Designing Collaborative European Projects for Remanufacturing Education: Lessons Learned from Experimentation with Universities and Companies

Helmi Ben Rejeb, Jyri Hanski, Jouko Heikkilä, Jan-Henk Welink, David Peck, Peggy Zwolinski, and Denis Dowling

Abstract This chapter presents the lesson learnt from several European projects supported by the European Institute of Innovation and Technology (EIT) which integrated remanufacturing (the process of restoring used products to like-new condition) education into the curriculum of engineering and business programs. The projects, implemented in partnership with both universities and companies, designed teaching materials and then experimented with those in formats such as workshops and online digital nuggets on remanufacturing. The projects' objective was to foster a skilled workforce that could contribute to the transition to a circular economy and to promote sustainable development. The projects emphasized interdisciplinary collaboration in order to promote sustainable product design and supply chain management. The chapter discusses the pedagogical approaches adopted, and offers evaluative case studies illustrating successful implementation in different educational contexts. The projects in question showed that a collaborative approach between universities and companies was effective in promoting the integration of remanufacturing education into the curriculum. The outcomes included the development of a network of educators and industry professionals who could share best

H. B. Rejeb (✉) · P. Zwolinski
University of Grenoble Alpes, CNRS, Grenoble INP, G-SCOP, Grenoble, France
e-mail: helmi.benrejeb@grenoble-inp.fr

J. Hanski · J. Heikkilä
VTT Technical Research Centre of Finland Ltd, Espoo, Finland

J.-H. Welink
Materials Science and Engineering, Delft University of Technology, Delft, The Netherlands

D. Peck
Architecture and the Built Environment, Architectural Engineering and Technology, Delft University of Technology, Delft, The Netherlands

D. Dowling
University College Dublin, Dublin, Ireland

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practices, experiences, and knowledge related to remanufacturing education. The projects' success highlights the importance of collaborative European projects in promoting sustainable development and fostering a skilled workforce which can contribute to the transition to a circular economy.

Keywords Remanufacturing · Circular economy · Lifelong learning · Collaborative projects

1 Introduction

The circular economy is a production and consumption model involving sharing, leasing, reusing, remanufacturing, refurbishing, and recycling existing materials and products if possible (Sodiq et al. 2019; Korhonen et al. 2018). In this way, the life cycle of products is extended. In practice, it implies reducing waste to a minimum (Geissdoerfer et al. 2017). The implementation of circular economy practices also helps to save energy and to reduce the climate impact of manufacturing new products creating value from the used materials that would otherwise be landfilled. Economic growth and rising levels of consumption in both developing and developed countries have been observed as being deeply coupled with natural resource usage and material consumption (O'Neill et al. 2018). The increasing need for natural resources has raised concerns regarding issues such as resource scarcity, undesirable environmental impacts due to material extraction, primary production, suboptimal product disposal, and social or political tensions (Denu et al. 2023). Product End-of-Life (EoL) options, such as reusing or recycling, attempt to limit or reduce the amount of waste sent to a landfill, providing strategic means to decouple the link between economic growth and resource usage. These EoL options have the potential to (mostly, since contamination of waste streams remains an issue) close material loops, further utilize wastes as resources, reducing environmental impacts, conserving natural resources, reducing material prices, and providing job opportunities in developing countries. Remanufacturing, on the other hand, is a unique EoL option due to increasing the number of life cycles of a product before final disposal. Remanufacturing can be defined as the process of restoring used or worn-out products to a like-new condition by disassembling, cleaning, repairing, and reassembling them. This often includes replacing or refurbishing parts to ensure the product meets original specifications and quality standards (Sundin and Bras 2005). In the ongoing pursuit of a sustainable and circular economy, remanufacturing stands out as one of the most challenging, yet profoundly important scenarios (Bocken et al. 2016). It has many benefits. First, recurring environmental benefits, such as emission and raw material extraction avoidance are obtained with each additional product life cycle. Second, individual resource efficiency yields increase through product remanufacture. Resource efficiency, or using more with less input, will continue to compound with each additional life cycle. Third, recirculating products decrease the demand and dependency on primary resource production, further closing the

material loop and creating a more circular economy. In addition, remanufacturing can initiate preferable EoL options such as recovery, recycling, and waste reduction.

However, the realization of remanufacturing's full potential depends on cultivating a skilled workforce, well-versed in the principles and practices of remanufacturing (Ben Rejeb et al. 2020). Education and training play a pivotal role by serving as the pillar that connects theoretical understanding with practical implementation (Kirchherr and Piscicelli 2019). At the heart of this educational transformation lies the collaborative synergy between universities and companies, which has proven to be a dynamic approach to integrating remanufacturing education into engineering and business programs (González-Domínguez et al. 2020). These collaborative projects offer a multifaceted educational experience, creating a platform for learners to engage directly with real-world challenges, innovative solutions, and industry best practices.

This chapter outlines the lessons learned from three various European projects that incorporated remanufacturing education into the engineering and business program curricula. The projects were carried out in collaboration with universities and companies, and entailed designing and experimenting with teaching materials such as workshops and online digital resources on remanufacturing. This study undertakes an investigation into two important research questions that are at the heart of our study of remanufacturing education and collaborative projects. The first research question focuses on pedagogy and materials, seeking to understand what approaches and materials have been successful in developing sustainable product design skills in the context of remanufacturing education. Through analyzing the plans, actions, and results of these projects, we aim to discover the most effective teaching methods that have successfully equipped students with the necessary knowledge and abilities to address the diverse and complex challenges of remanufacturing within a circular economy. Through this first research angle, our aim is to shed light on the pathways through which remanufacturing education can be improved and enriched to facilitate the development of a competent and adaptable workforce. Our second research question explores how workshop-based learning materials and activities impact participants' confidence, knowledge, and understanding in the context of remanufacturing education. Through examining how these materials affect learning, skills, and motivation, we aim to reveal valuable insights that can guide the development and implementation of future education strategies. This investigation into the impact of teaching materials encompasses the analysis of their influence on knowledge acquisition, skills development, and the cultivation of a proactive mindset towards sustainability and circular economy principles.

2 Literature Review

Many studies have reported that a lack of knowledge and education is a significant barrier preventing the development of remanufacturing. Firstly, decision makers in industry and business are lacking awareness of the remanufacturing concept

(Jansson et al. 2017; Fischer et al. 2017). Secondly, relevant university courses—like for example engineering, business administration, product and industrial design—do not yet include the concepts justifying remanufacturing, such as resource efficiency and waste prevention. Thus, the current education of responsible persons still rather promotes the linear economy (Fischer et al. 2017). The education required for remanufacturing extends to a wide range of knowledge and skills concerning the requisite remanufacturing activities (for example disassembly, cleaning and inspection), the strategic and operative product planning, sourcing of components and cores, marketing of products and services, logistics and reverse logistics, accounting, quality management etc. (Fischer et al. 2017; Koop et al. 2018). Education on remanufacturing enhances the comprehension of the environmental advantages linked to remanufactured products (Ijomah 2008). It provides insight into reduced carbon emissions, resource conservation, and waste reduction which result from implementing the remanufacturing process (Ramakrishna et al. 2020). Educating professionals and young engineers about the ecological benefits of remanufacturing is crucial in promoting sustainable practices in manufacturing and supply chain management (Gento et al. 2021). Furthermore, education on remanufacturing highlights resource efficiency as a crucial principle of circular economies (van Dam et al. 2020). Training on remanufacturing provides individuals with the necessary skills to maximize resource utilization by refurbishing and renewing products (Kurilova-Palisaitiene et al. 2018). This focus on resource optimization aligns with the circular economy's objective to minimize resource extraction and waste generation (van Dam et al. 2020). Additionally, remanufacturing education emphasizes the financial viability of such practices, taking both environmental and economic factors into consideration (Wang et al. 2021). It provides individuals with the knowledge to assess the cost-effectiveness and profitability of remanufacturing businesses (Sun and Liu 2023). This economic viewpoint is key to promoting entrepreneurship and innovation in the remanufacturing industry (Mortati 2015). Remanufacturing education typically employs an interdisciplinary approach that integrates varied fields, such as engineering, business, and environmental studies (Arredondo-Soto et al. 2019). The cross-disciplinary nature of this approach facilitates integrated problem-solving and collaboration, which are essential components in tackling the intricate challenges related to the circular economy (Kurilova-Palisaitiene et al. 2018). Collaborative expertise and cross-disciplinary collaboration are pivotal to propel sustainability initiatives forward, as emphasized by Gento, Pimentel and Pascual (Gento et al. 2021). Remanufacturing education is a concept that holds relevance across borders, as noted by Karvonen et al. (2017). As countries worldwide prioritize sustainability, especially amid pressing environmental crises, the need to implement remanufacturing principles becomes increasingly imperative, as emphasized by Abdulla et al. (2023). Remanufacturing has been developed differently in different sectors. For instance, in the automotive and aerospace sectors remanufacturing is well established, while—for example—in the construction sector remanufacturing is still quite underdeveloped (Arnold et al. 2019; Parker et al. 2015). Currently knowledge is shared, and remanufacturing is promoted, mostly within each sector. Measures for cross-sectoral knowledge transfer are thus needed (Parker et al. 2015). International collaboration and knowledge sharing are crucial

in the field of remanufacturing education as they help tackle shared challenges and achieve global sustainability objectives (Ben Rejeb et al. 2020). Interdisciplinary collaboration and industry-academic partnerships are essential for promoting sustainability by bringing together diverse expertise, fostering innovation, enabling real-world implementation, and facilitating evidence-based decision-making (Annan-Diab and Molinari 2017; Orecchini et al. 2012). Therefore, collaborative and interdisciplinary industry-academic efforts can effectively address the complex sustainability challenges and create a more sustainable future. The aim for this chapter is to highlight the importance of collaborative European projects in promoting remanufacturing and fostering a skilled workforce that can contribute to the transition to a circular economy.

3 Methodology

After explaining how remanufacturing education plays a vital role in promoting sustainability and transitioning to a circular economy, this chapter moves on to focus on the methodological basis of our research. In this section, we will examine the three important European projects that serve as the foundation for our study: RemanPath (Reman Path Finder), CARED (Catalyse Remanufacturing through Design Bootcamp) and LRM (Lean Re-Manufacturing). These projects were planned and carried out by researchers and industry partners, with the support of the European Institute of Innovation and Technology (EIT). They all aimed at integrate remanufacturing education into engineering and business curricula, to train future workers to drive sustainable practices. By examining the methods used in these projects, we obtain a better understanding of how education, practice, and sustainability connect. This section presents a complete view of how these projects were thought up, designed, and put into action.

3.1 Presentation of EIT Projects (RemaPath, CARED, LRM)

Reman Path Finder (RemanPath) was a project funded by EIT Raw Materials, and was carried out in years from 2018 to 2020 (RemanPath 2020). VTT Technical Research Centre of Finland coordinated the project, the other participants being Coventry University, Grenoble Institute of Technology, Technical University of Delft, Wuppertal Institut für Klima, Umwelt, Energie, and Oakdene Hollins. The Reman Path Finder project aimed to support European industries to move towards resource efficiency. The instrument for this was the creation of learning material and setting up of learning activities based on interaction, as well as the subsequent sharing of experiences within industries and SMEs. The developed educational learning package supports SMEs in developing their own remanufacturing activities and in developing new innovative business models. The output of the project was a learning package which was developed in the project, tested first in pilot workshops, and

then further developed and validated in the second round of workshops. 14 workshops with were arranged for 96 company professionals in Finland, France, Germany, the Netherlands, and UK. The finalized RemanPath learning content includes the "Reman Path Process Map", "Reman Checklist", "Introduction to remanufacturing, a remanufacturing case study", as well as advanced information for participants of workshops, and workshop invitation and schedule templates (RemanPath 2020). The project also included a market feasibility study and a delivery channel study concerning remanufacturing education for industry, as well as a raw material impact assessment study.

The Catalyse Remanufacturing through Design Bootcamp (CARED) project was funded by EIT Raw Materials, and was carried out in years 2019 and 2020. VTT Technical Research Centre of Finland coordinated the project and the other participants were Grenoble Institute of Technology, Technical University of Delft, and Metso Outotec company. The CARED project developed, and made available, training concerning design for remanufacturing. The training was carried out in the form of bootcamps where a group of company representatives from different functions learn about remanufacturing and—with bootcamp exercises—collaboratively elaborate on and study what remanufacturing would mean for their own business in practice. While the earlier RemanPath workshops were aimed for companies just exploring their opportunities in remanufacturing business, CARED bootcamps offered the next step for companies which had decided to start remanufacturing. The training materials and bootcamp was tested with two iterations of bootcamps provided for companies in Finland, France and the Netherlands. In total ten bootcamps was arranged with 93 participants. Due to the Covid-19 pandemic, most of the bootcamps were organized online in 2020. The project included also a market feasibility study concerning remanufacturing educations for companies. The material package developed in the CARED project include: "Remanufacturing theory presentation, with case studies", a "selection matrix tool for product selection for remanufacturing", a "Reman Process Map", a "Reman Checklist" and a "Remanufacturing business model based on the triple layered business model canvas". Agenda options were structured, so that a bootcamp agenda can be tailored to meet a company's or company group's needs whether they are a newcomer in remanufacturing or more experienced. Key phases of organizing and running of CARED bootcamp are presented in Fig. 1.

The Lean Re-Manufacturing (LRM) project was funded by EIT Manufacturing during 2022 and 2023. TU Delft coordinated the project, and other partners were University College Dublin, the Grenoble Institute of Technology, and VTT. This project was focused on the development of training content on lean remanufacturing with the objective of helping to minimize waste and improve productivity. The course content included the development of practical examples of the use of key supporting technologies, within an advanced manufacturing environment. The objective was to deliver a minimum of 16 workshops in four countries to a minimum of 110 industry trainees. This workshop-based course aimed at manufacturing professionals and brings "Lean" together with 'Remanufacturing'. Further, the project produced digital learning nuggets, which are made available on EIT Manufacturing's online learning platform. The learning goals of LRM trainings encompassed a multi-faceted approach. Participants were expected to develop the capability to

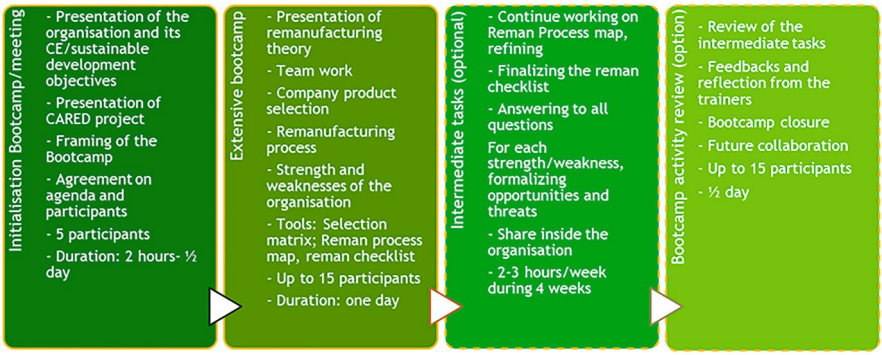


Fig. 1 CARED bootcamp phases

implement generic lean-remanufacturing principles within their own work environments and organizations. This included fostering collaboration with value chain stakeholders, customers, as well as suppliers, and the pivotal task of crafting a fundamental circular-remanufacturing business model. Additionally, the trainings aimed to equip participants with the skills to openly exchange information, evaluate the relevance and quality of data, and synthesize essential knowledge within the context of lean-remanufacturing. These multifaceted learning objectives were designed to provide participants with a holistic and adaptable skill set, aligning them with the complexities and demands of contemporary remanufacturing practices.

3.2 Data Collection

To comprehensively assess the workshops, we employed a well-structured methodology informed by best practices in education and evaluation. This approach involved administering a detailed questionnaire to workshop participants, aligning with contemporary educational research emphasizing effective assessment techniques (Mory 2004; Molloy and Boud 2014). The questionnaire, provided in both paper-based and online formats, adhered to established principles of survey design to ensure data integrity (Koivula and Sivonen 2022). The dual-part questionnaire reflected the workshop's progression. The initial survey (Appendix 1) collected general participant information, and assessed their initial understanding of remanufacturing concepts using an eight-statement evaluation grid. It included an evaluation grid consisting of eight statements. This grid served as a diagnostic tool to measure participants' initial levels of understanding. The second part of the questionnaire (Appendix 2) reevaluated participants' knowledge, allowing a quantitative analysis of the workshop's impact, aligning with active learning research (Prince 2004). Additionally, the post-workshop segment featured both semi-open and open-ended inquiries in line with best practices in qualitative data collection (Black and Wiliam 1998). These inquiries were designed to gain insights into participants' perspective on primary learning outcomes, unexplored aspects that future workshops

could address, ideal workshop durations for effective remanufacturing education, and the specific barriers that organizations might face when initiating remanufacturing projects. A set of barriers identified from Gunasekara, Gamage and Punchihewa (Gunasekara et al. 2018) propose predefined options such as "Lack of profitability", "Lack of training", "The need for funding", "Concerns over regulatory aspects" and "Other priorities". The open-ended nature allowed participants to offer insights beyond predefined options.

In total, about 300 participants engaged in the three projects' activities organized primarily by partner universities. For questionnaire analysis, 112 responses were considered, as some were incomplete or differed across projects and workshops.

4 Results and Data Analysis

The remanufacturing workshops, initially in-person, transitioned in some cases to hybrid or fully online formats following the COVID-19 pandemic, incorporating online whiteboard tools. Across the three projects, three distinct workshop templates were delivered, focusing on remanufacturing education. The "Introduction to Remanufacturing for Manufacturing Companies" template targets manufacturing firms seeking foundational knowledge of remanufacturing. The workshop covers key topics in sustainable manufacturing, legislative impacts, and the potential cost-saving benefits of remanufacturing. It also explores reasons to embrace remanufacturing, risk mitigation factors, and business opportunities. Practical tools, namely the "Reman Checklist" and "Remap Process map, are introduced. Real-world case studies and regional circular ambitions are discussed, along with financial support opportunities. Technical and business considerations are addressed, concluding with a review and feedback session.

The "Reasons for Going Sustainable - Circular Design Opportunities for Manufacturing" template is designed for manufacturing companies with broader sustainability interests. It begins with a feedback session and explores sustainability from environmental, social, and financial perspectives. The workshop analyzes sustainability's impact on climate, energy, materials and discusses remanufacturing case studies. Policy drivers and group discussions are covered, along with strategies for sustainable product and service development. Attendees learn about eco-design, R-strategies, the "Reman Checklist", and the "Reman Process Map", concluding with a wrap-up session.

The "Case-Driven Remanufacturing Workshop" offers an in-depth look at existing remanufacturing case studies. It starts with a feedback session and explores sustainability challenges, product design, remanufacturing processes, and business models. Real-world remanufacturing cases are analyzed, using tools such as the "Reman Process Map" and "Reman Checklist". The workshop promotes collaborative teamwork, ending with a feedback session.

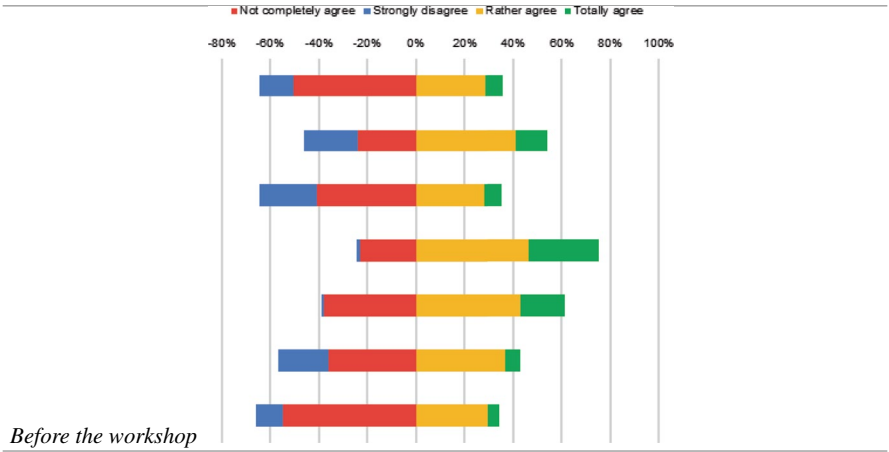
These templates provide a comprehensive approach to educating manufacturers about remanufacturing, addressing various needs and goals, and equipping

participants with a solid understanding of remanufacturing and its applications in the circular economy.

The effect of workshop activities on participants' understanding of remanufacturing is a crucial focus of our research, which is demonstrated through a set of charts. These charts used for evaluating the effectiveness of our workshop models in boosting participants' knowledge and insight. Through analyzing these graphs, we aim to provide a clear and data-driven assessment of the transformative impact these workshops have on the understanding of remanufacturing principles and their practical application. The data collected from the survey responses before and after the workshop provides valuable insights on the impact of the educational intervention on participants' understanding of remanufacturing. Before the workshop, participants levels of agreement with key statements related to their grasp of remanufacturing concepts and their applications is presented in Table 1.

The transformative impact of the workshop is evident in the post-workshop responses as Table 2 shows.

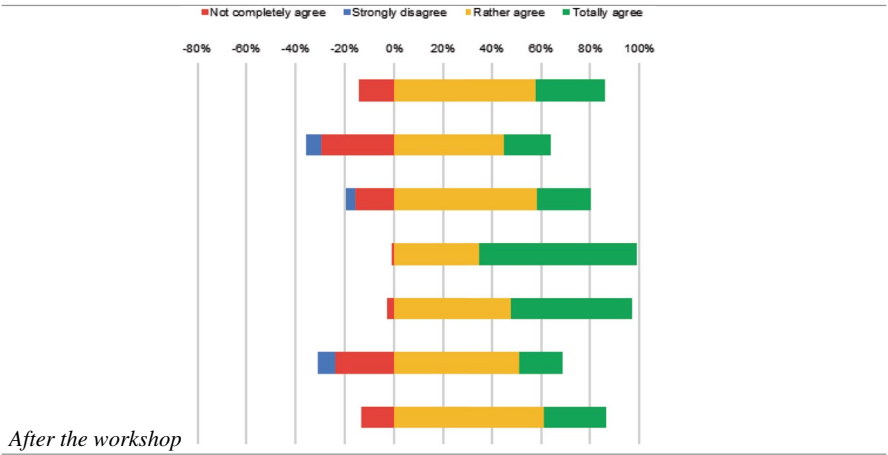
These charts reveal the educational journey of participants and emphasize the importance of experiential learning in cultivating a thorough understanding of remanufacturing's role in sustainable manufacturing and the circular economy. In the following section, we present the concise and objective findings from these charts, providing a comprehensive assessment of how our workshops enhance the proficiency of participants in remanufacturing.



Before the workshop

I am able to project the concepts I know in remanufacturing on other circular scenarios
I can consider new partnerships if my company launches remanufacturing activities
I can identify my company's position in the remanufacturing value chain
I fully understand the importance of design activities for remanufacturing
I fully understand what remanufacturing is
I identify value creation opportunities that my company has through remanufacturing
I understand completely the different business models of remanufacturing in relation to the CE

Table 1 Participants' understanding of remanufacturing before the workshops



After the workshop
I am able to project the concepts I know in remanufacturing on other circular scenarios
I can consider new partnerships if my company launches remanufacturing activities
I can identify my company's position in the remanufacturing value chain
I fully understand the importance of design activities for remanufacturing
I fully understand what remanufacturing is
I identify value creation opportunities that my company has through remanufacturing
I understand completely the different business models of remanufacturing in relation to the CE

Table 2 Participants' understanding of remanufacturing after the workshops

5 Discussion and Lessons Learnt

Table 1 revealed a number of notable pre-workshop disparities. For example, participants expressed limited agreement on projecting remanufacturing concepts (7% "Totally agree") and considering new partnerships (13% "Totally agree"), highlighting initial skepticism. Statements regarding design activities and remanufacturing's essence indicated room for improvement. After the workshops, Table 2 displayed significant improvement. After the workshop, 85% were confident projecting remanufacturing concepts ("Totally agree" and "Rather agree" answers combined), and 70% were open to new partnerships. Comprehension of design activities and remanufacturing principles also saw a boost, with 64% and 70% agreement. The workshop effectively broadened perspectives on value creation opportunities and different business models within the circular economy, with 69% and 87% "Totally agree" and "Rather agree" answers.

While the analysis of the survey results showed significant progress in enhancing participants' understanding and appreciation of remanufacturing, there is always room for further improvement. One consideration when launching remanufacturing activities is exploring "new partnerships". While post-workshop data showed increased agreement among participants with this statement, it is important to note

that openness to new partnerships can be further optimized. Collaborating with multiple stakeholders, such as suppliers, customers, and organizations, is vital in remanufacturing to establish a holistic circular value chain. It may be worth examining ways to further enhance the mindset of workshop attendees to foster even greater collaboration. Additionally, the post-workshop data revealed a significant improvement in participants' comprehension concerning "identifying opportunities for value creation". However, there is ample space to further explore the intricacies of value creation in the context of remanufacturing. Further discussions, practical exercises, or case studies, during the workshop could facilitate a more comprehensive exploration of the different opportunities for value creation that remanufacturing provides. This would allow participants to not only recognize but also fully utilize these opportunities. Moreover, while there was a noticeable improvement in responses to the "various Remanufacturing business models in relation to the circular economy" statement, a more in-depth investigation into this topic could lead to even greater insights. Expanding the workshop's focus to include comprehensive case studies and real-world examples of successful circular economy business models could help participants to better understand the complexities and opportunities in the field. The first research question regarding pedagogy and materials in remanufacturing education is addressed through the three workshop templates employed in the RemanPath, CARED, and LRM projects. These templates were tailored to cater to the diverse needs of manufacturing firms. The "Introduction to Remanufacturing for Manufacturing Companies" template provided a comprehensive understanding of remanufacturing, emphasizing hands-on learning with tools such as the "Reman Checklist" and "Remap Process Map". The "Reasons for Going Sustainable - Circular Design Opportunities for Manufacturing" template expanded the scope to sustainability and circular design, fostering interdisciplinary collaboration through feedback sessions and group discussions. The "Case-Driven Remanufacturing Workshop" delved into in-depth case studies, promoting collaborative teamwork and practical application of remanufacturing knowledge. These templates were adaptable to various workshop formats, whether in-person, hybrid, or fully online, highlighting their effectiveness in enhancing interdisciplinary collaboration and sustainable product design skills. The flexibility in duration allowed for customization to meet the specific needs and preferences of participants, further demonstrating the importance of pedagogy and materials in remanufacturing education. They served as pedagogical tools that facilitated knowledge transfer and skill development, demonstrating the importance of pedagogy and materials in remanufacturing education.

Over the course of three projects RemanPath, CARED and LRM, workshops have been organized in manufacturing companies in various sectors such as automotive, marine, mining, heavy machinery manufacturing, etc. These companies have mostly had limited experiences or information about remanufacturing, but have been interested to identify the potential of remanufacturing for their business. The results of the questionnaires demonstrated a clear transformation in participants' confidence and knowledge levels before and after the workshops, directly

addressing the second research question. Before the workshops, participants expressed limited agreement with statements related to remanufacturing concepts and new partnerships, indicating skepticism and uncertainty. However, after the workshops, there was a substantial increase in the "Totally agree" category, highlighting a remarkable shift in participants' confidence and knowledge. The post-workshop responses reveal improved comprehension of design activities, remanufacturing principles, value creation, and different business models, with a substantial percentage of participants agreeing with these concepts after the workshop. Based on this analysis, we provide a list of key insights and recommendations for educators, policymakers, and industry professionals interested in integrating remanufacturing education into curricula.

Industry-academic partnerships: Companies and academic partners have varying motivations for collaboration. Academia seeks collaboration with industry to supplement funds for academic research, test the practical application of research and theory, gain insights in the area of research, further the university's outreach mission, look for business opportunity, gain knowledge about practical problems useful for teaching, create student internships and job placement opportunities, secure funding for research assistants and laboratory equipment, or look for business opportunity (Ben Rejeb et al. 2020; Orecchini et al. 2012; Lee 2000; Annan-Diab and Molinari 2017; Annan-Diab and Molinari 2017; Gunasekara et al. 2018). Based on our experiences, remanufacturing workshops are a means for academia to begin collaboration discussions with companies interested in remanufacturing, provide state-of-the-art knowledge and learn about the practical challenges, opportunities and drivers that the companies face. Companies seek collaboration with academic partners to solve specific technical or design problems, develop new products and processes, conduct research leading to new patents, improve product quality and to reorient R&D agenda (Gunasekara et al. 2018; Lee 2000; Orecchini et al. 2012). The frontrunners are interested to finetune their manufacturing and remanufacturing processes over the product life cycles and optimize the environmental, social and economic impacts over the life cycle.

Interdisciplinarity: Remanufacturing is a complex R-strategy that involves people from several functions in companies. As an example, core takeback and remanufacturing may require input from sales, aftersales, manufacturing, repair & maintenance, product information management, environmental, waste management and legal departments. To provide rich research data and understand the challenges and opportunities in the interplay of the departments, crucial departments should be involved in the workshops.

Type of educational activity: Because of interdisciplinarity and varying motivations for remanufacturing workshops, a one-size-fit-all workshop approach might not work. Factors that affect the nature of the workshop include: (1) Target audience. Educational workshop for students, a workshop for multiple companies or a workshop for multiple departments within a single company. (2) Workshop content. Workshop could provide a general overview of remanufacturing or be more specifically focused on a certain topic such as remanufacturing process or business

models. (3) Online, hybrid or physical workshop. (4) Length. It could be anything from a couple of hours to a couple of days.

Sustainability assessment in remanufacturing: With the emergence of global and EU regulation on identifying the sustainability footprint of products, companies are investing in optimizing the environmental footprint and sustainability impact of their operations. There is a need for new training and competencies for assessing the sustainability of companies and the potential benefits brought by remanufacturing and other R strategies.

6 Conclusion

This chapter has outlined the lessons learned from three European projects that incorporated remanufacturing education into the engineering and business program curricula. The projects were carried out in collaboration with universities and companies, and entailed designing and experimenting with teaching materials such as workshops and online digital resources on remanufacturing. The specific research questions were: what the most effective teaching methods that have successfully equipped learners with the necessary knowledge and abilities to address the diverse and complex challenges of remanufacturing within a circular economy, and how learning materials affect learning results and increase learners' involvement in remanufacturing education.

In the literature, the lack and need for remanufacturing related awareness, knowledge and skill in industry and business is highlighted as a substantial barrier preventing escalation of remanufacturing. And in a broader perspective, the lack of sustainability education in technical, management, and business education is seen contributing to that most decision makers stick with linear economy production and business models. Remanufacturing requires new knowledge in various disciplines such as engineering, business, and environmental studies. Furthermore, establishing remanufacturing is more complex and requires more systemic operations models compared to linear economy solutions. Therefore, interdisciplinary approach is essential already in remanufacturing education. In transition towards the more sustainable world, the dialogue between theory and practice, and common efforts of academy and industry are needed to overcome the long and strong tradition of linear economy. In the three projects, the remanufacturing education concept, tools and materials were developed and evaluated by arranging practical education events—workshops and bootcamps—for industry representatives. Self-assessment of learning was carried out, feedback was collected, and trainers reflected the learnings from using the concepts, tools and materials. Participants' knowledge on the topic before the education varied considerably over the evaluation scale. This could be expected in the cases where participants are different professionals from companies. The lowest level of knowledge was concerning the remanufacturing business models and value creation, company's position in the remanufacturing value chain, and

application of remanufacturing concepts. Highest were the understanding about the importance of design for remanufacturing and the concept of remanufacturing itself. The evaluations after the event showed notable progress in all evaluated topic, but especially concerning business models and application of remanufacturing concepts. The least just slightly improved topic was about exploring "new partnerships" when launching remanufacturing activities. This topic needs to be strengthened in forthcoming remanufacturing education. The significant part of education was that participant applied the provided tools to explore remanufacturing process and readiness in the practical cases—either provided or company's own. The discussion between the participants in order to reach shared understanding was an essential part of the use of the tools. This accompanied with the information shared by different remanufacturing experts proved to be a fruitful solution. Adjusting the education with the actual company situation and need was also identified as important success factor. Interdisciplinarity is inevitable in case of complexity of remanufacturing. It was also beneficial for the education itself.

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Initial Questionnaire (Before the Workshop)

Remanufacturing workshop
Date:

Initial survey

Thank you for taking part in this workshop. Please answer these questions to find out what you think about the workshop and in order to collect your ideas about future perspectives. The results will be used anonymously to develop future workshops and for research work.

1. **Name, organisation?**

_____

2. **Size of your organisation?**

☐ Less than 50 employees
☐ Between 50 and 500 employees
☐ Between 500 and 5000 employees
☐ More than de 5000 employees

3. **How would you qualify your remanufacturing and Lean experience and knowledge prior to your participation in this workshop?**

Remanufacturing experience

☐ No know-how or knowledge on the subject
☐ A little know-how and general knowledge
☐ Fairly good knowledge from past experience
☐ Expert

Lean experience

☐ No know-how or knowledge on the subject
☐ A little know-how and general knowledge
☐ Fairly good knowledge from past experience
☐ Expert

4. **Have you attended workshops on remanufacturing in the past?**

☐ Yes – if possible to specify, _____
☐ No

5. **Do you know of other workshops or trainings on the remanufacturing topic?**

☐ Yes – if possible to specify, _____
☐ No

6. **Your experience with Remanufacturing** Please select the appropriate answer =>	**Strongly disagree**	**Not completely agree**	**Rather agree**	**Totally agree**
I fully understand what Remanufacturing is	o	o	o	o
I understand completely the different business models of Remanufacturing in relation to the circular economy	o	o	o	o
I can identify my company's position in the Remanufacturing value chain	o	o	o	o
I can consider new partnerships if my company launches Remanufacturing activities	o	o	o	o
I identify value creation opportunities that my company has through remanufacturing	o	o	o	o
I fully understand the importance of design activities for Remanufacturing	o	o	o	o
I am able to project the concepts I know in remanufacturing on other circular scenarios	o	o	o	o
I think Lean principles can be implemented in remanufacturing for better circularity	o	o	o	o

7. **Expectations from this workshop on remanufacturing?**

What are your expectations and what do you hope to learn or discover?

_____

Final Questionnaire (After the Workshop)

Remanufacturing workshop
Date:

Evaluation questionnaire

Thank you for taking part in this workshop. Please answer these questions to find out what you think about the content and in order to improve it in the future.

1. **Name, organisation?**

_____

2. **Your understanding of remanufacturing after attending this workshop** Please select the appropriate answer =>	**Strongly disagree**	**Not completely agree**	**Rather agree**	**Totally agree**
I fully understand what Remanufacturing is	o	o	o	o
I understand completely the different business models of Remanufacturing in relation to the circular economy	o	o	o	o
I can identify my company's position in the Remanufacturing value chain	o	o	o	o
I can consider new partnerships if my company launches Remanufacturing activities	o	o	o	o
I identify value creation opportunities that my company has through remanufacturing	o	o	o	o
I fully understand the importance of design activities for Remanufacturing	o	o	o	o
I am able to project the concepts I know in remanufacturing on other circular scenarios	o	o	o	o
I think Lean principles can be implemented in remanufacturing for better circularity	o	o	o	o

3. **What did you appreciate in this workshop?**

_____

4. **What did you learn and what new ideas did you get after this workshop?**

_____

5. **Are there other aspects that should have been addressed?**

_____

6. **In your opinion, what could prevent companies from taking up Remanufacturing?**

- ☐ Lack of profitability
- ☐ Lack of training
- ☐ The need for funding
- ☐ Concerns over regulatory aspects
- ☐ There are other priorities
- ☐ Other, _____

7. **How can we improve the content of the workshop?**

_____

_____

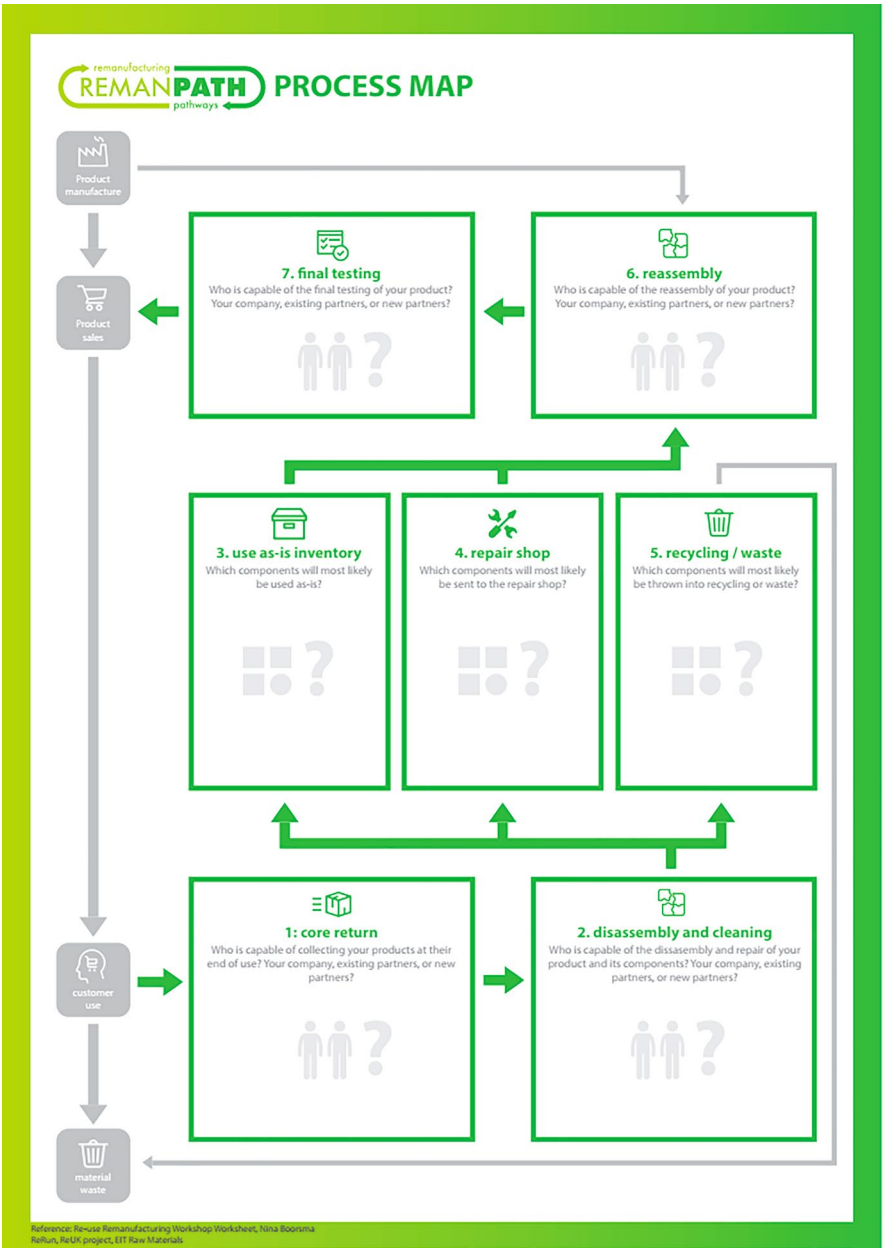
8. **How long should a workshop on remanufacturing last?**

- ☐ Half a day
- ☐ One day
- ☐ Two days
- ☐ One week
- ☐ More than two weeks
- ☐ Other_____

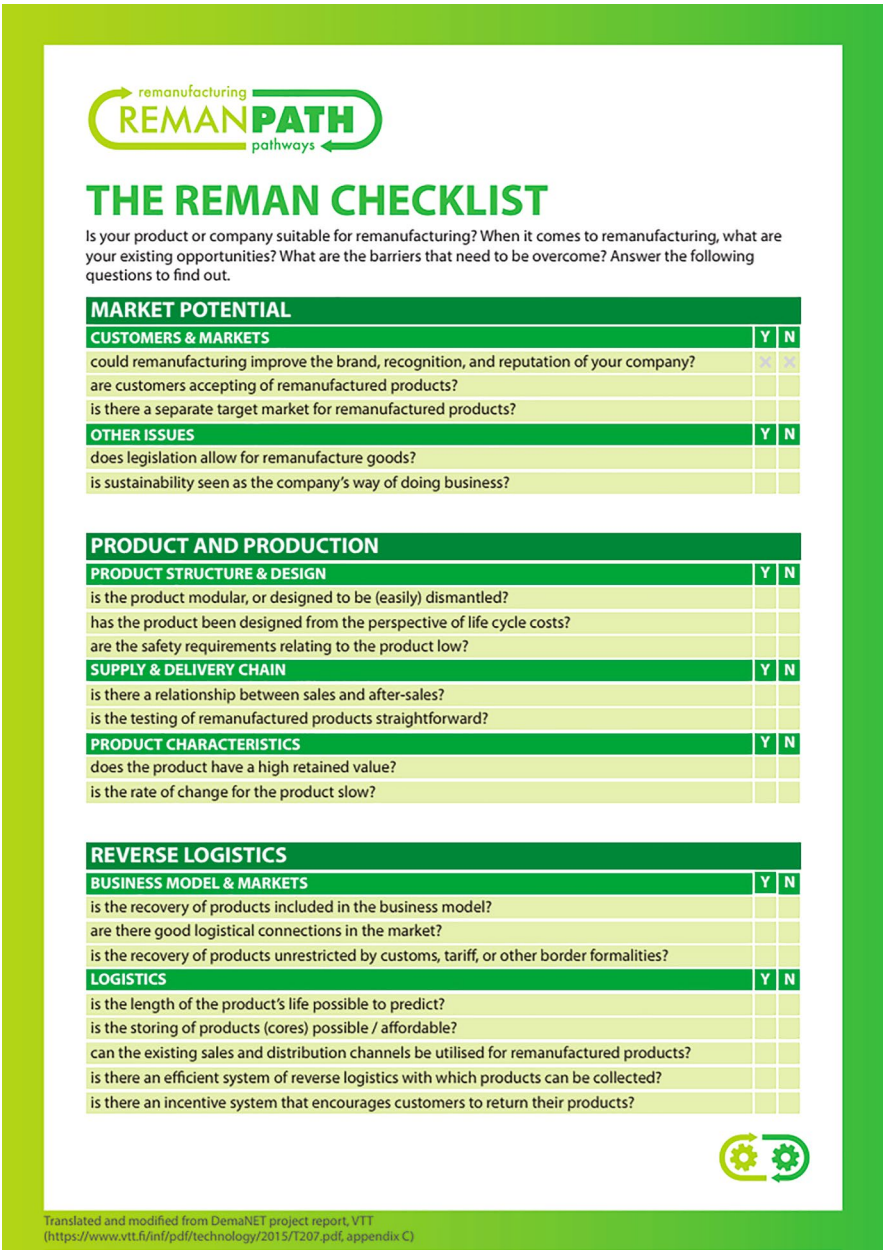
9. **How much do you think such training should cost?**

_____

The Reman Process Map



The Reman Checklist



remanufacturing REMANPATH pathways

THE REMAN CHECKLIST

Is your product or company suitable for remanufacturing? When it comes to remanufacturing, what are your existing opportunities? What are the barriers that need to be overcome? Answer the following questions to find out.

MARKET POTENTIAL		
CUSTOMERS & MARKETS	**Y**	**N**
could remanufacturing improve the brand, recognition, and reputation of your company?		
are customers accepting of remanufactured products?		
is there a separate target market for remanufactured products?		
OTHER ISSUES	**Y**	**N**
does legislation allow for remanufacture goods?		
is sustainability seen as the company's way of doing business?		

PRODUCT AND PRODUCTION		
PRODUCT STRUCTURE & DESIGN	**Y**	**N**
is the product modular, or designed to be (easily) dismantled?		
has the product been designed from the perspective of life cycle costs?		
are the safety requirements relating to the product low?		
SUPPLY & DELIVERY CHAIN	**Y**	**N**
is there a relationship between sales and after-sales?		
is the testing of remanufactured products straightforward?		
PRODUCT CHARACTERISTICS	**Y**	**N**
does the product have a high retained value?		
is the rate of change for the product slow?		

REVERSE LOGISTICS		
BUSINESS MODEL & MARKETS	**Y**	**N**
is the recovery of products included in the business model?		
are there good logistical connections in the market?		
is the recovery of products unrestricted by customs, tariff, or other border formalities?		
LOGISTICS	**Y**	**N**
is the length of the product's life possible to predict?		
is the storing of products (cores) possible / affordable?		
can the existing sales and distribution channels be utilised for remanufactured products?		
is there an efficient system of reverse logistics with which products can be collected?		
is there an incentive system that encourages customers to return their products?		

Translated and modified from DemaNET project report, VTT (https://www.vtt.fi/inf/pdf/technology/2015/T207.pdf, appendix C)

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