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Circular Economy in Integrated Product and Production Development Education

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Abstract

Global operations are accelerating the diffusion of technology and the pace of innovation. The increased demand for ICT and problem-solving skills requires new methods and tools to support continuous learning paradigm. The emergence of circular economy (CE) paradigm is demanding the companies to change and take broader role in the value chain. Within these new value-chains, the manufacturer plays central role re-designing products for multiple uses and proposing new consumption patterns to customers through innovative services covering the current and future life-cycles of the product. This new level of complexity and interconnection puts a pressure to the education system, which traditionally is highly focused on its own priority areas. The paper will present an approach to speed uptake of CE business potential by introducing an education module created in collaboration with industry and academia to support the creation of new talents in the field of manufacturing industry.

Keywords: Circular Economy, Education, Sustainable Production, Product development

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1. Introduction

The development of a talented workforce and trustful collaborative relationships with stakeholders, as well as a powerful technological and industrial base, are essential to address the challenges ahead and achieve high levels of employment and social cohesion, boosting at the same time innovativeness and competitiveness (So Smart, D4.2, 2015). The population in the western countries is growing older and living longer and the profound effect this will have on societal development. The careers are expected to be longer and more versatile. The re-learning cycle has become shorter and shorter. Meanwhile, the EU's workforce is forecast to become smaller and older, but better qualified. The younger generation is the most highly qualified in Europe's history (Cedefop, 2015). Globally a surplus of low-skilled workers and a potential shortage of high-skilled ones is expected in near future (Eurostat, employment, 2017). The share of labour force with high-level qualifications should rise from 31.2% in 2013 to around 38% in 2025. People with medium-level qualifications will also increase slightly from 47.3% in 2013 to around 48% in 2025. The share of those with low-level qualifications will fall from 21.5% in 2013, to below 14 % by 2025 (Cedefop, 2015, European Commission, 2014).

In recent years, analysis on employees' wellbeing highlights that increasingly individual have to deal with different objectives, desires, expectations and responsibilities, which can be clustered in two main categories of work and life. The rapidly advancing technological landscape in the European workplaces is challenging adults' problem-solving skills. Workers with vocational education and training need flexible abilities to solve problems in technology-rich work settings (Hämäläinen et al, 2015). Similarly, OECD policy frameworks' cornerstones for developing a suitably skilled workforce are defined such as 1) broad availability of good-quality education as a foundation for future training, 2) a close matching of skills supply to the needs of enterprises and labour markets, 3) enabling workers and enterprises to adjust to changes in technology and markets, and 4) and anticipating and preparing for the needs of the future skills (International Labour Office, 2011).

Recently, circular economy has received increasing attention worldwide with the intention to overcome the current production and consumption model based on continuous growth and increasing resource throughput (Ghisellini et al, 2016). Based on the review by Ghisellini et al (2016) there exist different definitions for circular economy tracing back to the 60's. From the economic viewpoint the circular economy can be defined as the economy based on a spiral-loop system that minimizes matter, energy-flow and environmental deterioration without restricting economic growth or social and technical progress" (Stahel, 1982). Within these new value-chains, the manufacturer plays the central role re-designing products for multiple uses and proposing new consumption patterns to customers through innovative services covering the whole life-cycle of the product. This approach makes it possible for manufacturers to gather value and materials from post-use products, increase resource efficiency, reduce energy consumption and emissions, also reducing manufacturing costs and providing more affordable products to a large set of customers in emerging countries.

The emergence of circular economy paradigm is demanding the companies to change and take broader role in the value chain. This also puts a pressure to the education system, which traditionally are highly focused on own priority areas. In order to provide solutions for the future skills requirement, a versatile learning environment is required. It provides a platform for teaching demanding engineering skills to university level students. The main educational challenge is to combine the theoretical knowledge with industrial practices (Toivonen et al, 2018). The paper will present an approach to speed uptake of circular economy business opportunities by introducing a new study module of circular economy created in collaboration with industry and academia to support the creation of new talents in the field of manufacturing industry. The focus of the paper is to introduce two courses from the study module focusing on product and production development.

2. Underlying assumptions, Research Methods and Material

Akkerman & Bakker (2011) introduced the elements for learning, these elements considered boundary crossing, problem solving, reflection and coordination. Wallin et al (2018) focused on expert learning by defining four key dimensions. These elements consisted four dimensions 1) problem solving, 2) reflection, 3) learning from errors, and 4) boundary crossing. On the center of these dimensions are knowledge transformation and integration. Lanz et al

(2018) modified the underlying assumptions further to consider especially technology rich environments. On this paper the key dimensions with their contents are defined as following:

- **Problem-solving:** Introducing non-routine and practical problems, challenging to solve problems collaboratively, encouraging learners to acknowledge and solve professional identity issues,
- **Self-Reflection:** stimulating critical reflection on learning and experiences, encouraging reconstruction of the meaning of experiences, promoting responsive guidance through mentoring, learning to value experience (even negative ones)
- **Learning from errors:** helping learners to resolve tensions and develop flexible imaging to overcome the challenge, promoting critical thinking help to identify flaws in mental models, promoting critical dialogue through collaboration and mentoring, coming to realize and explicate differences between practices and thus to learn something new about their own and others' practices
- **Boundary crossing:** developing learner identity (where we are) and adaptation (what we can become), creating multiple opportunities for participatory learning, targeted interaction between different disciplines, legitimating coexistence, explicating cyclical expertise development process between work and academic contexts,

3. Approach to circular economy teaching

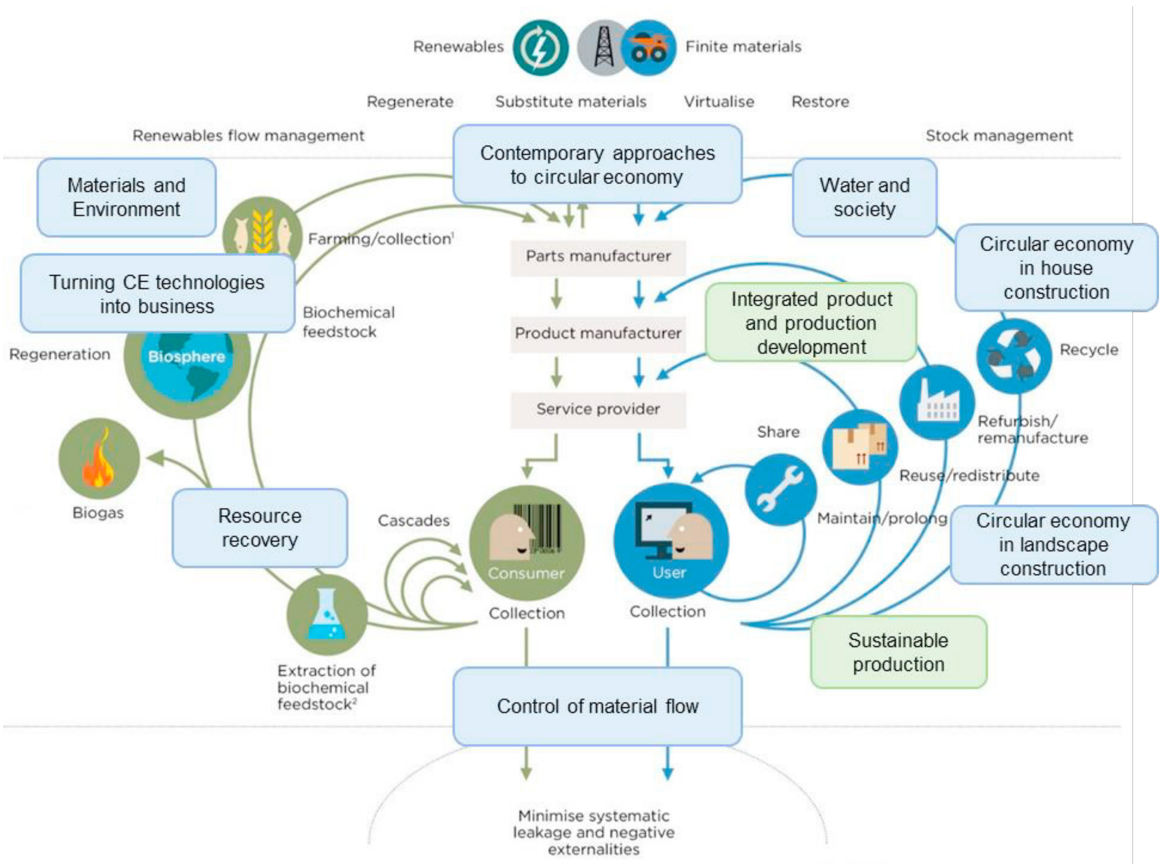

Fig. 1. Organization of study module of circular economy (modified from MacArthur, 2017).

Five laboratories at Tampere University of Technology formed a new study module of circular economy. These laboratories formed a wide interdisciplinary wholeness with technical and commercial viewpoints to the teaching of circular economy. The overview of the study module is presented in Figure 1. The courses serve several disciplines of research and branches of industry and offer many possibilities for the students to choose. The education module development is steered by industrial board that comprises experts from different fields of technology, thus contributing to the boundary crossing. The teaching is based on current research topics in the university as well as on many research projects that cover the aspects of circular economy. Therefore, the study module offers latest findings from the research and the findings are transferred into the knowledge of the students. The knowledge is then transferred into the industrial companies, where most of the students will work often already during their studies. This serves the main reason for the new study module i.e. the need of new know-how in the area of circular economy to collaborate with business life. Once finished, the developed circular economy module will be offered for industry as non-formal education module for life-long learning purposes.

The courses are organized by the laboratories of Mechanical Engineering and Industrial Systems, Chemistry and Bioengineering, Civil Engineering, Industrial and Information Management as well as Materials Science, totally contributing to 50 credit units of Master of Science (MSc) level education. Students can freely choose a combination that suits their interests. In this paper two of the courses, which are organized by the laboratory of Mechanical Engineering and Industrial Systems, are presented in the following cases. These have been organized first time at the spring of 2018 with the topic of circular economy included into the courses.

3.1. Case 1: Integrated product and production development

Integrated product and production development course (IPPD) teaches students Japanese approach, where product development, supply chain management and manufacturing are managed as one integral and organically linked entity. The main principles of Lean-approach and Toyota Production Systems are taught, but the focus is on the information flow. According the ideas of Fujimoto (1999, 2007) creation of the product starts with intention and there should be continuous information flow from concepts, designs, material procurement, manufacturing and assembly to perfect product delivered to customer. The education development combines theories of dispositional mechanisms (Olesen, 1992) of value creation in design and production.

The original IPPD-course did not include ideas of circular economy. The principles of circular economy could be built on the information flow model with surprising ease. Lean thinking is in many cases naturally directing the development towards sustainable solutions. The aim of circular economy to keep products, components and materials at their highest utility and value at all times is in line with Lean thinking. Modelling the information flow and dispositional value creating mechanisms in design, manufacturing and product life cycle, is capable of explaining the working of circular economics in product specific and very detailed level that is required to support the design decisions made in early phase in the product development.

After discovering the good balance between the old approach and new possibilities circular economy technical cycles, a pedagogical decision was made, that instead of giving the students a ready-made circular economy business model, they were challenged to design and innovate their own version of circular economy business models presented earlier in scientific papers. In this approach the students are given two scientific papers. First of these papers is research of the opportunities in re-using materials, components, assemblies (modules) in refrigerators done by Umeda (2000). The second paper is similar research of smartphones by Schissche et al, (2016). Both papers consider their topics from product design viewpoint. Those contributions propose similar circular business models. The students are then asked to define their specific business model, which suits best to theirs exercise topic. During the course the students are asked to consider, how difficult it would for a company to change their new business model and do they expect that the company would face resistance from their customers and from the society. It was pointed out to the students, that first paper has been published over 18 years ago. This gives a good starting point for discussion how scientific knowledge is often developing much faster than human societies are able to absorb or utilize it.

During the course, the students will make a detailed information flow model of the real product. Exercise is made in small groups and the students are assessed according the quality of their exercise work. The exercise is based on real business case of building new buses, with recycled axles, gearboxes and engines. The bus manufacturing company in this case is an old partner of our university and we are able to give students very detailed, authentic engineering data. The exercise is however not a real case as the production facility the students are expected to use, is bus a body factory owned by Volvo and located in Sweden. The business case, the product and the factory are all real, but their combination exists only in the exercise performed in the course.

The exercise aims to train especially the problem-solving, self-reflection and learning from errors perspectives. The problem-solving arises, as the students need to design a new business model with minimal constraints set in advance. The students learn from their errors based on the feedback they get during the course as well as learning from other groups by evaluating their solutions. The evaluation of the solutions of the other groups serves also for the self-reflection.

The student feedback from this course shows that this course is challenging and very rewarding. Students who pass this course are often given very good grades and their feedback is normally very positive. During the last learning session students were asked how they perceived their learning regarding the opportunities of circular economy for product development. On scale 1-5, 5 being the highest score, one student self-assessed score 3 and 43 students score 4. The course is however demanding.

3.2. Case 2: Sustainable Production

The course *sustainable production* focuses on sustainable development from the viewpoint of Finnish mechanical engineering industry. This is typically discrete part manufacturing including their part manufacturing and product assemblies. The core content of the course consists of the following:

- Social, technological, economic, environmental and political (STEEP) change drivers of sustainability
- Efficiency and effectiveness of operations of production systems
- Changeability in production systems
- Cross cutting theme of circular economy supporting the above

The change drivers explain the main pillars of sustainable development i.e. social, economic and environmental. Technological and political aspects are included to emphasize the industrial viewpoint of the change drivers. The topics of efficiency and effectiveness are gone through mainly introducing principles of lean manufacturing. This viewpoint focuses on improving the current manufacturing activities while the perspective of changeability is more concerned of the future of the production system. The learning events focusing on circular economy include the following:

- Introductory lecture of circular economy
- Workshop on challenges and opportunities of circular economy
- Lecture of energy efficiency on production systems
- Several lectures of closed-loop material flow and remanufacturing
- Simulation exercises including an exercise of closed-loop material flow

The lectures start with an introduction to circular economy as no prerequisites are required on the subject. The workshop is arranged after the introductory lecture and it serves to gather what the students know about and understand with the term circular economy. As the course focus is on mechanical engineering industry, other lectures focus on manufacturing related topics of circular economy. Some of the sub-topics of these lectures are based on the workshop on circular economy to bring out issues that the students know least.

The simulation exercise was built on discrete-event simulation software. It presents a closed-loop material flow of technical materials, see Figure 2. The exercise demonstrates the end-of-life options i.e. maintaining and reusing products as well as remanufacturing of products and manufacturing of needed spare parts. The input variables for different scenarios are the flow between the three options of maintenance, reuse, and remanufacturing. These are defined with percentage values of the probability of the three options. Other input variables are how many cycles a product can have before the product is disposed. In addition, the demand of remanufactured products can be set from zero to 100. The demand has an effect on how many new products are produced. The simulation model behaves in the way that the demand of remanufactured products reduces the need to produce products from virgin materials.

The simulation exercise is a simplified from a real situation as it is intended to be completed within a two-hour session. Figure 2 presents two example results from the simulation exercise. In the first example, the number of manufactured parts is divided into parts for new products and replacement parts for remanufactured products when the original part cannot be used. The variation of the number of replacement parts demonstrates that some type of parts are replaced more often than others. The second example illustrates the number of new products manufactured in two situations. The situations differ in the percentage of products that are remanufactured, that is 20% and 80%. The higher percentage of remanufacturing reduces the need to manufacture new products.

Fig. 2. The principle of the closed-loop material flow simulation exercise and example results.

From the elements for learning, discussed earlier, the main learning experiences of the course focus on problem-solving, learning from errors, and self-reflection. The simulation exercises include an initial state and several goals to be completed. They are by nature problem-solving cases that are solved as trial-and-error, where learning from errors advances the exercises. The students need to understand why the goals are not achieved and find alternative solutions to progress with the exercises. The exercises include also short written reports that are returned when the exercises are completed. The self-reflection comes up, as the students are required to return written reports of the exercises. The reports include, not only describing the results, but also how the results were achieved and what kind of decisions were made. The boundary crossing is still somewhat in the side but will be considered more in future.

This course covers a wide area of topics in the area of sustainable production. Based on the feedback, most of the students assumed beforehand that the course would cover mostly environmental issues. After the course, they have an understanding that sustainability in the area of production covers also many other topics. Circular economy, on the other hand, was a new term to most of the students. As many topics of circular economy have been existing before, the students found both familiar and new topics presented in the course. The students felt the atmosphere on the course very positive, which increased their motivation to learn the topics.

4. Conclusions

The courses presented in the case studies included topics of circular economy in the presented scope for the first time. The general feedback from both courses was positive and the knowledge of the students in the area of circular economy broadened. The feedback included also constructive comments that will help to develop the courses. The course *Sustainable Production* is intended to bachelor level students while the participants of the *Integrated Product and Production Development* course are mainly master level students. Therefore, how the courses complement each other, cannot be comprehensively evaluated based on their first implementations.

Some of the courses in the new study module of circular economy have not been piloted yet. Consequently, the evaluation of how the two courses presented in this paper fit to the study module can only be assessed after all of the courses have been piloted. This requires also feedback from students that have been attending several of the available courses. Industrial collaboration has insured the long-term relevancy of the learning methods. This support is important for both the development of the technical side and the focus areas of the exercises. The latest development opens new ways of leveraging the existing learning modules and system in education and in industrial use.

The future work of the courses will be based on the student feedback already mentioned. In addition, the future work includes normal enhancement of the study material as well as the reflections of the teachers of the courses. From the viewpoint of the whole study module, possible overlapping issues between the courses will be investigated. At this point, it is unknown, how much the number of participating students of the courses will increase. This issue may also affect to the future implementations of the courses.

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