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27th CIRP Life Cycle Engineering (LCE) Conference

Development of Educational Contents on Circular Economy and Critical Raw Materials Challenges

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Abstract

This article presents the case of three projects supported by the European Institute of Innovation and Technology EIT RawMaterials in the framework of consortium between academic and industrial partners from six European countries. EIT RawMaterials has among its strategic objectives the development of educational content for the main stakeholders in the European minerals, metals and materials sector taking into account the sustainability criteria through the value chain. First, the projects studied the need for these different contents in relation to circular economy, the challenges of Critical Raw Materials (CRM), the analysis of the environmental impacts of materials. Then, the educational contents and training were developed in a collaborative way, proposing theoretical contents but also practical and hands-on exercises. The contents were then tested during pilot workshops. Lastly, the knowledge and best practices proposed were disseminated to practitioners in the different countries of the project partners. The evaluation carried out in each project highlighted great interest from practitioners and companies for such educational contents. Online tools and interactive active learning methods were encouraged in these projects, which is considered as attractive. Shortcomings were addressed after pilot workshops which improved the content quality.

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Keywords: Circular Economy; Critical Raw Material; CRM; Education and Training; European projects

1. Introduction

Since 2018, Grenoble INP Institute of Technology has participated in several initiatives funded through collaborative projects funded by the European Institute of Technology EIT RawMaterials. Three projects aim to develop educational content concerning the circular economy, the assessment of the impacts of economic and industrial activities on the environment, and the implementation of a strategy to minimize these impacts. These learning contents can take many forms; they can be workshops, conferences, online contents or interactive tools. The target audience as defined by the EIT strategies includes industrialists, professionals, students and any other person who can play a decision-making role and has a power to minimize the environmental

impacts of its organization. The purpose of this article is to present the Grenoble INP experience in the implementation of three European projects started in 2018 as part of the EIT RawMaterials. Researchers from G-SCOP laboratory were involved in RemanPath [1], WM-CRM [2] and INNOMAT [3] projects. Their contribution consists essentially in the development of educational contents and their dissemination in relation to the research areas of the G-SCOP laboratory. The main scientific contribution are in the topics of engineering design, environmental assessment, eco-design and circular economy strategies. The outline of the papers contains a literature review on sustainability issues and the role played by the EIT-RawMaterials, then a market feasibility section presents in more details the three projects carried out in Grenoble INP and position them in regards to

similar existing projects. The following section presents the main achievements in terms of educational content for each project. Finally, the discussion and lessons learned section presents the main outcomes of the evaluation of the three contents.

2. Literature review

The issue of the impact of human activities on the environment and on the planet has continued to attract the interest of scientists and leaders of the world. Today, the scientific community agrees that global warming is a reality, and several scientific hypotheses and several scenarios have been put in place to estimate the rise in temperature by the year 2050. According to the IPCC, global warming is likely to reach 1.5°C between 2030 and 2050 if it continues to increase at the current rate [4]. But there is a consensus among scientific community that global warming must be limited to no more than 2°C above pre-industrial levels to avoid important and irreversible damages [5]. The rise in the Earth's temperature is a consequence of human economic activity, responsible for multiple impact on the environment, such as the release of greenhouse gases, the eutrophication of aquatic environments, the ozone hole, etc. A great challenge is to be able to meet the basic needs of humanity and the aspirations of people to a better quality of life without exceeding the critical planetary limits [6]. However, according to scientists, it is possible to curb these harmful effects on the environment by modifying our behavior and our way of life. The responsibility is shared among businesses, communities and citizens in the same way [7].

In 2015, the European Commission adopted a broad program on the circular economy including an action plan and proposals for new legislation on waste. This program aims to facilitate the transition to a more circular economy in which the value of products, materials and resources is maintained in the economy for as long as possible and waste production minimized. These efforts are therefore an essential contribution to the European Union's efforts for a competitive, sustainable, low-carbon economy and efficient use of resources [8]. One of the levers in this perspective is training and education. It is crucial to make industry, professionals, students and future economic decision-makers aware of the importance of these environmental challenges, but also of the impact of economic and industrial activities on the environment. Thus, it is necessary to have courses, workshops and lifelong training programs covering these topics. The European Institute of Innovation and Technology (EIT) was created in 2008 to address the challenges of EU innovation activity by integrating the knowledge triangle formed by business, education and research. The EIT's mission is to contribute to Europe's sustainable economic growth and global competitiveness by strengthening the innovation capacity of the Member States and the EU [9]. The EIT has set up a set of thematic Knowledge and Innovation Communities (KICs) to guide its strategy to best achieve the mission it has defined. The KICs are highly integrated entities that develop European collaboration and bring together several universities, research centers, small and large companies and other long-

term innovation actors around specific societal challenges. Among those KICs, the EIT RawMaterials aims at enabling sustainable competitiveness of the European minerals, metals and materials sector along the value chain by driving innovation, education and entrepreneurship [10]. EIT RawMaterial supported projects in which a special focus is dedicated to decision makers in the electronic equipment sector because of the environmental problems that this sector may pose. Throughout their entire life cycle, electrical and electronic products rise environmental challenges, from the extraction of materials to the end of life. These products contain some critical materials or rare earths which rise important challenges during their extraction, processing and recovery. At end of life phase, these products are an interesting secondary source of materials and are often referred to as "urban mines" [11]. In many countries, large amounts of municipal wastes contain a large number of rare and precious metals and critical raw materials CRMs [12]. Most of these materials are available in the wastes of electrical and electronic equipment (WEEE) [13,14]. A radical shift is needed, from linear thinking to circular thinking, where end-of-life products must be considered as a resource to form a closed cycle. The recovery of materials and especially CRMs contained in the WEEE could prevent and decrease the use of virgin resources in manufacturing and, consequently, it could contribute in reducing the environmental pollution [15,16].

3. Market and need analysis

Market feasibility study is carried out as part of work package and highlights the opportunities to be exploited and the interest that the educational content can generate. Table 1 gives a summarised overview of the projects.

Table 1. Presentation of the three projects.

Project	RemanPath	WM-CRM	INNOMAT
Goal	Remanufacturing learning contents	Critical raw materials, end-of-life products and circular economy	Introduction to Life cycle assessment methodology
Content format	Workshop	MOOC and 2-days course	2-days course
Start-End	Jan. 2018- Mar. 2020	Jan. 2018-Dec. 2019	Jan. 2018-Dec. 2020
Partners	VTT from Finland (project leader), Grenoble INP, University Grenoble Alpes (France), TU Delft (the Netherlands), Wuppertal Institute (Germany), Coventry University (UK), and Oakdene Hollins (UK).	TU Delft (project leader), Grenoble INP, University Grenoble Alpes, Ghent University (Belgium), and University of Limerick (Ireland)	TU Delft (project leader), Grenoble INP, University Grenoble Alpes (France), Ghent University, Wuppertal Institute, and the Slovenian National Building and Civil Engineering Institute (ZAG).

3.1. Market and need analysis for RemanPath

RemanPath project is motivated by the fact that Europe is currently reworking only 2% of products and that the concept of remanufacturing remains poorly known. From the

economic and social perspective, remanufacturing could satisfy consumers' needs (quality product with a lower price), create job opportunities and build eco-friendly image for companies [17]. To disseminate this concept in industry, it is necessary to develop the skills of companies' staff, especially small and medium-sized manufacturing companies. This lifelong learning project aims to develop educational content for the European remanufacturing sector. The project builds on the results of the ERN project (European Remanufacturing Network), achieved within the Horizon 2020 Framework Program of the European Union [18]. During the RemanPath project, guidelines of the ERN project were validated, and an educational content was proposed. This content will provide an opportunity for companies to identify their company's skills development needs, design innovative business models and position themselves in the circular economy through remanufacturing activities [19]. The market feasibility study aimed in showing the market opportunities for a remanufacturing training content. It described the current European remanufacturing market, future trends and areas where learning materials are needed. The project relied heavily on the results of the H2020 project ERN Remanufacturing [17], and the EIT RawMaterials ReUK project (Bridging the raw material knowledge gap for and remanufacturing professionals) [18]. These reports formed the starting point for the market feasibility study and were supplemented by 10 interviews with European experts, educational material suppliers and companies already carrying out remanufacturing operations. The RemanPath market feasibility study has shown that there is a need for learning materials in all sectors, even in sectors that have historically successfully implemented remanufacturing, such as the automotive or aerospace industry. It also showed that there are few training and education contents on the market. The study concluded with the proposal of three different scenarios with different learning contents formats, durations and targets. The study presented each solution highlighting the strengths and weaknesses of each. It allowed each of the partners to choose to test one scenario in order to collectively choose the format and education content of the RemanPath project.

3.2. Market and need analysis for WM-CRM

WM-CRM project is motivated by the fact that there is increasing interest of the recovery of Critical Raw Materials (CRM) via recycling or re-use in WEEE. According to the European Commission Circular Economy Action Plan, the collection target of WEEE is going to rise from 45% of the amount of products put in the market in 2016 to 65% in 2019. Waste management stakeholders sometimes lack knowledge on current waste management and new development options in order to get a flow of CRM-containing materials back in the loop. WM-CRM project is integrally focused on the waste management with the aim to get as much CRM-containing materials or products back for recycling and re-use. Its objective is to set a MOOC and a two-day course for more intensive training on the problems of CRM's and mismanagement of discarded CRM's. The purpose of the market feasibility study is to answer the following questions:

Who are the potential target learners; which existing courses already address the topics of waste management and critical raw materials relationship management; and how will be the education content proposed in the future once the EIT financing period is over. Eleven courses were surveyed for CRM related teaching content and four experts on the topic of the circular economy and waste management were interviewed. This analysis showed that there are significantly less courses on CRM compared to waste management courses. The main available teaching format are lectures and plenary discussions between experts. Most of courses targeted academic audience, including researchers, students and experts in the field. The topic of the courses covered the presentation of waste management processes and technologies, the impact of policies, introduction and importance of CRMs and solutions to mitigate criticality. The target user of the WM-CRM course were identified to be any professionals (business managers, designers, engineers, architects, consultants among others) and students (post graduates) willing to get new knowledge and skills on the topic of waste management and critical raw materials. In terms of the format, blended learning approach was chosen including a MOOC and a two-day course tackling the different challenges of waste management and critical raw material such as circular economy strategies, technologies, business opportunities and product design.

3.3. Market and need analysis for INNOMAT

The aim of INNOMAT project is to develop an innovative LCA/CRM two-day course that makes LCA and CRM analyses more accessible and easy to use by SMEs and other industries. LCA can provide information of the positive impacts of recycling, remanufacturing and re-use. However, a classical LCA is complex, usually for specialist, and requires expensive databases and software. In addition, in any environmental impacts study, proposals for change are proposed, in terms of product design, but also on the other phases of the life cycle (use, transport, end of life). In addition to the environmental aspects, the question of value is often topical for business managers and designers. The market feasibility study tried to identify existing courses that already tackle the topics of LCA, CRM, and Business Innovation. It also aimed in determining how the course will be taught and how will it sustain itself in the future after the end of the project. To answer to these questions, four interviews were conducted, among them an expert in LCA teaching from the Netherlands. There was also an internet search of courses of LCA, CRM, and Business Innovation delivered in Europe. A list of 33 courses has been identified and studied [19]. Their topics, formats and marketing strategies were analysed. Potential gaps in the learning materials market for LCA, CRM and innovation were also reported. This market feasibility study showed that LCA and CRM has become important topics for SMEs as awareness in sustainability related issues continues to rise globally, despite LCA is a relatively established field of knowledge than CRM. There are significantly fewer courses on CRM compared to LCA courses. No business-specific courses could be found. The

only closest content that has been identified is present in a MOOC on CRM. Moreover, the market analysis identified that SMEs in the EU are the main targets learners for the INNOMAT course. The education content on LCA, CRMs and innovation could be attractive to them as it offers a simple and affordable alternative to expensive course and software. Regarding the format and duration, the market feasibility study proposed that the course to be delivered during two days, with an agenda composed of theory and practical activities. The train-the-trainer approach was also chosen in order to be able to disseminate as far as possible the content of the course to other practitioners. This means that once the content is proposed and tested, it will be transferred to the trainers.

4. The development of the educational contents

The educational content of each project was developed based on the lessons learned from the feasibility studies. The different partners contributed in proposing theoretical contents, case studies and exercises of application, according to their expertise and research experience on the topics.

4.1. *RemanPath* content

The educational content is in the form of a one-day workshop. The main objective is to introduce participants to the concept of remanufacturing and present them with case studies of successful experiences of remanufactured products. The aim consists also in showing the different challenges that remanufacturing poses for companies, such as technological challenges, process, product design, logistics, managerial and business model. The content also includes two exercises. The first allows participants to work in groups on a case study in order to identify the actions that should be performed on all stages of the remanufacturing process. The second exercise allow them to think about the key success factors of the introduction of remanufacturing during the design process. This activity rely on the use of REPRO2, an online software developed in Grenoble INP. Based on the comparative study of remanufactured products, REPRO2 identified eleven profiles of remanufacturable products [20]. It is used during the *RemanPath* workshop as a tool that allows the participants to identify remanufacturing strategies that should be implemented in the design phase.

4.2. *WM-CRM* content

The educational content has been proposed and is divided into six modules:

- Urgency and challenges with CRM's and waste,
- Recycling,
- Remanufacturing, refurbishing and re-use,
- End-of-life solutions,
- Resource efficiency by product design, production and substitution of materials,
- New business models, and circular procurement.

From the point of view of the format, the content consists of presentation slides, exercises and self-assessment

questions. It is proposed flowing two educational approaches: a MOOC and a two-day face-to-face course. The MOOC can be followed online for six weeks and includes presentation videos made by partner university teams, self-assessment exercises, a forum for interactivity between participants and case studies. It is possible to get a verified certificate that highlights the knowledge and skills gained through the MOOC. The two-day course is proposed in each partner institution in the basis of the six modules. It has the advantage of giving the possibility of having direct contact with the trainers and thus of favouring face-to-face exchanges.

4.3. *INNOMAT* content

The educational content is divided into four parts:

- LCA principles
- CRMs presentation
- Business and production innovation
- Value creation and value efficiency

For each part, slides and exercises were prepared. A simplified LCA tool is also proposed by TU Delft which allows participants to practice on LCAs. It comes in the form of a smartphone app and an Excel file. In addition, a set of exercise and product cases were selected to perform LCAs, including simple products (felt pen), a more complicated product (rechargeable and non-rechargeable battery) and products which contain CRM's (magnets of wind turbines). For each example, the composition was defined, life cycle phases were described (manufacturing, energy, transportation, and use) and end-of-life scenarios were proposed (recycling, incineration, and landfill). The purpose of the business innovation and value creation section is to initiate reflections on the issues of the business model and the value provided by any action aimed at minimizing the environmental impacts of the products. The triple layered business model canvas presented by Joyce and Paquin [21] were proposed to allow participants to study different dimensions of the value of a product: economical, environmental and social.

5. Validation of the educational contents

In order to test the learning contents developed in the three projects, several workshops and courses were organized in accordance with the formats identified during the feasibility studies. These validation test actions were undertaken by the different partners during 2018 and 2019. Participants from industry, consultancy and faculty were invited to enrol to the workshops using different dissemination channels, such as email, newsletters, and partners' website among others. The contents were delivered in the native language of the participants. This section presents the experience of Grenoble INP.

5.1. *RemanPath* project:

A remanufacturing workshop was organized by the laboratory G-SCOP within Grenoble INP on December 2018. The title of the day was: "Remanufacturing: A possible path toward Circular Economy. *RemanPath* Project workshop". 17

participants enrolled to the workshop, among them 9 are practitioners and consultants. The agenda of the day included presentations by faculty and also external guests on the key and theoretical concepts of remanufacturing. Two presentations were given by SMEs to illustrate successful implementation of remanufacturing in their companies, highlighting the technical challenges and also stressing the importance of business models, legislation and reverse logistic processes, among others. Then, two teamwork activities were organised based on two learning materials from those used by Grenoble INP faculty. The first activity involved the analysis of remanufacturing case studies. The participants were asked to identify the products characteristics, the process of remanufacturing and the way value was generated. The second activity consisted of the use an online tool that analyses the profile of remanufactured products.

5.2. WM-CRM project

The MOOC Waste Management and Critical Raw Materials was launched on September 2018 and lasted for six weeks. It had almost 3000 registrations, and 50 passed the online certification. Based on this first experience, some adjustments were made on the content, mainly by improving some assignments and by adding some extra readings. The MOOC was launched again on April 2019, following a self-paced process. Moreover, a two-day course connected to the MOOC was organized by each partner. The course took place in Grenoble INP on June 2019 which was attended by 14 participants. During two days, the participants received theoretical and practical knowledge on circular economy strategies (including reusing, recycling, remanufacturing, repurposing...), CRMs, regulations and business models challenges. The assignments included the dismantling of WEEE (waste of electronic and electric equipment). This activity allowed the participants to be introduced to design challenges in regard of repairing, remanufacturing and recycling strategies in the perspective of circular economy implementation.

5.3. INNOMAT project

A pilot course was organized at Grenoble INP for companies, SMEs and researchers on June 2019. 13 participants attended the course. It aimed to test the educational content of the INNOMAT project on the final target of the program. The program took place over two days. The first day included an introduction to LCA, its general principles, its utility for the company and its steps and tools. An example of LCA analysis on felt pens was presented. Participants were then able to manipulate the provided simplified LCA tool. A battery exercise was achieve to conduct a comparative study of environmental impacts between a non-rechargeable battery and a rechargeable battery. The day ended with an introduction to CRM and an LCA application on wind turbine magnets. These exercises enabled participants to measure the environmental impacts of products, to highlight the importance of considering multiple

lifecycle indicators (such as global warming, acidification, human toxicity resource depletion, etc.), and to compare different scenarios (different designs, different modes of transport, different processes). The second day was focused on the value and business aspects. Thanks to the triple layered business model canvas, participants were able to examine the economic value of products. The results of the LCA analysis were also used as input for the environmental layer of the business model.

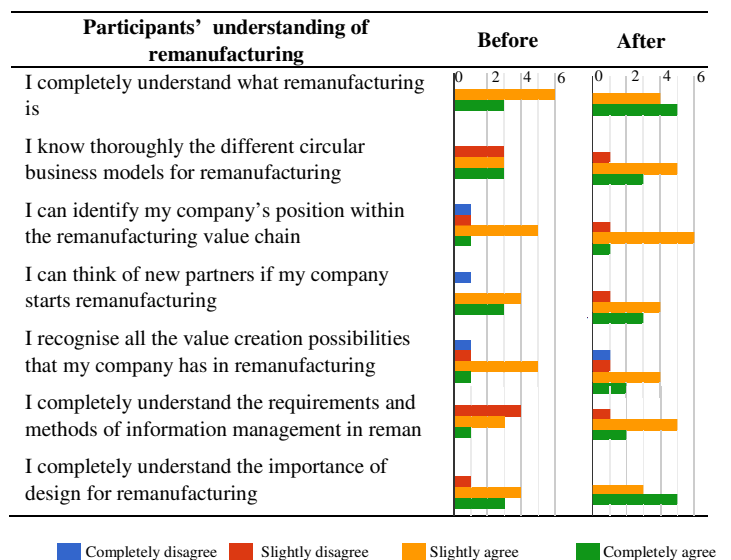
6. Discussion and lessons learned

Lessons learned from the course were evaluated through questionnaires submitted to the participants. Slightly different questionnaires were used in each project because of the differences in themes and also because of the difference in the composition of the consortia for each project. Overall and for each project, the answers helped to improve the content, but also to revise their organisation. This section presents the main results of the evaluations and the modifications made to the learning contents of the three programs.

6.1. RemanPath project

In order to assess the impact of the learning materials on the participants’ understanding of remanufacturing, the same questions were asked before and after the workshop. 8 participants answered to the questionnaire. Table 2 shows the impact of the workshop activities on the participants’ understanding of remanufacturing by determining how many agree with as set of statements that measure participants’ understanding of remanufacturing. Seven questions were asked at the beginning of the workshop and at the end, dealing with the general understanding, the capacity to identify business models, design for remanufacturing... Table 2 shows that globally, the understanding of the importance of remanufactured was improved thanks to the different activities.

Table 2. Evaluation of the participant’s understanding of remanufacturing.



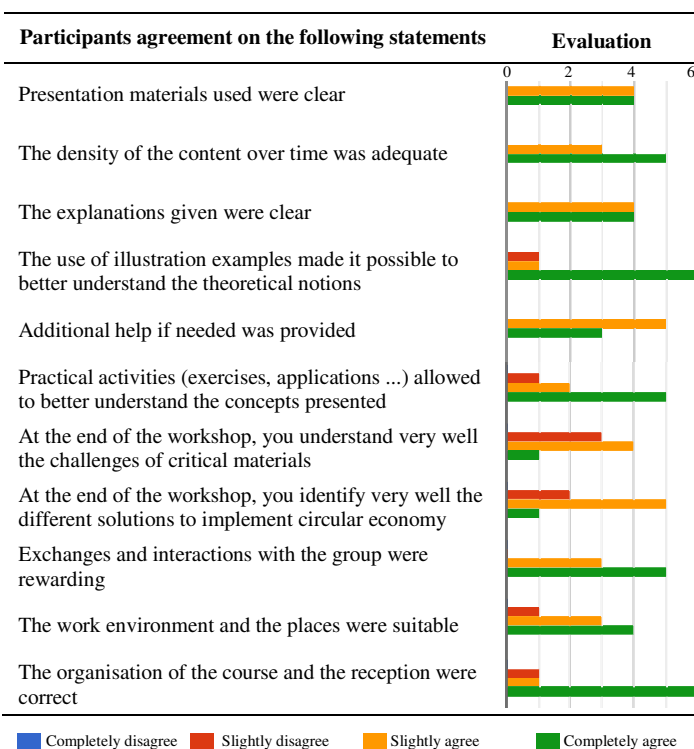
The participants appreciated very much the knowledge that they learnt during the workshop. The experience and the cases studies presented were very instructive. The focus made by SMEs on their business models and also the strategic axes of development of remanufacturing activities were very much appreciated. The participants were also interested in the relationship with product design and how it can have an impact on the ability to easily (or not) remanufacture a product. The participants appreciated the teamwork activities and were very keen to discuss with each other and to share their experiences and feedbacks. The participants highlighted also the issue of reverse logistics and legislation as two key subjects that should be discussed in more details. Even though these issues were mentioned by the speakers, it would be interesting to have more focus on them. Another subject also could have been discussed is the use of technologies such as embedded technologies in order to make the process easier and also the data gathered much more available.

6.2. WM-CRM

60 participants to the MOOC answered to a survey. They gave an overall grade of 8 out of 10 for the MOOC. They declared working around five hours a week on the content, and that finishing the course and allocating sufficient time were the main challenges. They estimated the length and the breadth of the course as convenient. Some shortcomings were identified regarding some exercises and quizzes. Therefore, the structure of the course was revised, and some activities were removed when they were considered too long or too complicated. A second edition of MOOC was launched on March 2019 following a self-paced process.

Regarding the face to face course, the participants were asked to answer to a questionnaire after the end of the course. Table 3 gives an overview of their answers.

Table 3. Answers to the WM-CRM questionnaire.

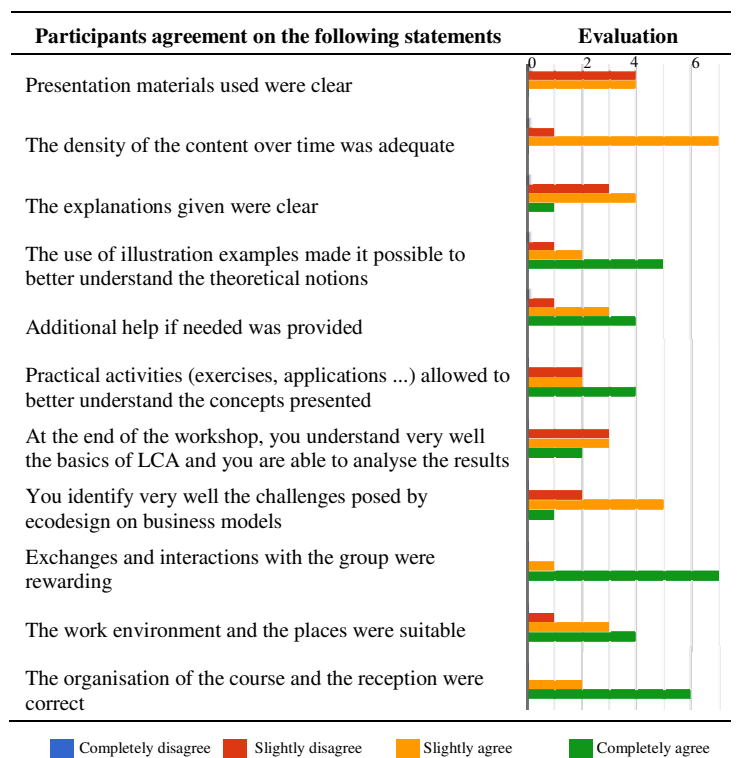


Overall, the participants appreciated the presentations and the use of illustrative examples by the trainers. They also appreciated the different exercises and their adequacy between their content and time. They proposed to have a clear focus on French context, in terms of laws, regulations and circular economy initiatives. They also indicated their interest on the CRMs topic and proposed to include methodological presentations on criticality evaluation.

6.3. INNOMAT

The participants were asked to answer to a questionnaire similar to the one for WM-CRM. Table 4 gives an overview of their answers.

Table 4. Answers to the INNOMAT questionnaire.



The participants very much appreciated the use of illustrative examples, videos and additional references. They also appreciated the different discussions and exchange with the trainers, but also with other attendees. They had different profiles and backgrounds (consultants, start-up managers, researchers among others), which led to interesting debates on environmental issues. They proposed to allow more time on LCA exercises and present additional LCA indicators, besides Eco-costs and carbon footprint. They suggested some changes to the agenda of the course in order to make strong connection between reducing environmental impacts of products and business opportunities for companies and social implication for communities.

7. Conclusion

This papers presented the experience of Grenoble INP as partner in three European programs supported by EIT

RawMaterials. The university played an important role in building educational content on the subject of circular economy, remanufacturing and LCA. The paper presented key activities achieved in the three projects, which included market feasibility studies, the development of learning contents and testing and validation during pilot courses. These courses brought interesting insights and learnings to the different projects and were conducted by all the partners of the project. New courses that consider the learned lessons from pilot courses are being prepared to be launched during 2020. The main limits in the achievement of these three projects lies in the success in reaching the target audience. The marketing channels exploited (i.e. online information networks and contacts with associations and local networks) should be maintained after the end of the projects. In addition, other channels marketing channels should be considered. For example, the university lifelong education department should be involved in the future in order to include the educational contents in future trainings for professionals on the topics of sustainable development and circular economy.

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