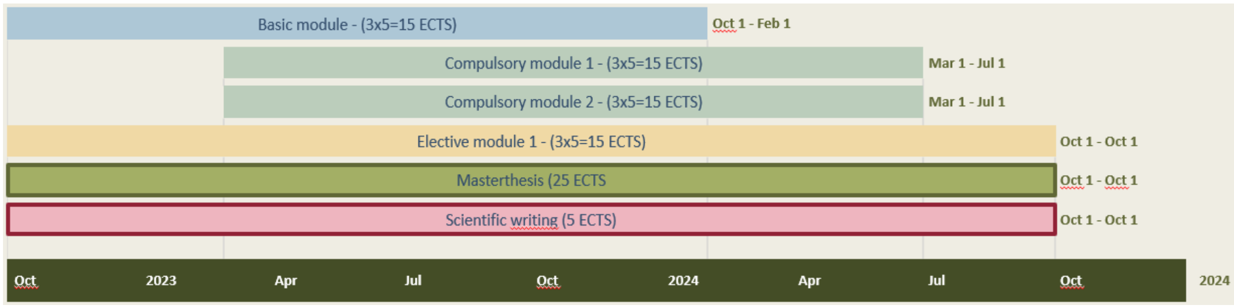

Figure 5. Structure of the model curriculum

Module overview

<u>Basic – Compulsory Modules</u>

- Circular Economy
  - Circular Economy in mineral processing (result open-ended question)
  - Tools to assess the environmental impacts of the different circularity options. Examples of circular economy in the industry (result open-ended question)
- Secondary raw materials
  - Increasement of the use of secondary raw materials and by products (reduce raw materials) out of waste steams
  - Creation of a secondary raw material market
  - Market Analyses – long-term trends and potential shifts in demand for particular raw materials
- Circular economy - (New) business models
  - Creation of new business models and rethinking of products
  - Shifting from a product to a service business model
- Cooperation and stakeholder involvement
  - Cooperation with other industries for a better understanding of material flows and closing loops
  - Transparency and engagement with customers and their needs towards circularity (including marketing and sales approaches)
  - Stakeholder involvement – cooperation between mining companies, communities, policymakers and consumers
  - Supporting policy frameworks
- Circular economy - Management and technologies
  - Management
    - Emission management especially greenhouse gases (GHG)
    - Water management (e.g., processing plant)]
    - Energy management (e.g., electrification of the mine site; providing net benefits to the communities)
    - Waste management (result open-ended question)
  - Processing technologies
    - New processing technologies
    - Development of sustainable mining methods and technologies to reduce the environmental impact and impact on local communities

Elective module

- New trends in the extractive industry
  - Remediation of old mine sites
  - Biodiversity preservation
  - “Urban Mining” - waste processing processes in mine sites
- Digitalization
  - Mine digitalization by automation and remote control (e.g., automated mining trucks)
  - Use of AI (e.g., ML/DL) by data digitalization and remote sensing

Master thesis

- In the master's programme a master's thesis has to be written. This comprises 30 ECTS credits. It is recommended to write the master thesis from the 3rd semester on.
- The topic of the master's thesis is to be taken from the subject of adult and continuing education. Alternatively, the topic of the master's thesis can be chosen from the subject of extractive industry-related studies.
- The student is entitled to propose the topic or to select it from several proposals made by the available supervisors.
- The topic of the master's thesis is to be chosen by the student. The topic of the master's thesis must be chosen in such a way that it is possible and reasonable for the student to complete it within six months.
- Students have to inform the Dean of Studies in writing about the topic and the supervisor of the master's thesis.
- The completed master's thesis has to be submitted to the dean of studies for evaluation. The supervisor must assess the master's thesis within two months of submission.
- The assessment of the master's thesis is to be documented by a certificate. This is to be issued within four weeks after the assessment of the performance at the latest.

6.4 Learning and teaching concept

Before the beginning of each semester, the heads of the courses shall appropriately inform the students about the objectives, contents, and methods of their courses and the contents, methods, assessment criteria, and assessment standards of the course examinations. Courses may also be conducted with the support of digital learning technologies. In particular, the possibilities of the Internet in the form of learning platforms and other online tools can be used. Content may be prepared in multimedia form. Course examinations may be conducted online.

Disabled students shall not suffer any disadvantage as a result of their disability. Requests for approval of suitable alternative forms of compulsory courses as well as for different types or methods of examinations shall be complied with if it can be proven that the disability makes it impossible or considerably more difficult to complete the course or examination in the intended manner and form. It must be ensured that the educational objective can be achieved through alternative forms of courses and/or examinations. Special requests of working students or students caring for children or students with similar care obligations (e.g., nursing) regarding the timing of courses and examinations shall be considered as far as possible.

6.5 Language of instruction

The language of instruction is English. If possible, all modules/examinations can also be held in popular European language courses, based on the nationality composition of the participants. Courses, examinations, and written work can also be held or written in the native language, as well as, in English as the common scientific language.

7. Conclusion

In a nutshell, it can be stated that the basic concepts and associated measures of the circular economy are indispensable for the sustainable use of resources, such as human capital or raw materials. The results of the primary data collection show how necessary the holistic integration of these topics is in current curricula and training at the tertiary education level. Here, the integration of the concepts and measures of the circular economy into all courses, as a multidisciplinary approach, seems to be successful to be able to further develop both the professional and the transversal competences of future engineers. This postgraduate model curriculum primarily serves as a model for the participating universities to implement such master's programmes in the university landscape. The implementation of this master's programme is planned for 2023 and will be implemented with the partner universities of the CIRCEXTIN project. For the long-term further development of the postgraduate master's programme, further studies or surveys in the knowledge triangle, education, research, and business are of course essential to be able to guarantee current topics and challenges as well as competence-oriented methods and techniques for successful teaching and learning.

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Biographies

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Manuel Woschank received a Ph.D. in Management Sciences with summa cum laude from the University of Latvia and the Habilitation in Industrial Engineering and Management from the Montanuniversitaet Leoben. He is currently Deputy Head of the Chair of Industrial Logistics at the Montanuniversitaet Leoben and an Adjunct Associate Professor at the Faculty of Business, Management, and Economics at the University of Latvia. He was a visiting scholar at the Technical University of Kosice and the Chiang Mai University. His research interests include the areas of logistics systems engineering, production planning and control, smart logistics/logistics 4.0 concepts and technologies, circular economy and the decarbonization of logistics systems, behavioral decision-making, and engineering education.

Mariaelena Murphy is the Education Portfolio Manager at the Resources Innovation Center in Leoben. She holds a master's degree in Business Ethics and Social Responsibility. She worked as a Senior Lecturer at the Hanze University of Applied Sciences for 17 years specializing in the Management discipline, also with a focus on cultural competences through the creation and involvement in learning labs. Alongside this, she was actively involved in cross-border projects connecting education, business and communities. Currently, her focus is on (co)creating partnerships and projects that implement new teaching & learning pathways that promote a transdisciplinary approach in connecting research, education, business, and society for the future of T-shaped raw material engineers.