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Excellence in education requires excellence in collaboration: learning modules in circular economy as platforms for transdisciplinary learning

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Abstract

Circular economy (CE) is drawing attention in the fields of sustainable science and engineering. The aim of the paper is to describe how a consortium of 6 European universities or research institutes (Lappeenranta-Lahti University of Technology, Finland; Delft University of Technology, the Netherlands; Fraunhofer, Germany; Technical University of Denmark; Università degli Studi di Padova, Italy; University of Helsinki, Finland) that build new co-created learning modules in CE based on modern collaborative pedagogical approaches that include flipped learning (Bergman & Sams, 2012). In the modules a feed-forward toolkit for student engagement and participation was applied. The paper also discusses student and teacher experiences and perceived benefits of using the pedagogical engagement approach.

1 Introduction

Circular economy (henceforth, CE) is drawing growing attention in the fields of sustainability science and engineering. CE refers to an approach to economic growth that is in line with sustainable environmental and economic development, and currently promoted by the EU and other governments and businesses globally (Korhonen, Honkasalo & Seppälä, 2018). The basic idea of CE is based on material cycles and reuse of materials. Circular economy provides an alternative, cyclical flow model in an economic system with a promise to reduce negative environmental impacts and further stimulate new businesses (Korhonen, Honkasalo & Seppälä, 2018). In their systematic literature review, Prieto-Sandoval, Jaca and Ormazabal (2018) present, based on a close analysis of 162 related article, the following definition of CE (p. 610): "*The circular economy is an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at* *the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions and governments) levels. Attaining this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces and consumes*."

Sustainable development was originally defined briefly by the Brundtland Commission as Humanity's "ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Later, sustainable learning and education have been defined as referring to the process where learning communities are seen as active agents in promoting sustainable practices (Sandström, Nevgi & Nenonen, 2019).

In engineering sciences and economics, the topics related to CE and sustainable development concern both complex and practical issues that need to be taught and learned. There is a need to address the challenges of CE and sustainable development, being complex and systemic concepts, both from a theoretical and a practical, hands-on point of view, through participation in expert communities (Hakkarainen et al., 2004) for instance in the form of industrial partnerships (Stephenson, Stephenson & Mayes, 2012). For historical reasons, education tends to establish niche competences - and neglects the holistic perspective. For example, the traditional mindset of mechanical engineering education often lacks the far-reaching consequences that material and production process selections as well as product design as a whole have on the entire life cycle of a product. The lecture model of teaching does not support students in learning complex issues or reflecting upon the practice and activity. Furthermore, in the working life, students will meet these challenges, and transdisciplinary learning is called for in order to prepare students to achieve capacities and competencies relevant for working life. These include for instance working in hybrid teams and collaborating with people from a different cultural background.

A consortium of 6 European universities or research institutes (Lappeenranta-Lahti University of Technology, Finland; Delft University of Technology, the Netherlands; Fraunhofer, Germany; Technical University of Denmark; Università degli Studi di Padova, Italy; University of Helsinki, Finland) was established 2019 for a three-year ongoing research and development project (EIT Raw Materials, e-CirP), and a common goal of the consortium is to build new co-created learning modules in CE. The modules share a pedagogical and thematic framing as well as learning at the university-industry nexus through cases provided by companies.

The consortium develops educational modules based on modern collaborative pedagogical approaches that include flipped learning (Bergman & Sams, 2012), cooperative learning (Foldnes, 2016) and service learning (Stephenson, Stephenson & Mayes, 2012). The aligned educational modules are provided on a common platform where the students can access the learning materials produced as part of the project. These include introductory and explanatory videos, scientific papers and encouragement for reflections before meetings with instructor and doing hands-on learning in the industrial cases.

1.1 Aims

In the paper we describe the project and the consortium, how the work packages were framed and what was considered important by the collaborating universities. In the core there is circular economy and sustainable development and the need for the creation of educational modules of CE among European universities. The paper discusses a toolkit for producing student engagement through participation in the framing of the course and its practices.

Circular economy and circular product design are rising in the EU and national agenda, but in practice, there is still a gap in implementation. Especially small and medium sized enterprises lack the resources and expertise to adapt life cycle responsible design in their business. Larger companies may have implemented already the reductionist approach through eco-efficiency, but disregarding the holistic sustainability, detrimental rebound effects may occur (Bocken et al 2014; Dyllick and Hockerts 2002; Kasurinen 2017; Korhonen and Seager 2008).

Material selection is often executed in hands-on manner without an integrated optimization process with relevant product and production engineering aspects (Kaspar et al. 2016). On the other hand, an environmental engineer can assess the overall result of the product's environmental performance. However, s/he would benefit from understanding the properties of materials as well as requirements of manufacturing processes in order to have an actual say on the product design phase. Moreover, for a successful change into sustainable business model in the product design phase these two approaches are not enough. Support is also needed from the business and industrial engineering educators.

Circular and sustainable product design requires new business models and concepts as well as value creation both in the context of creating better value for customers and shareholders. In addition, emerging concepts such as frugal innovation, "an ability to do more with less by creating more business and social value while minimising the use of resources such as energy, capital and time" (Radjou and Prabhu, 2014), need to be conveyed not only for use of academia but industry too. 'A holistic rethinking of products, services, underlying processes and business models so that companies can squeeze costs and expand the customer base, business and profit' (Jagati, 2011) is needed within Europe. Not only in Eastern Europe but also in developed economies, and this demand is likely to increase in future, as a result of socioeconomic and demographic change and increasing resource constraints. Moreover, lacklustre growth, aging population, environmental constraints and growing demand for sustainability are some of the reasons that create pressure for more frugal models of production and consumption in the developed world (Bound and Thornton, 2012). In addition, entrepreneurship is to be covered in a sense that the students would gain insights of the requirements of product design in a new business, and thus be more prepared as possible future entrepreneurs.

Besides the importance of developing the content of the courses delivered by this project, it is just as important to become aware of emerging technological solutions that can improve learning and lifelong learning markedly. Flipped classroom (Bergman and Sams, 2008; Kim et al., 2014) offers new ways to implement authentic and current topics for learning and teaching purposes, and gives the learner the possibility to study more flexibly before lectures. Combined with Virtual Reality (VR) solutions, for instance, the approach can help in educating employees, teachers and students alike, and in more engaging ways. Real-world objects and applications can be approached using e.g. VR in ways that bring them closer to each other despite geographical distance. Also, VR is more accessible than ever when the price sweet point will most probably be reached in the near future, making it easy to attain and maintain. Nonetheless, VR in itself is not the only way forward, but instead, better content is needed, including real-life enterprise cases and student-centred pedagogical approaches.

Accordingly, this project aims to combine these three viewpoints, 1) mechanical engineering and product design, 2) environmental engineering and sustainability assessment, and 3) business aspects in education modules - complemented with genuine industrial cases. The industrial cases will address the right level of complexity in education and enforce the system perspective and life cycle thinking. In addition, the companies will have an advantage when students address their cases from multiple perspectives. These viewpoints are passed on to students using novel teaching methods and techniques. The pedagogical innovations will be developed and trialled in parallel to combine the viewpoints of students and teachers who co-create learning experiences together when working on the industrial cases with help of e.g. Virtual Reality environments. The education modules will act as testing platforms for new ways of learning for both the students and the teachers.

2 Consortium and work packages

The consortium has seven partners from different parts of Europe representing the three knowledge triangles. The LUT University, TU Delft, DTU, University of Padova and University of Helsinki represent the academia, and their Master students are being targeted in this education development. Fraunhofer as a research institute offers an application-oriented approach to education, and in addition, enhances a course at University of Stuttgart. Outotec, a process technology and service provider in the field of metals and mining, complements the group by providing industrial insight and quality assurance, to ensure the students are gaining abilities required in today's working life. The project is financed by EIT Raw Materials, a Knowledge and Innovation Community under EIT, focusing on the raw material sector worldwide.

The length of the project is three years (2019-2021). In the first year, the learning outcomes of the five education modules were set, and education materials and teaching and learning practices were designed and created accordingly. Five courses were piloted in different campuses around Europe starting in the autumn semester 2019.

In 2020 and 2021, more education material is created, and student co-operation across different universities is initiated. The students will work on a real-life challenge (the learning object) from a case company, to optimize or improve the circular economy of a product or a service. On one hand this will teach the students to cooperate in a multidisciplinary team and recognize the value of different points of view contributing to a solution, while on the other hand the companies will benefit from the insights that are generated from this broad overall perspective. In these two final years of the project, we will also explore the possibilities that virtual reality (VR) can offer in supporting education and collaboration on shared learning objects between the countries, especially in the field of circular economy.

The project is divided into eight work packages (WP). Each WP is led by a partner with special expertise on that topic. The topics were formulated in order to cover the key points in optimizing the technical cycles in the framework of circular economy. LUT as the project coordinator is responsible of project management (WP1). Another overarching WP, the second one lead by University of Helsinki, ensures that high quality and novel teaching methods are implemented throughout the following six education modules. The education modules are presented in Table 1.

Table 1. Education modules of the project

Education module name	**Lead partner**	**Main content**
WP3: Circular Economy	University of Padova	Analyzing several concepts related to circular economy with a focus on companies' sustainability capabilities and strategies, and supplier management

WP4: Product design & Material selection & Production methods	LUT University	Optimizing sustainable production process focusing on material selection, product design and related production methods
WP5: New Business models & Innovation approach	LUT University	Integrating circular economy into the management of strategy, innovations and business models
WP6: Value chain optimization	Fraunhofer	Optimizing value chains in a global and local scale while aiming to close the material loops.
WP7: Assessment	DTU	Introducing quantitative sustainability assessment methods for supporting decision-making and development of sustainable technology with regard to circular product design and optimization
WP8: Case development	TU Delft	Co-creating and solving case studies with industry based on their actual challenges, such as selecting raw materials, production technologies, optimizing life time of a product, optimizing environmental impacts and increasing circularity.

3 Student engagement: active learning and participation

Following the lines of Kolb (1984), we take it that experiential learning, as in the educational modules here developed, is a process rather than an outcome. It takes place when instructors allow the students to participate through their unique concerns and thus promote learning and adaptation. The leading, radical principle in developing the educational modules is the change from describing learning objectives to student engagement.

Student engagement has been extensively studied since the seminal work of Alexander Astin's student involvement (1984). In his theory of student involvement, Astin emphasized students' active participation in the learning process, and stated that educators need to focus more on what a student does than what are the content, books, materials, teaching techniques and other resources of teaching. The construct of student involvement implies not only the psychological state of a student, but also the behavioral manifestation of the state, possible to be observed and studied (Astin, 1984). A sound body of research has identified a robust correlation between student engagement and positive student achievement such as persistence, academic achievement, and learning outcomes (e.g. Tinto, 1975; 1993; 2007; Pascarella and Terenzini, 2005).

During the past 20-30 years, researchers and professionals have produced a significant body of research pointing to the fact that student engagement is strongly supported by active learning (e.g. Aksit, Niemi & Nevgi, 2016; Nevgi, Virtanen & Niemi, 2006). Since 2012, the flipped format in courses of engineering education became popular (Karabulut-Ilgu, Cherrez & Jahren, 2018).

In teaching engineering sciences, educators are unanimous that engaging students to study complex problems and projects results in better understanding and learning (Lombardi & Oblinger, 2007). However, they prefer lecturing, seeing it as the best way to deliver theoretical and background information necessary for students to solve engineering problems (Bishop & Verleger, 2013a; 2013b). However, converting traditional lectures in flipped format requires quite a huge amount of investments and efforts from educators and instructors.

4 Toolkit to support student engagement and interactive participation

In the modules a feed-forward toolkit for student engagement and participation was applied. This was done to overcome the problems and biases that are found in most retrospective traditional feedback and student evaluations of teaching effectiveness - a challenge identified for decades (Kemp & Kumar, 1990; Emery, Kramer & Tian, 2003; Boring, Ottoboni & Stark, 2016). The toolkit's tenet is the timely and immediately beneficial participant engagement that affects the course content, the approaches used and potentially also the assessment criteria. The tool is a browser-based solution and it is based on close-to-zero effort participation through submission of ideas, concerns and questions, followed by pairwise comparisons of the submissions. The immediate outcome is a ranking list of participant submissions, made by the participants themselves, and it can be used immediately after the pairwise comparisons to discuss student ideas and concerns and co-design the learning module.

Through a systematic, anonymous collection and implementation of participant concerns and ideas, the learning module can be authentically co-created. We use participant experiences and concerns as the key in developing relevance in terms of skills for work life.

Data and analyses

The data consist of documents of different CE modules and students' responses using a feed forward toolkit and teacher reflection on the benefits of using the tool. Participant feedback was collected by individual and group interviews and by a feed forward toolkit. The toolkit - a browser-based solution - is based on close-to-zero effort participation followed by pairwise comparisons of the submitted participant ideas, concerns, questions etc. The pairwise comparison results in a "voting" or ranking result that can be used for a joint discussion in class. Ideally, the collection is done in 3 cycles: 0-10 % of the course, then at 49 % and eventually, at the end to collect a set of ideas, improvements and feed forward for next students taking the course. The collection is GDPR compliant (anonymous; no record of users is collected or archived). The engagement results were analysed using qualitative content analysis and semantic classification. First, a four-fold table was used to classify the participant submissions along dimensions theory (of CE, sustainability ⟺ practices/skills on the x-axis and curriculum ⇕ working life on the y-axis.

An abductive turn in the collaborative researcher effort resulted in the following analysis diamond, whose dimensions represent the ones found in the student expressions and that work on the facets of the diamond (moving e.g. from expectations related to curriculum/assessment and being coupled with reflections regarding future CE competencies needed in working life (Fig. 1).

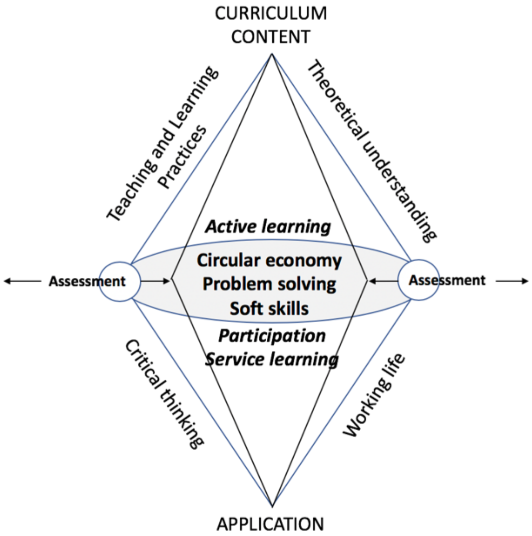

Figure 1. Analysis diamond with facets representing dimensions found in the data.

5 Findings

Expected outcomes include the stepping stones on how to build in co-operation education modules that serve the needs of various universities teaching circular economy for students with different disciplines and backgrounds. During one of the courses, several student concerns that ranked high after the submission–ranking regarded the pilot nature of the course and the curricular setting, the workload and its relation to the ECTS granted for taking the course. These were content-related worries. Another dimension found ranking high was the relationship of learning theory and the ability to later apply the things in working life and when applying CE strategies in organisations.

Also, the students seemed to have pre-knowledge about methods used in CE and assessment of CE (e.g. LCA) and were concerned about learning to use the tools in improving CE in a company. The students also called for quizzes and *formative* (feed forward, supportive) assessment during the modules. They also wanted field visits to industries applying CE, and hoped for interactive tasks during lectures. In addition, as the modules are part of a research and development network, the students expressed a wish to be able to collaborate with others from different universities, mentioning e.g. the use of Virtual Reality to make sharing the learning objectives more concrete.

One of the most unexpected results was the obvious expectation to learn soft skills and working in groups when attending a learning module in CE. This relates to the dimension of working life/application.

6 Discussion

6.1 General

Engaging the learners right from the beginning of the learning module showed to be an engaging approach: the students felt engagement through the opportunity to do "learning crafting" and participating in e.g. the formative assessment practices during the course. This kind of engagement has been shown to have a strong correlation with student achievement (e.g. persistence and learning outcomes; Pascarella and Terenzini, 1991; Tinto, 2007). According to the teachers, the student engagement practices changed their courses for the better. This was partially due to creating a safe space and sense of belonging in the students. The engagement gave the teachers the ability to make visible that some of the concerns can be solved by immediate adjustments to the course arrangements. In the deeper interviews, we expect to find out more about the pedagogical implications and connections with active and flipped learning that this engagement approach can produce in curricular work, student engagement and eventually also academic achievement.

Virtual Realities are being planned to be applied when students from different countries go on the same learning modules simultaneously, sharing learning objectives and working on conceptual and material artifacts (Hakkarainen et al., 2004), essential for the real-life cases provided by collaborating industries. The developing pedagogical approach can also lead to identifying implicit new student expectations, central to working life competencies, such as soft skills as in this case.

6.2 Educational implications

The student engagement has several practical implications for education. First, it obviously gives the teacher a quick and close-to-zero way of understanding the concerns with which the students come to take a course. Solving at least some of the most salient concerns and communicating about it to the students can relieve the stress and uncertainty, factors that hinder deep learning and engagement. Second, the mere act of engaging the students in discussing the course contents and possibly also making them agents in laying out the criteria for student assessment has positive impacts on student interest and well-being (see e.g. Tinto, 2007). Third, group discussions based on anonymous submission of concern or ideas makes it possible to do evidence-based decision-making in a participatory manner, thus supporting a sense of belonging and respect created by communal practices and engagement in affecting what is learnt and how.

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