Teaching Circular Economy: An interactive and multi-disciplinary approach

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Abstract

Circular economy (CE) is gaining interest from practitioners and academics who recognize its potential for environmental challenges. On-field CE projects implicate the

collaboration of professionals with different backgrounds and competencies. Today's students - future professionals - need to be prepared to face multi-disciplinary subjects as CE from theoretical and practical perspectives. Therefore, this research aims at investigating issues in addressing real case studies in case-based learning (CBL) for a multi-disciplinary subject in multinational groupwork. We adopted action research analyzing the current development of several CE academic courses by a European consortium.

Keywords: Circular Economy, Sustainability, Modular Education

Introduction

The existing economic system is mainly based on the linear approach, which consists of the sequence of four steps, namely *take-make-use-dispose*. Despite its simplicity, this approach is no longer sustainable from the environmental perspective. There are just not enough resources to keep the system growing and simultaneously preserving environmental quality. Therefore, the transformation towards another approach to guarantee sustainability, i.e. circular economy (CE), is required by the European Union and national agendas, companies, and other stakeholders (Ghisellini et al., 2016; Geissdoerfer et al., 2017; Murray et al., 2017; Saidani et al. 2019; Werning and Spinler 2020).

Despite the importance and urgency of this transformation, enterprises often lack the expertise to develop and implement CE projects. An element of complexity derives from the multi-disciplinary nature of this type of projects, which must address issues ranging from product, process, and supply network redesign, to material selections, business models, life cycle assessment, to mention just a few. This means that a team of different experts in various fields - e.g. composed of supply chain managers, process engineers, materials engineers, persons responsible for new product development, etc. - must collaborate to find an innovative solution that contemplates different integrated aspects related to supply chain management, business models, and product development. Conversely, education generally tends to establish niche competences neglecting this holistic perspective. For instance, material selection issues are generally presented to students without an integrated optimization process which considers all the relevant aspects related to the product and production engineering (Kaspar et al. 2016). The traditional mindset of mechanical engineering often overlooks the consequences that material and production process selections, as well as product design, have on the whole life cycle of a product. The support of an environmental engineer is needed since s/he can assess the overall result of the product's environmental performance. However, s/he would benefit from understanding the characteristics of materials and the requirements of the manufacturing process in order to contribute to the product design stage. Nevertheless, these two perspectives are not still sufficient for successfully changing into sustainable business models during the product design stage. Indeed, a contribution from the business and industrial engineering is also strongly required.

Today's students, the future professionals, need to learn how to develop and implement CE principles in a company by experiencing the implications of a CE field project and understanding how the various competences may be integrated. To this aim, a group of universities and research centers - LUT University, Fraunhofer, Technical University of Denmark, University of Padova, Delft University of Technology, University of Helsinki with support of Metso Outotec, a Finnish technology company - has launched a research and development project with the purpose of planning and testing a course for Master

students that can help to train professionals capable of meeting the needs today's companies have. This research project is financed by the European Institute of Innovation and Technology (EIT) Raw Materials (RM), (title of the project: "Embedding Circular Economy into Product Design and Optimization", acronym: E-CIRP, period: 01/2019-12/2021, Specific Grant Agreement No. EIT/RAW MATERIALS/SGA2019/1, lead partner: LUT University).

From the educational perspective, the overall purpose of the project is to develop and assess how different ways to learn can be used and combined in order to provide an excellent learning experience to both students and educators, as well as for the companies taking part. The partners of e-CirP project decided to adopt a modular approach, splitting the whole course into educational modules. One of the modules concerns challenging case studies in collaboration with real companies which are currently involved in CE and environmental sustainability initiatives. The selection of the case studies was made trying to address the correct level of complexity for Master students and considering the time constraints that students had to perform them. On the other side, the partners carefully selected the case studies in order to effectively enforce the system perspective and life cycle thinking. The development of case studies did not provide only one-way advantages. Indeed, companies obtained interesting solutions from students. These solutions can be exploited by companies to solve their real problems. In the first cycle of the project (academic year 2019-2020), the case studies module was individually developed and executed by each of the partners of the consortium, by forming groupworks made up by local students. In the current cycle (academic year 2020-2021), the partners decided to offer again the case studies module. The novelty is that students from different universities had to collaborate in groups to solve the case study proposed.

In this perspective, *the aim of this paper is to understand what are the potential issues, challenges, and positive facets in planning, developing, and executing case studies in case-based learning (CBL) concerning a multi-disciplinary subject (i.e. CE) in a multinational group work.*

Theoretical background

McMaster Medical School is known as the first of a kind to apply what is known as problem-based learning (Chung & Chow, 2004). In problem-based learning (PBL), the main medium of learning is small tutorials and sometimes cases. The students are presumed to have an active role in finding information using various sources and different disciplines to mesh information and evidence to solve the problem (Chung & Chow, 2004). Although for instance a study by Srinivasan et al (2007) showed that some students preferred PBL because they felt it encouraged more self-directed learning, the majority even in that comparative study preferred case-based learning (CBL) over PBL as it, for instance, offers more opportunities for practising applied skills.

The role of the faculty in problem-based learning approaches resembles the role they have in case studies and CBL: not as sources of subject-matter and content, but more as facilitators of the team process and active learning dynamics. Case studies provide a platform for combining theoretical and content-specific knowledge with real-life situations either through e.g. simulations (nursing, medical sciences, natural sciences, engineering) or solving a problem-based set-up that comes in the form of a case (the aforementioned disciplines, business studies, social sciences, etc.; see Billings & Halstead, 1998; DeYoung, 2003).

Case study, CBL, or case method – the latter being a lighter approach – promotes the students' abilities to apply critical approaches and critical thinking, solve problems, decision-making and collaborative effort, and for instance communicative skills, self- and

group-regulation, and leadership skills (Tomey, 2003; Hung, Jonassen & Liu, 2008; Allen, Donham & Bernhardt, 2011). This follows, as naturally, in addition to trying to get on with the assignment, the students also have to try and get along with each other (Andriessen, Pardijs & Baker, 2013). In collaborative learning activities and knowledge co-creation, the relevant goals and values have an impact also on the social and group-regulated dimensions of the process (e.g. Karau & Williams, 1995); this is particularly true for case-based learning, where the group of students are supposed to form a team that works on a shared learning objective and often also have a concrete expected outcome to achieve.

The case used for learning, be it a pre-described one or one that combines something relevant for e.g. the industry in question (engineering, business studies etc.) with something of interest for the students, can at best also work as a trigger for authentic stakeholder engagement: the students have to find a stakeholder that is interested in using their case or, in more concrete terms, the artefact that they have created; this can be seen in light of knowledge creation and cross-fertilisation of knowledge (cf. Paavola & Hakkarainen, 2005).

Vivas and Allada (2006) applied CBL in engineering studies and used theme-oriented case studies to frame the learning situation. Yadav and colleagues (2014) found that the conceptual understanding of students that had been involved in CBL was statistically significantly higher than for students that participated in more traditional, lecture-based teaching. For the purposes, in the present study, the cases were not only intending to, but actually did provide the students with immersive experiences that they could foresee to face in their future professional lives, such as group work skills. CBL has, indeed, been shown to promote so-called soft skills, for instance in medical sciences (Gade & Chari, 2013). The expected benefits of this CBL approach include:

- Authenticity
- Ability to promote the university-industry nexus as a platform for learning
- Learning of "soft" skills (decision-making in multi-disciplinary teams, communicative skills, etc.)

In the present paper, the CBL approach was chosen based on a university-industry nexus collaboration. There was also the aim of creating shared learning objects that would support collaborative learning and knowledge co-creation between students coming from different organisations. The student groups were multi-disciplinary (engineering, business studies and administration), and came from different countries, posing a challenge and a possibility for developing means for promoting sustainable ways of collaboration between members of distributed teams (Saunders & Ahuja, 2006; Connaughton & Shuffler, 2007). The various backgrounds were supposed to add to the outcomes and to the process dynamics. The industries represented both local and international companies, and contributed by providing real-life cases that worked as the shared learning object for the student teams. The student teams, in turn, provided solutions and potentially also proposed concrete artefacts that could be used as part solutions to the challenge.

This study presents the development of courses for CE and how industry cases were used for learning and how they were experienced by students.

Methodology

The e-CirP project covers three academic years (i.e. 2019-2020, 2020-2021 and, 2021-2022). This project aims to develop a course for Master students, combining the different perspectives required to face a multidisciplinary subject such as CE. Specifically, the

viewpoints that the project wants to amalgamate are i) mechanical engineering and product design, ii) environmental engineering and sustainability assessment, and iii) business aspects. The partners are building the course trying to ensure that students get skills on raw material choices and product performance, the company's circular business development, and the circularity of the economy as a whole. During the course, a core activity that students are called to face is working in groups to solve case studies in collaboration with real companies.

The methodology adopted is in line with the principles of action research. Analyzing literature concerning action research, Coghlan and Coghlan (2002) resumed those principles as follows: "i) research in action, rather than research about action; ii) participative; iii) concurrent with action; iv) a sequence of events and an approach to problem solving.".

The authors are involved in experiencing and resolving the issue behind this paper. Additionally, the consortium is not developing the course and the case study activity following a linear path. Conversely, the partners are adopting iterative cycles. Each cycle has a length of one year and consists of four steps, i.e. planning, implementing, testing, and improving/re-planning (see Figure 1).

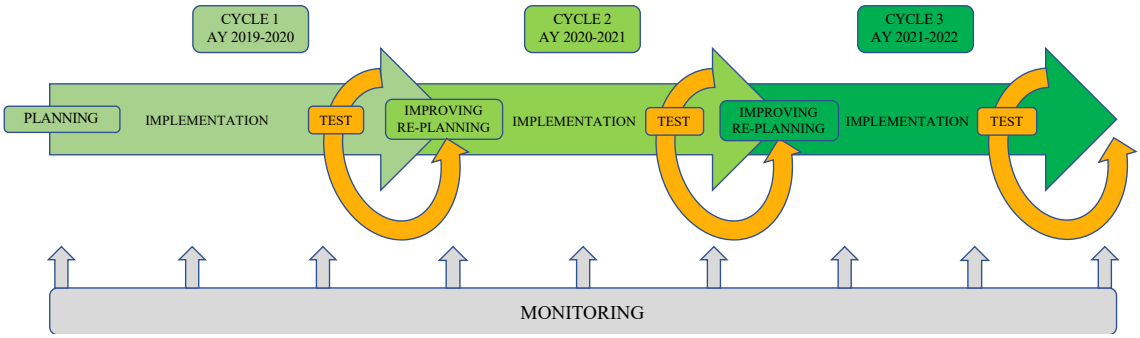

Figure 1 - The action research cycle

Project, course and case studies.

Covering five European countries, the consortium involved in the project consists of 7 partners. In respect of academia, the partners involved in the project are LUT University (Finland), Technical University of Denmark (Denmark), University of Padova (Italy), and Delft University of Technology (Netherlands). Fraunhofer (Germany), as a research institute, presents a deeper application-oriented approach to education. Finally, Metso Outotec (Finland) is a process technology and service provider specialized in the field of metals and mining.

The strength of the consortium is that the partners are complementary in fields of environmental, mechanical, chemical, energy, civil, and industrial engineering, sustainability assessment, product design, and business.

The e-CirP project is divided into 8 work packages (WPs). WP1 concerns project management and is led by the coordinator of the whole project, i.e. LUT University, while WP2 is related to the pedagogical aspects. The leader of WP2, the University of Helsinki, is responsible for supporting the partners during the pilot phase of the education modules development, by providing them specific pedagogical training. Additionally, the University of Helsinki is called to guarantee the correct implementation of innovative teaching methodologies within all the education modules. In the early stage of the project, the partners designed the teaching and learning practices, delineated the learning outcomes of the modules, and created the educational materials.

In Table 1 the main contents related to the education modules is reported.

Table 1 - e-CirP education modules description

WP	Education Module	Learning objective
WP3	Circular economy	To understand how CE principles can be connected in techno-cycle of products to manage sustainability challenges.
WP4	Product design & Material selection & Production methods	To apply CE principles in design, material selection and production while understanding the possibilities of the 6 R's.
WP5	New Business models & Innovation approach	To identify the enablers and drivers of sustainable business around product design and innovation.
WP6	Value chain optimization	To rethink products, services, underlying processes and business models in viewpoints of different actors in the value chain and product life cycle.
WP7	Assessment	To apply life cycle thinking and assessment in the design and optimization of the techno-cycle of products.
WP8	Case development module	To develop in a multi-disciplinary team a solution for a real-life case that acknowledges the complexity of the circular economy approach.

The choice of modularity was made by the partners to effectively introduce the course within the existing curriculum of the different involved universities. The prerequisite knowledge to deal with the modules concerns general issues related to product and process development and sustainability. Even if the contents of the education modules are set a priori, universities can modify them. For instance, universities can provide additional topics that are required from the specific academic course but that are not fully covered by the module. Moreover, the partners can choose which modules to include in their academic course. Only the module case development (WP8) is mandatory. In the first semester of the academic year 2019-20, each university implemented the course, based on a subset of education modules jointly developed. Each of the five piloted courses used flipped classrooms as a learning approach. Moreover, the courses included the "Case development module". Students were asked to solve real assignments in collaboration with real companies. However, since universities individually developed the case studies activity, there were no collaborations among partners. After analyzing the experience of the first cycle, the e-CirP partners decided to implement pairwise collaborations in order to offer their students the possibility to work in an international context. This choice allows us to compare the implications of using international groupworks.

University of Padova – Fraunhofer

One collaboration involved University of Padova and Fraunhofer. Whilst the faculty of Management Engineering at the University of Padova includes the course Circular economy, Fraunhofer offers the course Sustainability in engineering in the module Life cycle engineering and sustainability at the University of Stuttgart. A total of six different case studies were proposed to students. The case studies were derived from Italian companies that are currently involved in CE and sustainability initiatives. The total number of students that participated in the case study was 52, of which 40 from University of Padova and 12 from University of Stuttgart. Students from both universities were divided into 9 different groups to examine the different cases. Groups were meticulously formed in order to ensure that students from both universities were present. Each case

study included two different assignments. To be evaluated, groups had to prepare one written report and discuss a final presentation at the end of the semester.

One case was related to an Italian tannery that produces leather for various sectors, including automotive, leatherware, footwear, fashion, furnishing and contract, smart devices, and transportation. The full production of this company is located in the Italian headquarter with the aim to guarantee product and production process control, quality, reliability, and respect for the environment. The second case was set in collaboration with a manufacturing company operating in the furniture industry. In particular, the focus of this company is on furniture for outdoor use, suitable for various settings and styles. The headquarter is in Italy, but the company is present with its products in more than a hundred countries worldwide. Lastly, the third case involved a winery that is strongly involved in preserving the environment through responsible use of natural resources. The collaboration with producers' cooperatives allows this company to ensure short, transparent, and controlled supply chains for its products.

In all the cases, Italian and German students and companies collaborated through online meetings with managers who cover a relevant position concerning environmental aspects. Additionally, managers provided the needed documents to students in order to effectively face the assignments. During the case study execution, tutors from the University of Padova gave to each group work the possibility to have a weekly meeting. The aim was to monitor the progress of the work and to discuss any issues with the assignments arisen during the week. Participation in the weekly meeting was not mandatory. However, the frequency of participation of the student teams was high.

LUT University - Technical University of Denmark

In the academic year 2020-2021 LUT University and Technical University of Denmark organized in close cooperation the groupwork activity to face case studies. This activity was empowered by a partnership with a Spanish start-up, TELANTO, which offers a digital platform to engage and scale university-industry collaboration. The start-up provided three different cases related to the topics of the academic course. Students from the LUT University and the Technical University of Denmark were divided into 10 groups. All the groups had participation from both universities. The students examined their case assignments in cooperation with companies, holding with them weekly or bi-weekly meetings. In these meetings, the teachers/tutors were involved too. Each workgroup had to elaborate a final written report and a presentation of the case study.

In respect of topics, one case regarded the feasibility analysis of extending the life cycle of plastics needed in blood plasma bags and bottles. Nowadays the waste amount generated by blood plasma packages is extremely high, and the company is looking for solutions that are sustainable in terms of environmental sustainability. The solution has to be also technologically and economically feasible and legally compliant, considering that plasma packages are considered medical waste.

Three groups worked in collaboration with a company, whose core business is a materials search platform that connects engineers and material suppliers through material databases worldwide. Students were called to understand the possibilities of including sustainability information on the materials databases. The company wanted to increase the information provided to their clients by including data relating to environmental issues.

The third case involved the collaboration with one of the most known software providers of ERP systems. Six groups worked on how circular economy objectives could be included in the supply chain planning. In particular, students were analyzing what, why, and how the software could be helpful to its clients in operating and controlling the

flow of products and components sustainably. In order to conduct the analysis, students were given three exemplary products (i.e. sneakers, smartphones, beer). The six groups presented heterogeneous solutions, focusing on different aspects such as sales and operations planning, demand-driven replenishment, response and supply, return and recycling, demand, and inventory.

Delft University of Technology – LUT University

The collaboration between Delft University of Technology and LUT University was sequential instead of parallel. The reason behind this setting is that the time slots of the courses were not compatible. The course Sustainable Design of LUT University covered the whole first semester, while Delft University of Technology arranged an intensive four-week course (Design Approaches) during September and October. The results achieved by Delft University of Technology students were used as input from their Finnish colleagues. During the planning of the case studies activity, these universities chose to establish a partnership with the above-mentioned start-up.

At LUT University students were divided into four groups to face the cases and propose their solutions. Checkpoints and tutoring sessions provided by lecturers and company representatives were established for monitoring and evaluating group works' progress. Students submitted a final report and presented the final results during a dedicated session in which teachers, company representatives, and guest evaluators attended.

The first case study was developed in collaboration with a company operating in the construction industry. The challenge concerns the storage and handling of working tools (e.g. drills, hammers, cables) needed in the construction sites. The company used to store and transport the tools from the warehouses to the construction sites using wooden boxes. Additionally, tools were randomly located inside the boxes, without specific layouts. The company aims to design and build new cupboards. The internal layout of the cupboard has to guarantee high efficiency in finding, picking, and storing the tools. Moreover, the material of the cupboard has to be durable. Indeed, a big problem encountered by the company is that wooden boxes get easily warped or deteriorated. Therefore, operators have to frequently discard and substitute the ruined boxes. Consequently, a great deal of waste is generated.

For the second case, three groups from Delft University of Technology and two groups from LUT University worked on the analysis and design interventions for the plasma packaging (the same case of the collaboration between LUT University and Technical University of Denmark). The teams from Delft University of Technology assessed the plasma bags' current lifecycle, highlighting current and potential sustainability issues. A material health analysis was done for the current materials, considering different aspects (e.g. the toxicity level). Students analyzed different solutions to adopt during the product's lifecycle and identified criticalities for the various hypotheses. Leveraging the Dutch colleagues' outcomes, students at the LUT University proposed different solutions, which involve aspects in material replacement, reusing existing material, modification in geometrical and structural design of the existing packages.

Preliminary findings and conclusion

Up to the present time, the course is at the final stages of the second cycle. The implementation of the course and the group works activity have been completed for the academic year 2020-2021. Intending to successfully improve and re-plan the activities for the third cycle (academic year 2021-2022), e-CirP partners initiated the test phase. To do

so, they analyzed both the positive aspects and difficulties encountered by the student teams in conducting the case studies during the academic year 2020-2021.

Students adopted problem-solving to face real challenges of a multi-disciplinary subject in a multinational context. The purpose was to simulate the context in which most of the students will work in one or two years. There is a common agreement among partners that students showed a high level of interest in participating in the case studies activity. Students' motivation was constant and intense throughout the entire execution of the assignments. It emerged that one of the main reasons behind the students' satisfaction is the possibility for enhancing practical knowledge and improving soft skills. This result is coherent with Srinivasan et al (2007)'s study. Moreover, students got extremely enthusiastic to collaborate with colleagues from different universities and countries. In respect of this, we observed that the different backgrounds owned by students were not a limitation. Conversely, even if some challenges related to different cultures inside group works arose, we can assess that having different backgrounds was a benefit. Indeed, students could learn from each other and improve the whole perspective regarding the multi-disciplinary subject they were called to face. In the interim student feedback, learning of soft skills was deemed very important by the students.

From the companies' side, all the partners received positive feedback. In respect of group-assignment matching, some companies particularly appreciated that more than one team faced the same assignment. This way, companies could exploit the different perspectives and solutions provided by different groups. For some assignments, it is expected that companies will continue to analyze the ideas provided by students for understanding if and to what extent these ideas can be implemented.

Overall, the consortium assessed that the planning and implementation of the case study activity were smooth. However, some criticalities arose. One of them is strictly related to international collaboration. Specifically, universities may own different timetables for the academic courses. We observed that LUT University and Delft University of Technology had no opportunity to collaborate timewise in parallel. Indeed, they were forced to challenge the case studies activity in sequence, since their courses had non-compatible timetables. From this perspective, the collaboration between the University of Padova and Fraunhofer was not completely effortless. Italian students started the academic course some weeks before the German ones. Therefore, the time slot to conduct the case study activity did not coincide with the entire duration of both courses. This discrepancy reduced the total available time for students and generated difficulties for performing a joint final presentation. In line with this, our suggestion is to check possibilities for schedule alignment in advance, since this a critical parameter for fruitful interaction. Another dimension that still requires improvement in online distributed teamwork is the mechanisms for building trust and a psychologically safe atmosphere for the groups. In the future, virtual reality solutions are planned to be integrated to support inter-group activities on a shared learning object, improving possibilities for shared-space interactions.

During the planning phase, another set of problems concerned finding and selecting case studies. Indeed, case studies need to simultaneously be feasible, challenging, and of interest to the various disciplines involved. Moreover, the practical topics provided by the case studies need to be in line with the theoretical contents and purposes of the academic courses. Resuming, case studies have to be thoroughly selected. Some partners of the project highlighted that not all the case studies were optimally suited for the purpose of their courses. To avoid this problem, we assess that at first the two (or more) universities that will work collaboratively need to understand the theoretical contents and aims of both courses. Then, the two (or more) universities are called to identify the common contents

and aims of their courses. Taking into account these commonalities, they can start to investigate case studies that are suitable in respect of both their courses. We suggest the universities to designate a large slot of time for the process of identification and selection of case studies. The reason behind this suggestion is that we observed how this activity could strongly impact the success of the learning experience for students.

We observed that establishing a partnership with a specialist (i.e. TELANTO) to plan case studies can be a successful alternative. However, we recognized the relevance of clearly sharing with the specialist the theoretical contents of the courses, the aim of the case study activity, and the constraints (e.g. students' time, competences) to perform this activity. During the execution phase, the main criticalities regarded the collaboration with companies. For a collaboration, the industry side involved was composed of companies located in the same country of one of the partners. Some students belonging to the other involved partner reported difficulties in communicating with the company representatives. Therefore, it is important to assure that the representatives of industrial companies have a good level of English language. In addition to language issues, some partners reported that students had needed more information from the managers to effectively conduct the case study activity. In particular, it can be challenging if a company is vague about the real objective of the case study. This was seen frustrating for students since they did not understand what companies expected from them. It represented a problem also for tutors/teachers because it is difficult to supervise students when the ultimate target is not clear enough.

Nowadays, the building of the course is a work in process, since we are at the end of the second cycle. We think that this project can advance research and practice in teaching in different ways. By using modularity in education, this course proposes to explore CE according to a multi-disciplinary perspective, which is a prerequisite in any CE field project. The collaboration with different universities and with real companies gives students the opportunity to experience participation in an international team of experts with complementary knowledge on CE, and to understand how to manage a real CE project. This kind of activity can be particularly useful to train future professionals in the CE field because it stimulates reflections and problem-solving. The insights that emerged from the case study module description can be helpful to practitioners that intend to develop case studies for multi-disciplinary subjects in cooperation with international partners and real companies.

For the third cycle (academic year 2021-2022), future plans include improving the teaching material and modules. In particular, leveraging the experience of the second cycle, e-CirP partners will rearrange the planning and execution of the case study module. For instance, partners will start the research and selection of case studies in an earlier stage, aiming to avoid problems of incompatibility with the theoretical contents of the courses. Moreover, partners intend to plan and develop an ad hoc Virtual Reality solution that will help students, teachers, and companies to interact remotely from their respective universities.

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