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EXPERIENCES FROM TEACHING CIRCULAR ECONOMY CONCEPTS TO ENGINEERING STUDENTS

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ABSTRACT
For several years, a mandatory bachelor-level course at the University of Agder (UIA) has been educating engineering students on a range of topics and ideas related to system thinking, ethics, and sustainability including circular economy. This paper investigates the learning outcomes of engineering students in this course by evaluating their knowledge of circular economy before and after attending this course to determine if current methods for teaching circular economy are effective for educating future engineers. Active learning and problem-based learning are the two primary learning techniques used in this course and students are evaluated based on their overall application of circular economy principles in group projects. The learning outcomes of the course have been evaluated based on a set of surveys given to students before and after the course to determine to what extent they have had prior knowledge of circular economy principles and how these students believe that knowledge gained in the course can be used to support regenerative and sustainable transformations in their future working life. The survey results show that engineering students have weak prior knowledge of circular economy concepts but that engineers are both enthusiastic towards sustainability issues and understand their importance. The results of this paper show that there is a need to improve circular economy education for engineers.

Keywords: Circular economy, systems thinking, sustainable engineering

1 INTRODUCTION
The need for circular economy teaching in education follows in line with the increased societal focus on circular economy as an international response to environmental damage. Circular economy has three main overarching goals: slowing resource loops (by extending product lifetime and introducing comprehensive systems for managing materials), eliminating waste and pollution in production, and regenerating nature [1]. Achieving a circular economy has thus far involved setting out strategies for change and developing policies that push society towards a consensus on a circular economy framework [2]. The European Green Deal and the series of the European Circular Economy Action plans [3, 4] have shown that the push for circular economy is well rooted in European policy. The challenge for educators is to translate important circular economy concepts and policies into the classroom so that future generations can contribute toward a circular society.
Circular economy concepts have been implemented in education using games in the classroom [5, 6, 7], through eco-design and sustainable product design [8, 9, 10], through project-based learning [9, 11, 12], and through active learning approaches [13,14]. Large emphasis has been placed on life cycle thinking and systems thinking [5, 12] and multidisciplinary approaches towards circular economy are emphasized in existing course structures [15]. However, the teaching of circular economy concepts is neither extensive nor informative enough to create transformational societal change [6] and that previous knowledge on circular economy topics is not widespread among engineering students [16, 17].
For the past several years, the mandatory third-year bachelor-level course ING200 at the University of Agder has been educating engineering students on a range of topics and ideas related to system thinking, sustainability and ethics. The curriculum has been updated in 2021 to teach about the important yet sometimes diffuse concept of circular economy as part of a broader approach towards teaching sustainability to our engineering students. Circular economy is a term that is increasingly used in a sustainability context but is often misunderstood as there are few concrete definitions or guidelines for engineers. The ING200 course has approximately 400 students per year from all engineering

disciplines1 at the University of Agder who learn about basic sustainability and circular economy principles as part of the general course curriculum. It is important to understand to what extent these engineering students have prior knowledge of circular economy concepts to understand better what needs to be taught and how these concepts can be practically applied for future engineers. This paper thus investigates the learning outcomes of students by evaluating their knowledge of circular economy before and after attending ING200 and to determine if current methods for teaching circular economy are effective at educating future engineers towards a circular future.

2 METHODS

2.1 ING200 course content

The course ING200 presents circular economy to engineers with three main principles: system thinking, material loops, and circular design principles. The course covers sustainability and circular economy topics over four separate two-hour lectures by addressing the "why, what and how" of sustainability. The first two-hour lecture covers global environmental trends and foundational knowledge on sustainability (Topic: "*Why sustainability is important*"). Trends such as climate change, biodiversity loss, plastic pollution, and environmental impacts on human life. Foundational knowledge such as the history of the sustainability movement, definitions on sustainability, and frameworks for sustainable development are presented to the students (Topic: "*What it means to be sustainable*"). The second two-hour lecture introduces students to the concept of complex systems thinking, life cycle thinking, and general industrial ecology approaches to sustainability such as eco-efficiency, industrial symbiosis, material flow analysis, and green product design (Topic: "*Technical solutions for sustainability*"). The third two-hour lecture covers life cycle assessment and how to evaluate the environmental impact of systems (Topic: "*Environmental foot printing*"). Finally, the fourth two-hour lecture focuses on circular economy and the green shift. The circular economy topics covered include the basic principles of circular economy from the Ellen Macarthur Foundation [1], the 9Rs of circular economy and material loops [18], and basic circular design principles for engineers [19] before finishing with a critique on circular economy. The overall emphasis is on practical examples of circular economy in action (Topic: "*Circular economy for engineers*").

The students then apply what they have learned through problem-based learning methods to evaluate circular economy, sustainability, and ethics issues on a technology of their choice, preferably a technology that they work with regularly, in a semester project. The semester project challenges students to think about technology in terms of systems, ethics, sustainability, and circular economy. The students are also given access to advisors once per week to discuss their work through active learning methods. The overall learning outcome of the ING200 course is that students learn how to evaluate the sustainability and ethical aspects of technologies as future engineers.

2.2 Survey design

Two surveys were carried out to test the effectiveness and importance of circular economy topics for ING200 students. The first survey was intended to determine their opinions and prior knowledge of circular economy and sustainability topics while the second survey was intended to understand how the students evaluated the importance and application of circular economy topics within their disciplines. The first survey had questions focusing on students' prior knowledge of basic aspects of circular economy (such as material loops and circular design principles) while also evaluating the importance of sustainability for them personally and how they felt that their study programme prioritized sustainability issues. The second survey built on the findings of the first survey and integrated some of the topics covered in the lectures on circular economy to evaluate their importance for the students within each study programme. The questions focused on how the students felt that circular economy and circular design principles were applicable to their respective disciplines and to try to determine their opinions on how society can transition to a circular economy.

2.3 Data collection and analysis

The two surveys were made with the survey tool SurveyXact and were distributed on two different occasions on the Canvas learning platform used in the course. The first survey was distributed to the

[1] Mechatronics, renewable energy, civil constructions, electronics, and ICT/IT

students after the first three two-hour lectures on sustainability but before their lecture on circular economy started. The students had one day to complete the survey, but the lecturer also gave the students time in the classroom before lecture to finish the survey. The first survey had 16 questions in total, with two additional questions given if the students answered "yes" on two qualifying questions. The second survey was distributed two weeks after circular economy topics were covered in lecture. The second survey had 11 questions. Most of the questions were multiple choice questions, while some questions required answers to be given as a free text. The two surveys were compared to see the change between the students' knowledge, opinions and attitudes before and after the lecture on circular economy.

3 RESULTS AND DISCUSSION

Table 1 gives an overview of when the surveys were distributed and closed, and the response rate for each survey.

Table 1. Survey response rates

	Distributed	Closed	Response rate
Survey 1	10-Feb-22	11-Feb-22	25%
Survey 2	25-Feb-22	27-Feb-22	23%

The distribution in gender on the surveys was 73% male and 27% female on Survey 1 and 68% male and 30% female on Survey 2 (2% did not want to answer). The distribution on the students' field of study is shown in Figure 1. This shows that engineering students from all disciplines replied to the surveys.

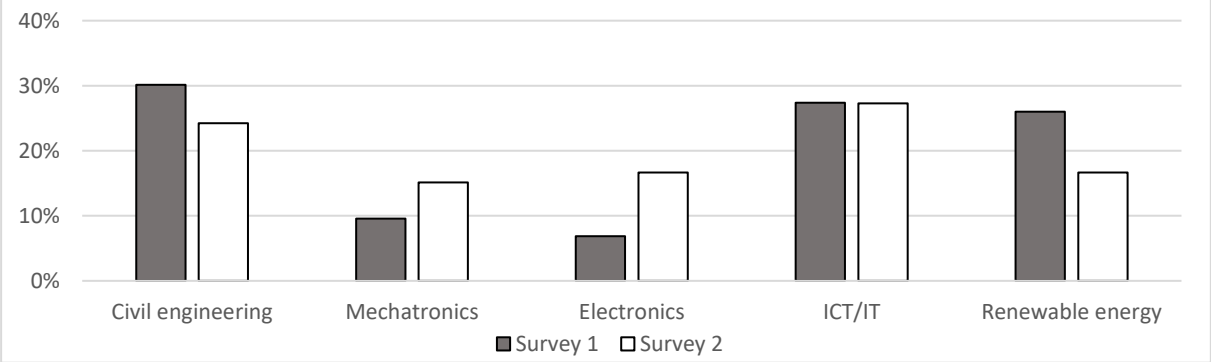

Figure 1. Response rates according to field of study

One of the first questions in the first survey was "*Have you heard of the terms 'linear economy' and 'circular economy' before?"*, where 52% answered that they had heard the terms previously. This indicates that only half of third-year engineering students have heard of the terms linear and circular economy. This was also made clear when asked "*What do you think the term 'circular economy' means?"* as shown in Figure 2. This question required a free-text answer and many of the engineering students answered that circular economy is associated with "money". This changed when students were asked the same question in the survey 2 after receiving lectures on the subject where "reuse" and "waste" were the most common associations. This indicates that many students were not familiar with the term before the circular economy lecture was given but more familiar afterwards.

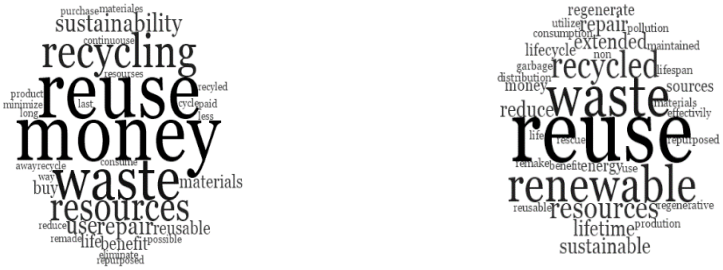

Figure 2. (Left): Word cloud from Survey 1 and (Right) Word cloud from Survey 2 "What do you think the term "circular economy" means?"

When students where asked the question "*How important is sustainability for engineers in your discipline?*" in the first survey, 83% rated it as very important or somewhat important. On the second survey this had a slight increase to 88%. When asked "*How do you feel that sustainability topics are considered in your study programme?*" 70% responded it was somewhat or very much considered on the first survey. On the second survey they were asked how important circular economy topics are in their discipline, where 94% rated it as very important or somewhat important.
The question "*Which of the following sustainable product design principles do you think can be applied in your discipline (mark all that apply)?*" was asked in both surveys with several options for the students to mark. The results from this question are shown in Figure 3 and indicate a consistent decline in all the options from survey 1 to survey 2. This means that the students had a different view on the possibilities within circular economy in their discipline after receiving lectures on this subject. The students have likely learned more about the limitations and challenges regarding circular economy and could have a more cautious view on circular economy based on their answers from the second survey. This could indicate that the understanding of the subject also informed the students about the difficulties or limitations of implementing circular economy in their disciplines.

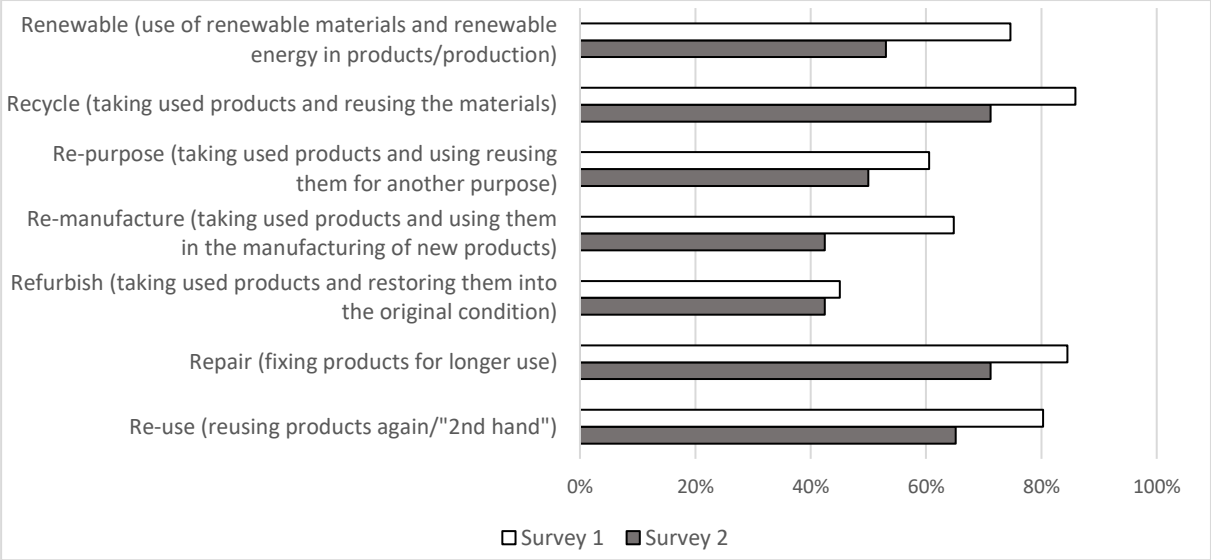

Figure 3. "Which of the following sustainable product design principles do you think can be applied in your discipline (mark all that apply)?"

To get an overview of the students' knowledge on circular economy survey 1 contained questions regarding different circular economy terms. Figure 4 shows the result from these questions, where 73% had never heard of the concepts "*products as services*" and "*dematerialization*", and only 40% had heard of the concept "*regeneration*". On survey 2 these concepts were included, as possible options on the question "*Which of the following sustainable design principles do you think are most relevant in your discipline (mark all that apply)?*". As Figure 5 indicates, many students saw these concepts as sustainable design principles that could be relevant in their discipline. Hence, the students had a better understanding of circular economy and its relevance to their field of study after receiving lectures on this topic. Since 48% had never heard of the terms "linear economy" and "circular economy" before, there is a clear need for teaching these topics in the curriculum for engineers.

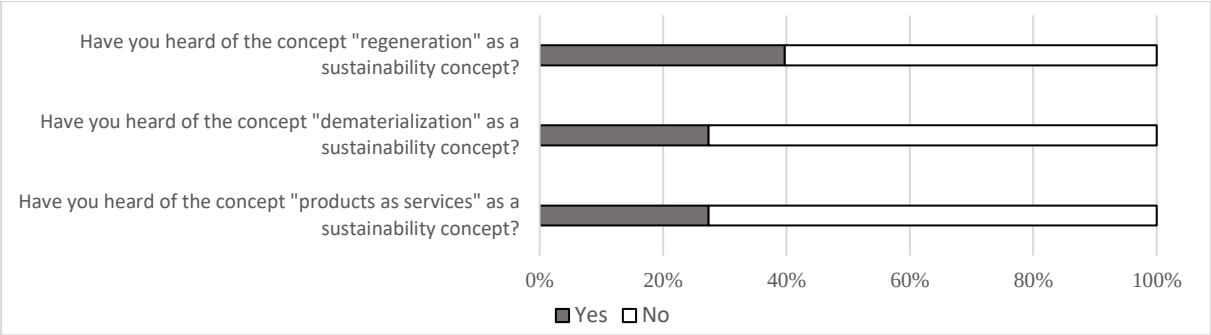

Figure 4. Questions from Survey 1 regarding background knowledge of different terms

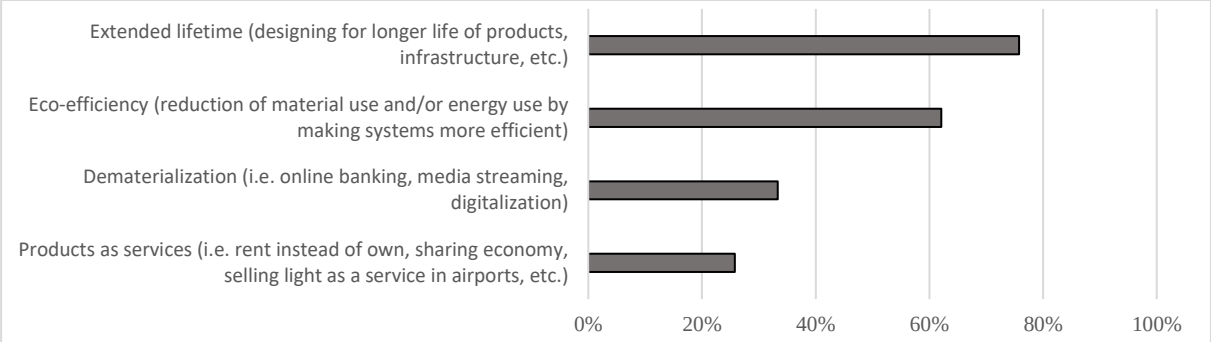

Figure 5. Results from "Which of the following sustainable design principles do you think are most relevant in your discipline (mark all that apply)?" in Survey 2

The results of this study indicate a need for more circular economy teaching in engineering programmes and is consistent with other findings in literature where engineering students are shown to have a low understanding of circular economy topics [6, 17]. This is especially important as results from this survey and previous literature shows that engineering students feel that sustainability is very important to them [5, 13]. Hence it recommended that circular economy topics are taught to engineers in other courses throughout their education. This may be difficult to achieve without training educators and support from educational institutions [16]. It is also important to note that the approach in ING200 is to present foundational knowledge in sustainability before presenting circular economy topics. This is because we consider circular economy and sustainability to be complementary topics to each other as supported by other educators [10]. We also feel that is important to present the transformational nature of circular economy to our engineering students, but that critique of the circular economy concept is necessary in order to not apply the same ideas on existing systems where circular economy will not work [9, 11]. In general, we recommend that engineers are given a discipline focused, practical education in sustainability and circular design topics so that they can use their skills to find transformative circular solutions in the future.

4 CONCLUSIONS

The results of this study show that engineering students do not receive enough training on circular economy topics despite the growing interest in sustainability among engineering students. The results of this paper should be used to show the need for more circular economy curriculum throughout an engineering education if circular economy strategies are to be implemented in wider society. The results of this survey indicate that this need is consistent across different engineering disciplines and that transformational change towards a circular economy will be difficult without greater knowledge of circular economy topics among engineers.

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