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Education for optimized Life Cycle Management: The Project e-CIRP and its insights into embedding circular economy aspects to product design via teaching

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Abstract. The integration of circular economy-based life cycle management (LCM) into product design and optimisation is essential for the transformation towards a circular economy (CE). However, companies often lack the expertise to adapt life-cycle design (LCD) thinking in their business operations and are in need of respective capacity building. To close this apparent gap is the aim of the project e-CirP (Embedding Circular Economy into Product Design and Optimization) where LUT University, Fraunhofer, Technical University of Denmark, University of Padova, Delft University of Technology, University of Helsinki and Metso Outotec have worked together to develop a program that allows Master students across Europe to learn how to integrate CE and Life Cycle Thinking principles into product design by analysing real industrial cases. In the project, modern pedagogical approaches have been applied. A modular training package covering general circular economy aspects, as well as detailed value chain perspectives, has been created. Next to the content-related aspects, a great focus was also on the support of so-called soft-skills development, e.g. through international student cooperation on case studies. The paper presents the perspective of participating students as well as the cooperating companies that supplied the industry cases to allow an overview of opportunities and challenges.

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1 Introduction

Emerging new digital technologies and tools, and new pedagogical approaches, have rapidly changed the education system of the 21st century. These rapid changes require innovation efforts from all university teachers. In recent years, flipped learning (cf. flipped classroom) [1, 2] has become one of the most promising and popular pedagogical approaches in the field of education and especially in higher education. The most mentioned motivation for switching from a traditional to a flipped learning format has been the idea that students should engage in active learning, peer interaction and discussions rather than listening to a lecture [3]. In order to meet both challenges posed by emerging new technology and new pedagogical approaches, the five European technical universities (LUT University, Fraunhofer, Technical University of Denmark, University of Padova, Delft University of Technology), and University of Helsinki with support from the Finnish company Metso Outotec established a consortium that aimed to develop a pedagogical module for Master students, combining the different perspectives required to face a multidisciplinary subject such as circular economy (CE). The consortium 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.

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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 to provide an excellent learning experience to both students and educators, as well as for the companies taking part. The partners of the e-CirP project decided to adopt a modular approach, splitting the whole course into educational modules. One of the modules concerns developing a program that allows Master students across Europe to learn how to integrate CE and Life Cycle Thinking principles into product design by analysing real industrial cases. The pedagogical model chosen was flipped learning, in which students became acquainted with the subject prior to joint teaching sessions by studying independently or in a group using videos, combined with case-based or as we call it challenge-based learning. The students deepened their learning on online lectures and by solving real-life problems with challenges provided by industrial partners.

The aim of this paper was to understand what the potential issues, challenges, and positive aspects are in planning, developing, and implementing flipped learning and challenge-based learning concerning a multidisciplinary subject (i.e., CE) in multinational teamwork.

2 Theoretical background

In the e-CirP project, modern pedagogical approaches, such as virtual reality (VR) and flipped learning [4], have been adapted and applied. The learning modules integrated industry cases, or better real-life challenges, at most partner universities. Case-based learning (CBL) works in promoting the students' critical abilities and critical thinking, problem solving skills, decision-making and collaborative abilities, while supporting for instance communicative skills, regulation skills (individual and group), and leadership skills [5, 6]: in addition to getting on with the task, the students also have to manage their professional relations with each other [7].

CBL and challenge-based learning (ChaBL) has, indeed, been shown to promote so-called soft skills, for instance in medical sciences [8]. We refer to the CBL approach applied here as challenge-based learning (ChaBL). The expected benefits of this ChaBL approach include *Authenticity and real-life meaningfulness*, *Ability to promulgate the university-industry nexus as a platform for learning*, and *Learning of soft skills (decision-making, management skills, communicative skills in multidisciplinary teams, etc.)*
In such collaborative learning activities and knowledge co-creation, the relevant values and goals also impact the social and group-regulated dimensions of the process [9]. The benefits of collaborative and challenge-based learning have been shown to be significant. For instance Vivas and Allada [10] applied case-based (in our vocabulary, challenge-based) in engineering studies by using theme-oriented case studies to the learning situation. Yadav and colleagues [11] found that the conceptual understanding of students that had been involved in challenge-based learning was statistically significantly higher than of students that had participated in content-wise similar but more traditional, mainly lecture-based teaching.

3 Method and process to develop the learning modules

3.1 The aims and methodology of the e-CirP project

The e-CirP project covers three academic years (i.e., 2019-2020, 2020-2021, and 2021-2022). The project aims at developing a course for Master's students, combining different perspectives that are essential in facing a multidisciplinary area such as CE. In specific, the project amalgamates the following perspectives: i) mechanical engineering and product design, ii) environmental engineering and sustainability assessment, and iii) business aspects. The partnering university colleagues build the modules with the aim of ensuring that students acquire skills on choice of raw materials and product performance, the company's circular business development, and the circularity of the economy as a whole. During the course, a core activity for the students is working in teams using ChaBL in collaboration with real industry partners.

The methodology applied follows the lines of action research. Based on a literature review concerning action research, Coghlan and Coghlan [12] phrased the 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 consortium authoring this paper is not developing the course and the case study activity following a linear path, rather, 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).

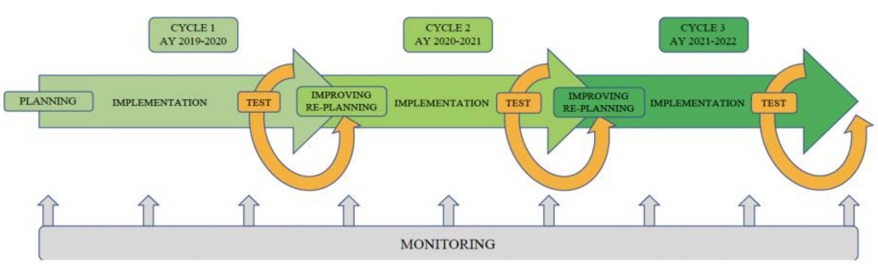

Fig. 1. The action research cycle [13].

A modular training package covering general circular economy aspects, as well as detailed value chain perspectives, was created. Next to the content-related aspects, a great focus was also on the support of the development of so-called soft skills, which took place through international student cooperation on the challenges and through the pedagogical choices that laid emphasis on co-creation and student activity and agency in formulating the course structure and even content. During the three-year project, three academic terms are covered, where two cycles have already been completed and evaluated.

The intended learning outcomes (ILOs) of the educational modules for LCM express that after completing the modules, the student is able to apply life cycle thinking in the design and optimization of the techno-cycle of products and to understand how CE principles can be connected and integrated in techno-cycle products to address sustainability challenges. A strong emphasis is on students' ability to discern the role and importance of the product design phase for the life cycle of a product and to be able to integrate systematic product design possibilities with circular product design. The students can also apply circular economy principles in systematic material selection by following the rules of the 6 R's (*reduce, rethink, refuse, recycle, reuse, repair*). They learn to analyse the impacts of the decisions made by the product designer and to identify the enablers and drivers of sustainable business around product design. They also learn to rethink products, services, underlying processes and business models from the perspective of different actors in the value chain and product life cycle.

For the pedagogical development and evaluation of the learning environment, a scale tool for measuring affordances was created and tested. Affordances are the properties "of the environment… what it offers the animal, what it provides or furnishes, either for good or ill", and they provide action possibilities for the user [14, 15]. The tool that was created includes the volitive (conative), cognitive and affective dimensions of affordances [14, 15, 16, 17, 18, 19], an integrative approach that has, to our knowledge, not been undertaken in education before. The scale incorporates items (on a Likert scale) such as the following.

- **Supporting self-directed learning**: "During the course I have been offered possibilities... *to realise how the content of the course is useful for my future career… for tasks or assignments that have aroused my interest to study the topic further"*
- **Supporting collaborative learning**: "During the course I have been offered possibilities… *to coach others in tasks and assignments… to get timely feedback from a teacher and/or peers"*

In addition, the tool includes questions/statement related to the course overall (the assignments and tasks and the student experiences regarding the content and processes, such as 'It was clear to me what I was expected to learn in the course/module' and 'The exercises and solving challenges deepened my understanding of the theories and topics taught', as well as open-ended questions for improvements and general feedforward. The items in the three affordances scales (volitive, cognitive and affective) were formulated based on myriads of previous research on affordances, both observational and other approaches [cf. 19; 20]

3.2 Engaging students in learning with a feedforward toolkit – Innoduel

Gathering student feedback in a constant manner was chosen as a student-centric approach to promote student participation and agency during the courses. The engagement was supported by a digital tool (https://www.innoduel.com/en/) that enables quick and anonymous feed forward collection and ranking the participant submissions in order to create a holistic picture of the concerns and wishes that the students have. The method (trigger question/task – data submission – pairwise comparison – automatic creation of a ranking list) is optimally used at the very beginning, mid-term and end of the course. Based on the student feedback, the actions were taken or not taken and reasons for actions were openly shared with students. The method enables both face-to-face and remote engagement, and decisions can be made at once based on the collective preference list that reflects the group's hopes and challenges.

When used in iterative cycles, the participatory approach becomes part of the co-creative practice that in itself promotes a sense of belonging and agency. Instead of retrospective and non-timely traditional feedback systems, mostly benefiting statistical sampling for the uses of administration, with demonstrably little or no impact on improving teaching and pedagogical practices, the timely feedforward is co-created and provides the participants with a real possibility of bringing forth their experiences and gains and challenges that can be collaboratively solved [cf. 21].

4 Findings

On a practical level, the collaboration offered a notable expansion of the course offer at each university. The courses received very positive feedback from students and companies: the real-life challenges and company collaboration produced authentic learning that integrated and promoted 21st century skills such as communication and management abilities supported by the international cooperation. One of the partially surprising highlights from the student engagement cycles (using Innoduel platform) was the expressed need and interest in developing students' soft skills, as opposed to the more substance and content-driven wish to learn the technical side of circular economy, which was ranked lower than the soft skills.

Students highlighted that they got an overview of evaluating environmentally relevant topics and learned how to carry out practical solutions. They emphasized that by studying in flipped and challenge-based learning modalities, they could study both independently and work in groups to deepen their knowledge and understanding of how to analyse complex environmental issues by utilising life cycle thinking. Students said they found international collaboration with their peers and working with real-life company cases very motivating and inspiring.

Teachers reported experiencing pedagogical support as crucial for them to develop and transform their teaching into flipped learning. Creating videos was the first step in reorganizing teaching so that students can first study and then during lessons the focus can be shifted to active learning, such as discussions and group work.

As for companies, they gained new ideas and solution paths from a fresh point of view. Teachers collaborated more intensely than during their normal teaching, and collegial sharing improved their pedagogical "touch" and increased their interest to develop further their pedagogical skills and teaching.

5 Discussion and conclusions

The challenge-based approach was chosen due to the university-industry nexus collaboration and the authenticity of the challenges. The aim was to create shared learning objects that would support team learning and knowledge co-creation between students coming from different institutions and countries. The student groups were multidisciplinary (engineering, business studies and administration), posing a challenge and a possibility for developing means for promoting sustainable ways of collaboration between members of distributed teams that work in different administrative cultures and different time zones. The universities noticed that rather a lot of time should be invested in finding suitable challenges: good alignment between the challenge and the intended learning outcomes was found to be critical for the learning experiences expressed by the students. The integration of computersupported learning tools and environments such as VR, on the other hand, was found to depend on proper guidance and mentoring face to face, which due to travel restrictions was not possible during this project, and due to this shortcoming, the critical nature of shared physical premises and collaboration in producing VR-enhanced learning environments became obvious. Pedagogical support was crucial to enable teachers to develop learning materials, such as videos, and to change the course curriculum according to translated learning. In addition, it became clear that in future projects should set aside more time for pedagogical support at the beginning of the project.

For the third and final cycle (academic year 2021-2022) of the project, the collaborators are in the process of improving the materials and the entire modules and leveraging the experience from the middle cycle the partners will reformulate and redesign the execution of the challenge study module. Additionally, the partners plan and develop an ad hoc Virtual Reality solution that will promote remote interaction and working on a shared learning object between students, teachers, and industry partners. All cycles and improvements are continuously facilitated and pedagogically designed by pedagogical experts, and the work has resulted in a validated, integrative affordances toolkit [19] that is being further improved for use in designing learning modules and learning environments.

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