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Summer School on Circular Economy for Sustainable Manufacturing: A Case Study and Lessons Learned

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Abstract

The Circular Economy Action Plan is the main building block of the European Green Deal, Europe's new agenda for sustainable growth. Businesses need new technologies, new methods and new industrial organization either to create new businesses or to transform their products, processes and business models. They also need new talents to innovate, create businesses and new jobs, and transform society into a more sustainable one. Circular economy has grown significantly in recent years as a topic taught in engineering curricula. The purpose of this paper is to present the design, implementation and evaluation of a summer school program dedicated to the development, transformation and implementation of circular economy systems and new business models in manufacturing. The program was designed in collaboration with three university partners during a European project and relied on contributions from industrial companies, including start-ups and innovative companies. At the end, some lessons are drawn in order to show the main added value based on the evaluation of this summer school and to identify recommendations for the design and implementation of similar summer schools.

Keywords: Circular economy, summer school, education, sustainable manufacturing

1. Introduction

The transition towards a more resource-efficient society is a core goal of governments in Europe and worldwide. In March 2020, the European Commission adopted the new Circular Economy action plan (CEAP) [1], as one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth. The EU's new circular action plan paves the way for a cleaner and more competitive Europe. The Circular Economy (CE) comprises an integral approach to a resource-efficient future, necessitating the cooperation of stakeholders along the value chain. To achieve this, next-generation engineers need to link product and service design with (reverse) supply chain management, manufacturing technologies, product and service use, and product treatment and end-of-life (EoL), while making innovative use of digital technologies (such as blockchain, digital twin and AI). It is also one of the main objectives of the European Institute of Innovation and Technology (EIT) Manufacturing strategic agenda for 2021-2027 [2]. Manufacturing companies are among the main enablers to achieve this plan. They need new technologies, new methods and new industrial organization either to create new businesses or to transform their products, processes and business models. They also need new talents to innovate, create businesses and new jobs, and transform society into a more sustainable one.

Achieving circularity in innovative and complex industry sectors is very challenging. The absence of innovative and entrepreneurial skills in engineering graduates and professionals for developing circular business models in

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various industrial sectors represents a significant gap in the CE [3]. This holistic approach has been the focus of the CircularDev summer school, funded by EIT Manufacturing and implemented at University College Dublin, Ireland. The current paper presents the curriculum development and delivery experience of the CircularDev, Cross-Sectoral Digital Circular Economy Training and Business Development, summer school.

The reminder of this paper is organized as follows: Section 2 presents a literature review of CE and its application in sustainable manufacturing. This section also reviews the literature related to circular economy curriculum development in engineering education. Section 3 presents an overview of the pursued methodology in developing and delivering the CircularDev summer school. Section 4 presents the summer school program design followed by some implementation results presented in Section 5. Sections 6 and 7 present some lesson learnt and some concluding remarks.

2. Literature Review

The Circular Economy (CE) is an emerging concept that is currently promoted by the EU, governments and industry worldwide [4–6]. While a great deal of academic work has been devoted to the theoretical foundations of the CE concept, literature on the real-world applications of CE in the form of case studies is limited. Case studies are an important contribution to research as they allow for the integration of theory and practice and facilitate in-depth exploration of specific problems and solutions in context [7].

A review of the literature suggests that automobiles and their components case are among the most common products covered in manufacturing CE case studies, particularly in relation to the remanufacturing of components [6] and the reuse of lithium-ion batteries from EVs [8,9]. In the electronic devices industry, case study subjects include refurbished photocopiers [10] and mobile phones [11], as well as repurposed laptops [12]. Most case studies found on home appliances focused on the facilitation or optimization of product-service systems (PSS) for products such as washing machines [13], water purifiers [14] and solar heating systems [15]. Indeed, this may simply reflect the PSS focus that Bressanelli *et al.* [7] argued is dominant across CE initiatives within the home appliance industry at large.

The basis for higher education in engineering should focus on teaching students to efficiently solve real problems related to implementing the CE. But sometimes, traditional, lecture-based education takes precedence over practical classes based on solving real problems [16]. Recently, scholars strived to develop educational programs for the CE education among engineering students [16–22] and promoting new ways of education based on active learning and gamification [19,21,23]. Whalen *et al.* [19] evaluated 'In the Loop' serious game in facilitating education about material criticality and CE. Ben Rejeb and Zwolinski [24] implemented a project-based learning approach to develop content related to critical raw materials and CE. Rodríguez-Chueca *et al.* [16] investigated the use of challenged-based learning and flipped classroom approaches as a learning facilitator for higher education engineers to deliver content related to sustainability and CE. Del Vecchio *et al.* [18] performed a cross-case analysis of 16 EU universities programs to create competences and skills for CE in students with different profiles. Scalabrino, Navarrete Salvador and Oliva Martínez [20] developed a theoretical framework for CE and sustainability. Mesa and Esparragoza [25] made a systematic literature review for the implementation of CE in engineering education

Reviewing the published literature related to CE manufacturing applications and curriculum development revealed that CE has not been yet globally introduced in the engineering curriculum globally, and the research in the field of sustainable circular manufacturing has also been limited. This trend, however, seems to be changing since 2020 with more case studies has been published covering these aspects [25]. This paper presents the results of the curriculum development and delivery experience of the CircularDev, Cross-Sectoral Digital Circular Economy Training and Business Development, summer school.

3. Methodology

The paper aims at presenting the design, the implementation and the evaluation of the CircularDev program. Firstly, for the design of CircularDev activity, the EntreComp framework has been adopted. Its aim is to develop the entrepreneurial capacity of European citizens and organisations [26]. CircularDev consists of three interrelated and interconnected competence areas as developed by EntreComp framework: 'Ideas and opportunities', 'Resources' and 'Into action'. Each of the areas is made up of five competences, which, together, constitute the building blocks of entrepreneurship as a competence. CircularDev program addresses all those 15 competences through the introduction of Industrial Challenges in its developed program.

In addition, it is crucial to carefully analyze the specific learning outcomes during the design of the CircularDev summer school content. These outcomes are defined to provide participants with a deep understanding of the CE and circular business models, enabling students to make a significant contribution to the realm of sustainable circular manufacturing. Master students need to develop competencies aligned with the EIT Overarching Learning Outcomes (EIT OLOs) [27]: OLO 1 (Entrepreneurship), OLO 2 (Innovation), OLO 3 (Creativity), OLO 5 (Making value judgments and sustainability) and Leadership (OLO 6). Based on this framework, the consortium identified three main learning outcomes that the students need to acquire at the end of the summer school:

1. Learning Outcome 1: Develop and propose creative circular opportunities and circular business models
2. Learning Outcome 2: Perform customer discovery and customer engagement through a customer discovery, design thinking and creating value propositions
3. Learning Outcome 3: Craft an intrapreneurial and/or entrepreneurial value proposition for using circular principles and gain insights into the transition pathways from linear to circular

Secondly, for the implementation of CircularDev, the content covers core topics which are Circular Business Model

Innovation, Circular Design, Agile, Lean thinking, and Customer Discovery. This is aligned with the European and National policy shift focus from the linear take-make-waste industrial model to a CE [28,29]. Design plays a central role in this transition, necessitating the redesign of products, business models, and linear systems [30]. The CircularDev summer school explores the pivotal role of design in creating a circular economy, utilizes a circular design process, and underscores six strategies for integrating CE principles into business model designs. Designed for students and professionals, this program empowers individuals to acquire skills in CE and business models. The program places a strong emphasis on solving authentic challenges from the industrial partners to provide hands-on experiences to the students. It forces them to engage early with potential customers to understand the problem they are fixing, build a product closely aligned to the problem and constantly impose tests on their assumptions. This iterative process helps them find product-market fit quickly and efficiently. In the customer discovery process, students used an online tool for product management system that helped the teams to bring all product knowledge together in one place and make data-driven decisions on what to build, from roadmap through discovery, launch and iteration. For start-up culture, team-building and leadership skills, students used the Emotional Capital Report [31] with group-to-group coaching and mentoring. In addition to the face to face content, there was an objective to design an online learning path composed of six "digital nuggets" which are self-contained units of information designed to convey concise and relevant insights on CE.

Thirdly, in order to comprehensively assess the effectiveness of the Summer School, this study collected valuable data through pre- and post-workshop surveys with the participants. The gathered information provided a dynamic perspective on how the program influenced the attendees' understanding of CE concepts and principles, and how the program influenced the attendees' abilities to meet the targeted learning outcomes. Each of the three main learning outcomes of the summer school program was further subdivided into a set of six distinct sub-categories, as shown by Appendix 1. These sub-categories were designed to focus on specific skills and competencies that students needed to develop to achieve the broader learning objectives, enabling us to assess their progress in each sub-category with precision. Both pre- and post-workshop surveys featured identical sets of questions designed to assess the students' perceived abilities and skills within the learning outcomes and their corresponding sub-categories. Students were asked to rate their proficiency in these areas using a Likert scale in the initial survey, providing a baseline assessment of their capabilities. Subsequently, after following the CircularDev summer school and receiving the content, the students were surveyed again. This post-program survey was designed to gauge the progress they had made in acquiring and honing the targeted learning objectives.

4. Results

4.1. Summer School Program Design

The CircularDev summer school program was managed in collaboration with three university partners recognized for their expertise in research and innovation: University College Dublin (UCD), Grenoble Institute of Technology (Grenoble INP-UGA) and Mondragon University (MU). It was based on contributions from industrial companies, including startups and I&E, and ethics experts. Two industrial companies were part of the consortium in addition to the academic partners. The program offered a roadmap for participants to develop and innovate circular business models and designs.

The pedagogical strategy of CircularDev was designed to actively engage learners. The summer school was delivered during a period of three weeks from July 13th until August 4th 2023. The structure of the program was the following:

- Self-Paced Learning: During the two first days of the summer school, online materials were proposed to the participants in order to provide flexible and accessible learning resources about CE and innovation.
- Real-World Case Studies: The program incorporates real-world case studies from manufacturing companies to immerse learners in practical challenges. For example, learners received several keynote presentations presented by different industrial experts, focusing on a range of topics related to CE. These presentations covered subjects such as the environmental impact of key products and services, the potential for nature's CE, insights into large company's environmental strategy, innovation and business creation ecosystems in Europe, and the role of digitalization in the Plastic industry.
- Industrial challenges: The CircularDev program included innovation challenges for the industrial partners, where participants are tasked with proposing innovative CE solutions. These challenges encourage creativity and competitive problem-solving within the context of real industry issues. Seven challenges were proposed related to the subjects of plastic recycling, cooking oil recycling, GHG emission calculation, energy consumption estimation and digital product passport.
- Design Thinking Workshops: The program included design thinking workshops coordinated by innovation coach. During these sessions, learners worked on real circular product design projects. They collaborated in teams to propose innovative ideas for the industrial challenges. Diverse student groups were formed, ensuring a mix of engineering backgrounds within each group. This encouraged cross-disciplinary collaboration and knowledge sharing, and fostered creativity and problem-solving skills.
- Gamification of Learning: Incorporating serious games into the program can introduce an element of competition and achievement, which can further motivate learners to actively participate and excel in their studies. 3 serious games where organised after the face to face session in order to implement this practice: Climate Fresk [32], Circular Challenge [33], and 2tonnes game [34].
- In addition to this content, and following the delivery of the summer school, a learning path composed of six digital nuggets was created and hosted on a the EIT Manufacturing online learning platform. Designed to reach the three learning outcomes, the purpose of the learning path was to provide a comprehensive exploration of essential elements of the CE principles. It covered several topics, such as

circular scenarios, reverse logistics, case studies, circularity measurement, and the challenges of industry 4.0 in CE.

4.2. Implementation and delivery of the Summer School

The delivery of this summer school program lasts over 16 days: 2 days online, 10 days in presence at UCD, and 4 online days for serious games and for final pitch. 50 students took part of summer school: 49 from the EIT Manufacturing master school and one external; all from various engineering disciplines. They all traveled to UCD in Ireland where they have met the company representative of 6 start-ups and firms who all did presentations about their company activities. The summer school content was delivered by 12 mentors and teachers, from Ireland, France, Serbia, Spain, and Germany. The teachers were a mixture of engineers, I&E and Ethics experts, business creations managers, company owners, and researchers. Overall, 14 out of 62 learners, and trainers participating in this program were women participants which accounts for around 22% of the participants.

4.3. Evaluation of the learning objectives achievement

By comparing the responses from the pre- and post-workshop surveys, we were able to quantitatively measure the transformative impact of the summer school on the students' understanding and competence in the specified areas of CE. The charts in Appendix 1 provide visual representation of the data, and allow us getting an insight into how students fared in each of these sub-categories, offering a detailed picture of their growth and capabilities in key areas related to CE. The overall trend highlights the effectiveness of the program in enhancing students' knowledge and skills. Considering the achievement of the objective learning outcomes, for Learning Outcome 1 "Develop and propose creative circular opportunities and circular business models", before the summer school, participants exhibited varying levels of proficiency in different aspects of this learning outcome. However, after the program, there was a substantial improvement in their responses across all sub-categories. Notably, LO1.1 "define circular economy and circular business models" and LO1.5 "generate innovative and practical ideas for designing new circular business models" saw significant shifts, with more than 60% strongly agreeing to defining CE and generating innovative circular business ideas. This reflects the program's success in enhancing participants' understanding of and ability to propose circular opportunities and business models. Regarding Learning Outcome 2 "Perform customer discovery and customer engagement through a customer discovery, design thinking and creating value propositions", the students generally started with some level of recognition of the importance of value propositions and value proposition components. After the summer school, their understanding significantly improved, especially in recognizing the importance of value propositions. LO2.1 experienced a remarkable shift, with 77.50% strongly agreeing to its importance. This suggests that the program successfully enhanced their understanding of these concepts. Regarding the Learning Outcome 3 "Craft an intrapreneurial and/or entrepreneurial value proposition for using circular principles and gain insights into the transition pathways from linear to circular", similarly to Learning Outcome 1, participants demonstrated varying levels of understanding and skills before the summer school, but their responses improved considerably across all sub-categories after the program. Notably, LO3.3 (utilizing intrapreneurial and entrepreneurial approaches) and LO3.5 (designing comprehensive transition plans) stood out with substantial changes. This suggests that the summer school effectively equipped them with the knowledge and skills to craft value propositions and understand the transition to circular business models.

5. Lessons Learned and Recommendations

The core of CircularDev Summer School was industrial challenges. Seven Industrial challenges were designed and scoped out in collaboration with the industrial partners. As part of these seven industrial challenges, the learners were exposed to various inter-sectoral environments from start-up to large multinational companies. Groups of learners did many interviews with the industry representatives. This was a quite valuable activity as it helped the learners develop their technical communication skills while working on their assigned industrial challenge with the companies. The motivation for the learners to participate in such activity was to shape the challenge, gather relevant data and validate the developed solution. On the other hand, the benefits for the involved organizations was to have a group of engineers working on their proposed industrial challenge, helping them scoping some innovative ideas. Thanks to the methods for emotional capital and design thinking that were followed, the students gained an understanding of what skills are required to build companies. These combined approaches of fast-tracking competencies plus giving them tools to validate ideas and learning will helped them get to market faster.

While the students the students made substantial progress across all learning outcome, there are specific areas where they could have made even better progress toward becoming more proficient in CE. In LO1, further attention to the analysis of existing business models for circularity and sustainability is warranted, allowing students to better identify opportunities for circular practices within traditional models. In LO2, enhancing the application of user-centered design thinking in customer engagement and prototyping is a promising focus area. Lastly, within LO3, students might benefit from more extensive training in the creation of comprehensive transition plans to circular models in entrepreneurial contexts. These identified areas represent valuable opportunities for future programs to equip students with a deeper and more practical proficiency of circular economy principles, ensuring they are well-prepared for the evolving landscape of circular business models.

6. Conclusion

In conclusion, the CircularDev Summer School program has demonstrated its effectiveness in enhancing participants' understanding and proficiency in CE principles and practices. The industrial challenges provided a valuable experiential learning opportunity, enabling students to develop technical communication skills and gain insights into real-world circular business challenges. The combination of emotional capital

development and design thinking approaches fast-tracked competencies and equipped students with the tools to validate ideas, fostering an entrepreneurial mindset. Notably, participants showed substantial improvement across all three main learning outcomes, with significant shifts in understanding CE definitions, generating innovative circular business ideas, recognizing the importance of value propositions, and crafting intrapreneurial and entrepreneurial value propositions. However, to further improve students' proficiency in CE, future programs should focus on areas such as analyzing existing business models for circularity and sustainability, enhancing user-centered design thinking in customer engagement, and providing extensive training on creating comprehensive transition plans for linear to circular models in entrepreneurial contexts. The success of the CircularDev Summer School underscores its value in preparing students to meet the evolving challenges of sustainable and circular manufacturing, contributing to a more resource-efficient and environmentally sustainable future.

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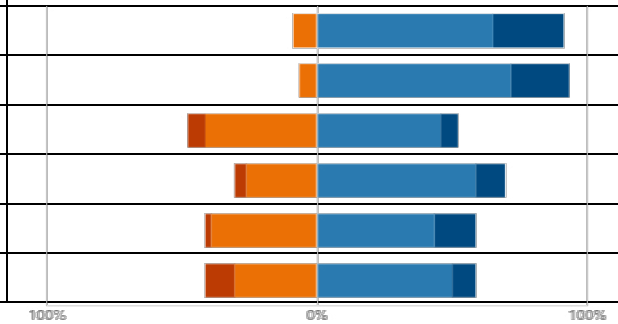
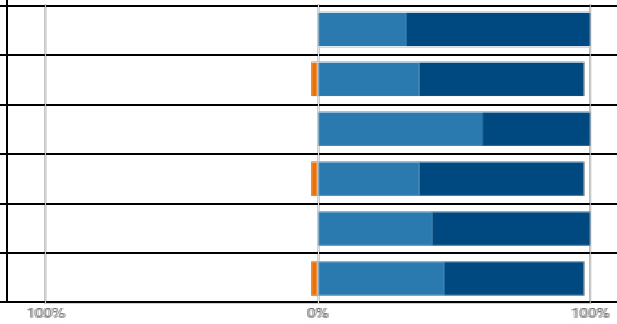
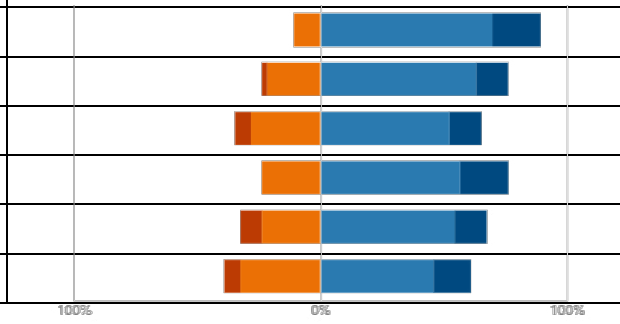
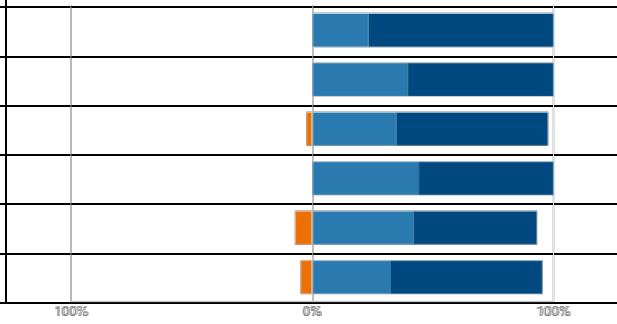
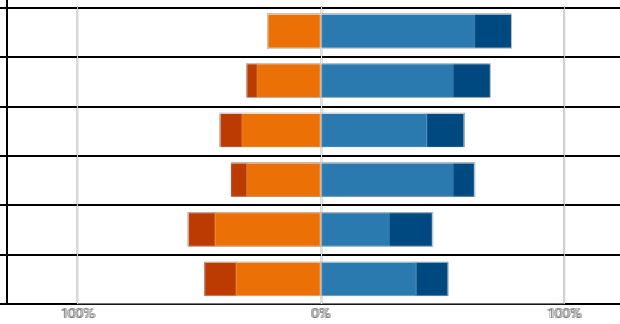
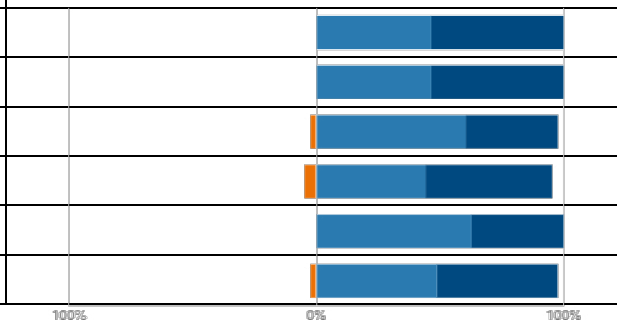
Appendix A. Learning outcomes (LO) measurement (before and after the summer school)

LO1: Develop and propose creative circular opportunities and circular business models		**Start** Strongly disagree Disagree Agree Strongly agree	**End** Strongly disagree Disagree Agree Strongly agree
LO1.1	define circular economy and circular business models.		
LO1.2	explain the benefits and challenges of implementing circular economy and circular business models.		
LO1.3	utilize specific tools to implement circular economy scenarios and develop circular business models in an industrial context		
LO1.4	analyse existing business models to identify opportunities for circularity and sustainability.		
LO1.5	generate innovative and practical ideas for designing new circular business models.		
LO1.6	critically evaluate the impact of circular economy on sustainability and resource management.		

LO2: Perform customer discovery and customer engagement through a customer discovery, design thinking and creating value propositions		**Start** Strongly disagree Disagree Agree Strongly agree	**End** Strongly disagree Disagree Agree Strongly agree
LO2.1	recognize the importance of value propositions in customer engagement		
LO2.2	summarize the components and elements of effective value propositions		
LO2.3	utilize appropriate techniques to conduct customer discovery and engage with potential customers.		
LO2.4	assess the alignment between value propositions and customer needs.		
LO2.5	design user-centred processes and design thinking for customer discovery prototyping and testing.		
LO2.6	critically evaluate the success of customer discovery efforts in understanding customer needs and preferences		

LO3: Craft an intrapreneurial and/or entrepreneurial value proposition for using circular principles.		**Start** Strongly disagree Disagree Agree Strongly agree	**End** Strongly disagree Disagree Agree Strongly agree
LO3.1	identify the key components of a value proposition.		
LO3.2	summarize the benefits and challenges of adopting circular practices for a better resource and energy efficiency.		
LO3.3	utilise intra and entrepreneurial approaches to identify opportunities for the transition from linear to circular BM.		
LO3.4	assess the barriers and enablers to transitioning from linear to circular models.		
LO3.5	design comprehensive transition plans from linear to circular models within an entrepreneurial context.		
LO3.6	critically evaluate the success of an innovative value proposition based on circular economy principles		