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CIRCULAR ECONOMIES: SUSTAINABLE TRANSFORMATION OF WORKSHOP WASTE INTO EDUCATIONAL TOOLS

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ABSTRACT

This study explores the integration of Circular Economy (CE) principles in design education, assessing students' understanding of CE, revealing gaps in knowledge and barriers to practical adoption such as recycling facilities and material identification. Through surveying the student population their understanding of CE and their receptiveness to its principles were measured. By implementing sorting systems, plastic reprocessing, and module alignment the project aims to transform workshop plastic waste into educational tools, fostering material intelligence and encouraging sustainable prototyping practices.

Keywords: Circular economy, design education, product design, experiential learning

1 INTRODUCTION

Ireland is one of the worst offenders in the EU for addressing and recycling plastic waste. It is estimated that of the 53.1 million tons of plastic waste created, only 38% is currently recycled. [1]. Before this project, the university could not reprocess plastic waste internally. Additionally, increasing materials costs and decreasing budgets mean that supporting student learning through physical making is becoming more challenging.

A circular economy (CE) is an economic and systems thinking model with a focus on reducing waste material and energy by promoting the reuse, recycling, and regeneration of resources [2]. This approach contrasts the linear economy used for centuries, approaching resource use with a "take, make, use & dispose" mentality [3] and leading to ongoing resource depletion and significant environmental damage. The central principles of the CE models include designing out waste, keeping products and materials in use, and regenerating natural systems [2]. Core principles are commonly outlined as the "R" principles, with the classic formulation being Reduce, Reuse, Recycle, with Remanufacture added in industrial contexts. In addition, many circular economy frameworks include additional Rs such as Repair, Refurbish, Repurpose and Recover [4].

From a pedagogical perspective, it is imperative that educators support students in understanding principles behind concepts such as CE, the UN Sustainable Development Goals [5], and the Right to Repair [6]. Some work to bring sustainability to the classroom has focused on design strategies [7], exploring values and strategies behind sustainable design, others have explored small design actions, aiming to have a collective impact on issues such as the "plastic soup" of ocean waste [8]. The introduction of case studies can help contextualise the impact of interventions to increase circularity [9], and to begin to align theory with the models outlined in course content, for example, Slowing and Closing resource loop models outlined by Bocken et al [3]. However, as this generation of design and engineering students will be required to apply these concepts, we must embody them and demonstrate applications in our learning environments. This includes the honest engagement about the challenges, limitations and contradictions faced in applying these concepts [10], [11]. By doing so, students become active participants in the circular economy and in finding solutions to the challenges faced.

At the core of Product Design education, students learn through hands-on studio practices, building a deeper understanding of the materials and processes available to them and developing Material Intelligence [12]. This understanding of materials is reached through hands-on experimentation and interaction with materials, building parallel mindsets and skills to those seen in the maker movement [13], [14], [15]. Many of the tools in both makerspaces and design workshops use plastics (3D printing,

laser cutting, thermoforming, foam modelling, etc), and it is easy to see where a conflict or perceived conflict with sustainability principles could arise if practices encourage excessive material waste.
The goal of the circular economies for design workshops project is to reduce the amount of plastic waste going to landfills from our workshop while still supporting the development of Material Intelligence and tacit making skills. It aims to explore the remanufacture of thermoplastic waste into educational artifacts, benefiting students and staff in more sustainable education. By engaging with this project, students and staff are challenged to reflect on how we source and use materials for projects, taking inspiration from work already undertaken in the maker community, adopting open-source tools and applying low-tech approaches to inspire sustainable thinking in an education context [16], [17], [18], [19], [20].
Through active learning, students will develop the necessary skills of plastic waste recycling for industry practices. Students will learn how to repurpose waste materials from laser cutting, thermoforming, and 3D printing. This hands-on approach aims to foster a change in students' attitudes toward recycling and guide them to view recycled plastic as a valuable material resource for the university rather than waste.

2 RESEARCH OBJECTIVES AND METHODS

This research aims to assess Product Design students' understanding of circular economy concepts and their attitudes towards sustainable workshop practices before any interventions were made in their workshop environments. A mixed-methods approach was used, combining multiple-choice, Likert scale, and open-ended questions in a questionnaire. The survey engaged students across all four years of a university programme (n=64), providing an overview of their knowledge and attitudes. The key objectives were to identify gaps in understanding, explore factors influencing sustainable practices, and inform future interventions designed to improve the adoption of circular economy principles within the academic curricula and workshops.

3 STUDENTS UNDERSTANDING AND OPINIONS OF CIRCULAR ECONOMY

After reviewing the survey data, many students were able to identify some aspects of the CE concept, particularly its emphasis on reusing materials, minimising waste, and recycling materials. Responses such as "*A system based on the reuse and recycling of old products in the creation of new ones that can again be put through the cycle*" and "*Everything gets recycled over and over again*" highlight the understanding of circular material flow within the system.
Sustainability was also a common theme, with one response noting that a CE is a "*sustainable structure that reduces waste and carbon footprint by reusing materials*.". While 59% (see *Figure 1*) of students who have previously heard of the CE, and many responses show they lack a deeper understanding of the subject. Students largely overlooked topics such as design for circularity and system thinking. This suggests that students have the correct idea about elements of CE concepts but miss the important aspect of design for CE and system design within the CE concepts. This points to the need for education on systems thinking and practical design aspects related to CE, such as Cradle-to-Cradle design [21] which could have a very positive influence on product design students within the university and industry.
Prototyping within the course is heavily based on an iterative design process that enables students to create high-fidelity prototypes and build Material Intelligence. However, this can lead to substantial waste primarily from plastic materials such as PLA, PETG, and XPS, which poses a significant waste management challenge. Given that students engage in high levels of prototyping across all 4 years of the course, the waste levels could be quite significant. The survey revealed that 70% of students are not aware of the amount of waste generated during the prototyping stages within modules as a whole. The two most prominent issues are that 45% of students prioritise speed and convenience over sustainability and do not have the facilities to use recycled material. However, 92% of students said they would consider using recycled materials if they became available.

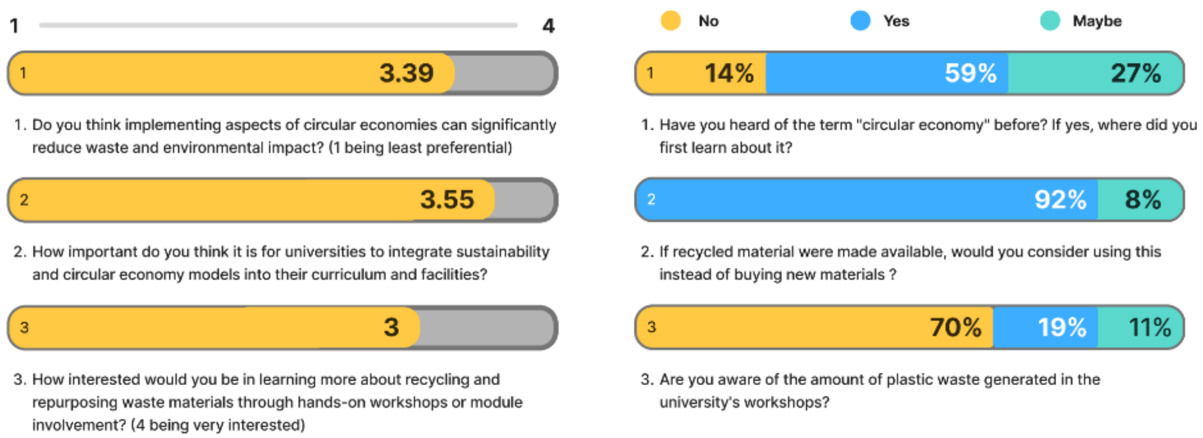

Figure 1. Insights from questionnaire

Currently, the biggest challenge for students wishing to be more sustainable in the workshops is an inadequate waste management system. Whilst the current system can handle large amounts of prototyping waste, the bins are unlabelled and treated by most as general waste, leading to contamination of recyclable materials. Many students have experienced frustration over the absence of designated recycling bins, and 41% of students have stated they use the 'nearest bin'. This clearly indicates that students would likely recycle if provided with the proper facilities. The lack of dedicated bins leads to easily recyclable plastics being disposed of incorrectly. As a result, the workshops discard large quantities of materials that have the potential to be reclaimed with proper waste management.

89% of students reported negative perceptions when identifying plastic types, with 11% stating that they are not confident in identifying the plastics they use. This is compounded with 50% of students only sometimes feeling able to identify plastic types. This would deter students from engaging with a workshop CE model and add the technical issue of misidentification creating mixed plastics that cannot be recycled due to the different processing requirements of various plastics.

Figure 2. Typical waste materials in a prototyping workshop

To address the issues identified above, the course is moving to integrate more sustainable design and prototyping approaches. Students need more education on sustainable prototyping techniques composed of prototype assessments reflecting appropriate material selection, optimisation, and appropriate feature testing. Students often print iterations of prototypes to test only one feature at a time. Additionally, they often reprint the entire prototypes rather than feature sections, which stems from a lack of experience implementing effective prototyping.

If these practices were to continue and reusing these materials were an option soon, the fast-paced prototyping process would become much more financially sustainable and less damaging to the environment.

4 IMPLEMENTING CHANGE: TOOLS & INTERVENTIONS

4.1 Empowering students to be circular

It is paramount that we improve facilities and processes to encourage students to adopt a more circular approach, as 22% of students feel they cannot do so in current workshop environments. One tool introduced to make positive changes in the workshop is a reconfigured recycling and sorting system to educate and assist in sorting offcuts and support materials from plastic components. Sorting keys and education content will be assigned to each bin area to increase confidence and success students have in the process of identifying a plastic compound to recycle, and in future, this will be augmented with plastic identification tools such as an Open-Source Plastic Scanner [22] or PlasTell [23].

Currently, 70% of students do not know how much waste they are generating when using workshop facilities, with only 11% having some idea of how much waste they are generating.

Funding was sourced to purchase a suite of equipment to enable the reprocessing of materials. By actively engaging students with a hands-on approach in gathering and reprocessing materials, they can directly see the positive effect of CE concepts. The equipment is based in a new Material Intelligence Lab, *Figure 3*a space to explore materials and their use in a hands-on way,

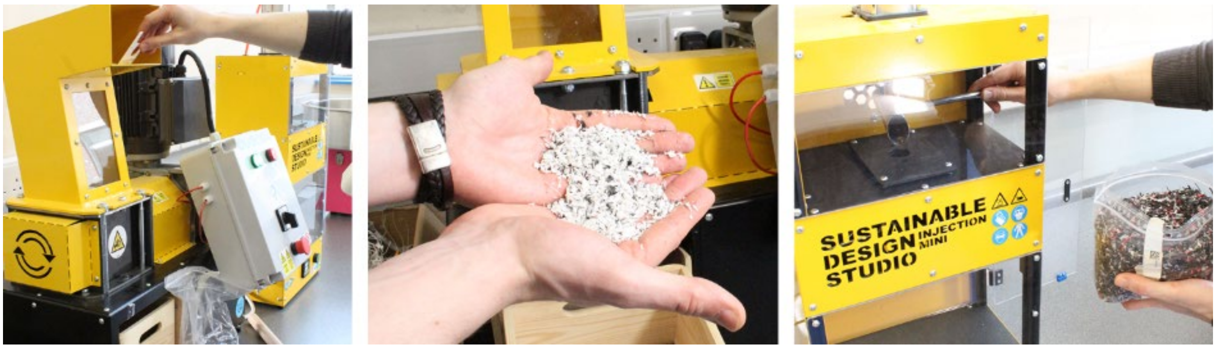

Figure 3. Plastic Recycling Equipment in the Materials Intelligence Lab

The byproduct of this subsequently increases their knowledge of how much material they can reuse, which is often discarded, how much waste is currently generated and what the cost of this material is to the cohort and university. This also helps students develop ideas around generating value from the current waste or reducing their environmental impact.

There is a positive attitude towards change among students, with 62% being willing to recycle with due and proper care. Through implementing new, accessible recycling facilities, we hope to increase the number of students willing to engage with the recycling process. Students are eager to undertake hands-on practices like injection moulding and 3D printing with recycled materials, as 61 out of 65 respondents answered positively about the practice. We hope that utilising the materials lab to allow students to create and test the plastics they generate will provide them with the facilities to choose more sustainable alternatives.

4.2 Prototyping spaces as a Living Lab

93% of respondents believed that incorporating aspects of circular economies into the educational environment would significantly reduce generated waste in the workshops, and 90% were interested in learning more about circular economy principles. By adopting a Living Lab approach to the teaching spaces, learning environments can be co-developed between the university, the student body and organisations external to the university [24]. This approach and the accessibility of the facilities will encourage student engagement and allow the evolution of spaces to find real solutions.

While there are several modules where CE principles can be explored and tested, one particularly suited to engaging students with the spectrum of challenges we face in implementing CE models is the Year 4 module *Studio 401: Ethics and Sustainability.* This is split into two strands; the first, *'Design for Behaviour Change',* focused on design approaches to positively influencing people's behaviour. The second strand, *'Design for the developing world',* challenges the students to engage with external partner Engineers Without Borders (EWB) to develop solutions for communities in low-income countries.

In exploring the practical development of CE models in our own spaces, the first strand can engage students to think about the behaviour changes we wish to see in the workshops, what prompts and tools we can use to elicit these, and what is currently blocking the changes.

The second strand is already focused on many elements of CE principles, such as remanufacturing waste materials to higher-value products, low-tech solutions to community challenges, and sustainable energy, water, and food production. This strand can allow students to test the practical use of circular materials in a problem-based learning environment.

5 CONCLUSION

Working to introduce CE into projects has been a great educational experience for the course, the use of recycled materials is enabling design students to learn about plastic separation, injection moulding and design for manufacture. In the past, these processes were only theoretical rather than practical, which often prevented students from making a real connection on the topic, which limited students' abilities in understanding plastic manufacturing methods.

A significant area that has become popular among students is the shredding of failed 3D printed components from past projects. These failed prints were discarded in the past due to the lack of separating and recycling facilities, but now, the shredded plastic is used to feed the new desktop injection moulding machines. By implementing this system where these materials are collected, shredded, and reprocessed, the students are already actively developing a circular workflow within the workshop spaces.

Once this process is integrated more within modules, it will provide hands-on experience with circular economy practices for all 4 years. Instead of relying solely on theoretical knowledge of injection moulding and material value and reuse, students could actively engage in collecting, processing, and remanufacturing waste plastic into usable and useful products.

By applying these concepts in a real-world setting, the design students will gain valuable skills that align with industry trends toward closed-loop manufacturing and sustainable product design. This shift is enhancing student learning, reducing university expenditure, and promote a more resource-conscious mindset, preparing students to implement these exact sustainable practices in future careers.

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