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In the book:
Weaving Universities and Companies to Co-create Fashion-Tech Future Talents

Using problem-based learning to engage engineering students in circular economy

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Abstract

In this paper, we explored a design methodology for teaching circular economy concepts to 52 engineering students in a French higher institution. Considering the collaboration between fashion and sports industries, students explored disassembly solutions for diving masks and swimming goggles in order to use the material for recycling or recuperate spare parts for repair strategies. The methodology was based on the Double Diamond diagram for innovation, starting from a general problem to get to a specific solution. Deliverables include machinery and tool prototypes, as well as service design. Finally, students evaluated the course, presenting promising results regarding support materials, interest in the course and comprehension of circular economy.

Keywords

Circular economy, fashion and sports industry, problem-based learning, students workshop

1. Introduction

Sports are a significant source of inspiration for fashion designers (Lee & Park, 2012)). Considering collaborations within the fashion industry, sports and casual clothing manufacturers and distributors may have synergy and win-win effects (Jang, 2006). Also, once we combine fashion and sports technology, sports lines can get more refined and fashion can be displayed more vividly (Jang, 2006).

Parallelly, circular economy (CE) emerges as an alternative to our current linear logic of extracting, producing, consuming and throwing away, as it proposes a restorative system that relies on renewable energy, minimising tracks and eliminating the use of toxic chemicals; and eradicating waste by careful design (Ellen MacArthur Foundation, 2013). Educating engineers for CE is an important action towards circularity, once they will shape the industry's future (Kirchherr & Piscicelli, 2019).

In the sustainability and CE context, the fashion industry plays an essential role considering its strategic areas of innovation, especially in the textile sector, and its environmental impact (Jacometti, 2019). Considering these factors, in this paper, we analyse the results of a workshop based on a methodology for teaching CE to engineering students, focusing on diving masks and swimming goggles

from a partner sports company, responsible for developing and distributing its products.

2. Literature review

CE is defined as "an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design" (Ellen MacArthur Foundation, 2013). Singh and Ordonez (2016) add that it is a strategy that uses innovation to transform the current linear system of consumption into a circular one that leads to economic sustainability combined with material savings. CE is usually seen as a condition for sustainability, in which human activity happens in a way that does not harm Earth's ecosystems (Geissdoerfer et al., 2017).

Putting CE into practice demands the transformation of businesses, especially in the manufacturing industry, which calls for the re-thinking of design and engineering education in order to develop new proficiencies related to material science, engineering technics, operational processes, service design and human behaviour (De los Rios & Charnley, 2017). Higher education can play a significant role when grounded in five principles: interactivity, non-dogmatism, reciprocity, constructive alignment and problem-based learning (Kirchherr & Piscicelli, 2019).

In this context, active learning is defined as "any instructional method that engages students in the learning process. In short, it requires students to do meaningful learning activities and think about what they are doing" (M. Prince, 2004). Active learning methods focus on involving the students in activities that promote manipulating, applying, analysing, and evaluating ideas (Crawley et al., 2007). As part of active learning, problem-based learning confronts students with "an open-ended, ill-structured, authentic (real-world) problem and fosters them to work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators rather than primary sources of information" (M. J. Prince & Felder, 2006). In sustainability and CE courses using problem-based learning, engineering students recognise the project as a stimulating challenge that enables reflection and learning on sustainability issues (Alves et al., 2017). It resulted in deliverables based on the choice of raw materials, digital and physical projects, and the production systems design and product prototypes (Alves et al., 2017).

3. Methodology

In this section, we will explain each step of this course, focusing on active learning practices for CE. Also, we present how students evaluated the course.

3.1. Course methodology

We gave this course to 52 students from the first year of engineering studies in a higher education institution in France. We planned each class (2 hours long) to be focused on a phase of the Double Diamond framework for innovation : (1) discover, (2) define, (3) develop, and (4) deliver. The objective is to pass from a general problem to a specific solution.

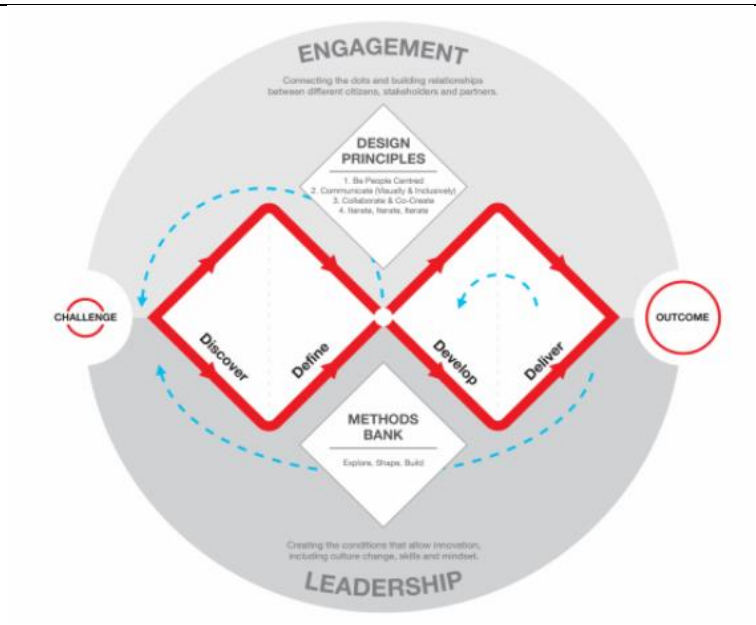

Figure 1. Double Diamond Framework (Framework for Innovation, s. d.)

3.1.1 Discover

We invited a designer from the sports company who explained the circularity challenge for swimming goggles and diving masks. These products are composed of glass, buckle, and frame in polycarbonate; textile straps; metal screws; and silicone skirt. Based on internal research, the company found that 57.0% of sold goggles and 81.4% of sold masks are products from the cheapest range. Analysing the customers' reasons for switching products, most of it is due to fog (22%), scratches (14%), mould (16%), broken glass or buckle (12%) or torn strap (11%). Masks and goggles are considered products of individual protection, so repairing them in workshops can be difficult once it demands re-homologation through a destructive test. Thus, the company explores do-it-yourself (DIY) solutions. Their research shows the percentage of customers that said that they would repair their own masks (Figure 2). In addition, we can think of recycling solutions for polycarbonate and metal and reintroducing crushed silicone with virgin material. Thus, the generic problem was: what are the circularity solutions for masks and goggles at the end of life?

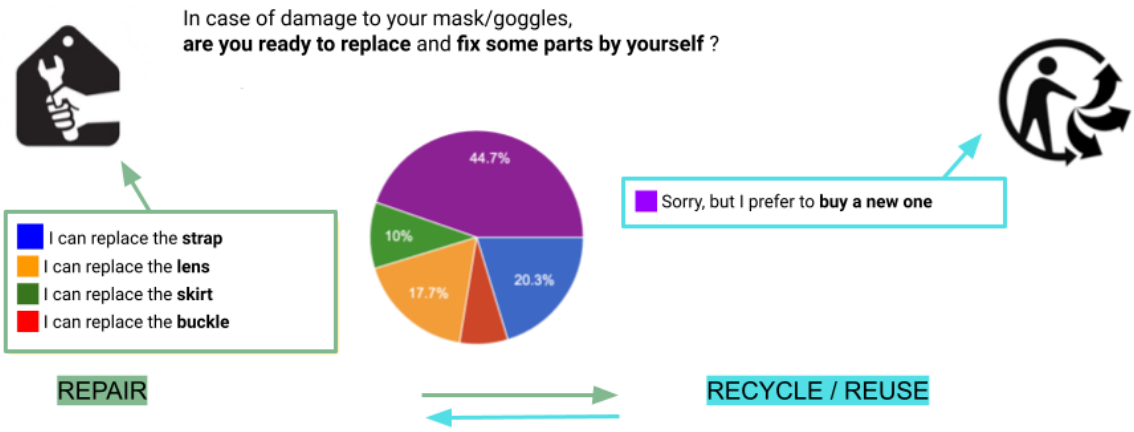

Figure 2. Customer positioning towards DIY repair solutions

The designer brought two products of two mask models (M1 and M2) and two goggles modes (G1 and G2): one product for each one of the eight groups. Then; the students dismantled them and classified

each component and assembly type, following the Unlinear Methodology (Demarcq et al., 2022).

3.1.2 Define

We started the class with the question: "What is CE for you ?" Afterwards, we presented CE concepts that were developed by Ellen MacArthur Foundation (2013), focusing on the technical loops and the analysis by shape degradation (Menu et al., 2019). Based on it, we showed them the framework from Figure 3, which combines the previous studies.

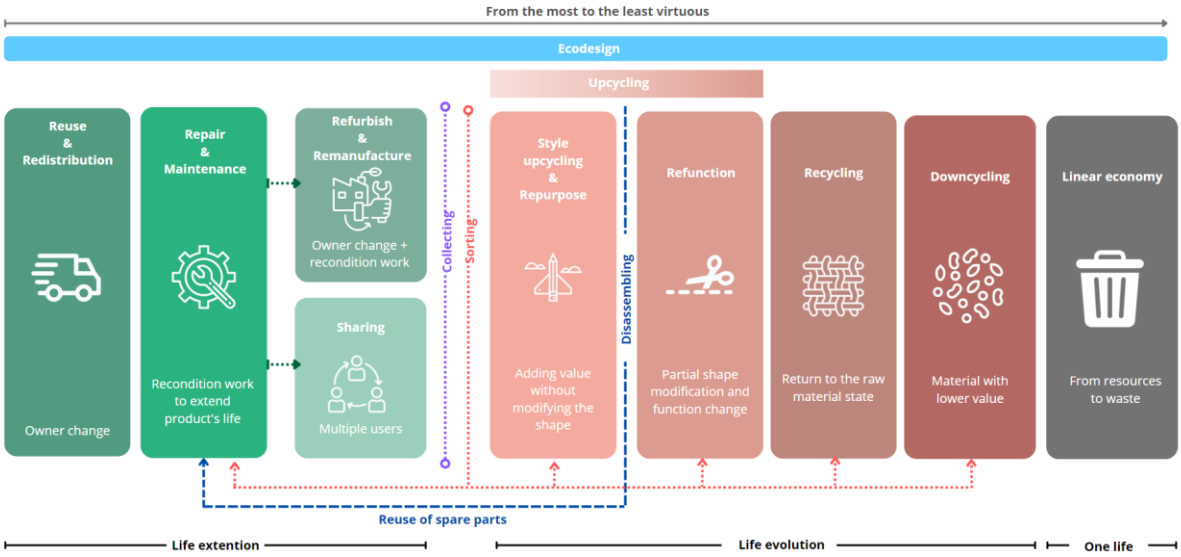

Figure 3. Circular Loops Framework by Shape Degradation (by the author)

Next, the students had a practical activity. Considering the information they had in the last classes, they had to create a mindmap describing the possibilities of disassembly for their group's end-of-life product and reflect on the circular loops related to it. Then, they should synthesize their discussions following the framework below (Figure 4). The goal was to pinpoint a specific problem when dismantling masks and goggles at the end of life, so that they can fit certain circularity loops, such as reparability and recycling.

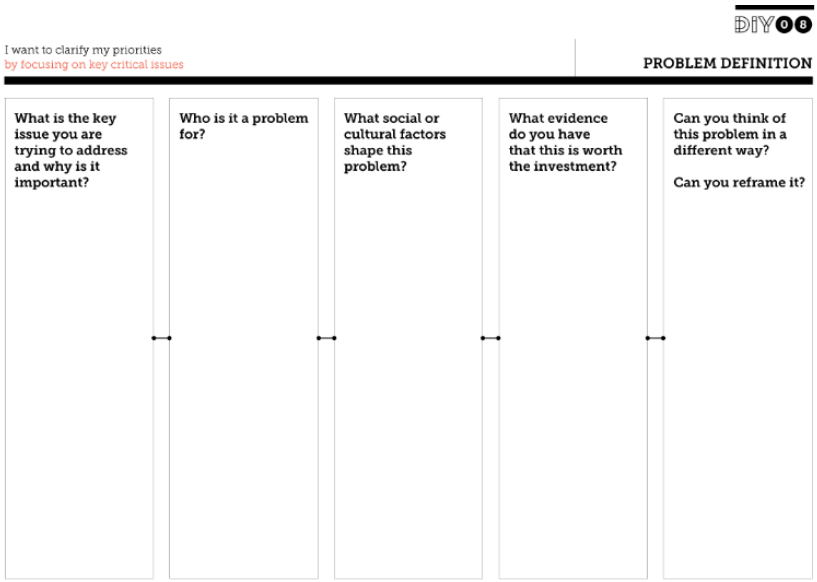

Figure 4. Problem Definition Framework

3.1.3 Develop

The students should explore different solutions to enable end-of-life solutions for the masks and goggles. We incentivized them to explore and experiment with possibilities regarding the technical process, service storyboards and scenarios, and creating through computer-aided design.

3.1.4 Deliver

Finally, the students selected one of the proposed solutions. In order to give more structure, we asked them to make a business model canvas (BMC) to explain their solutions. It pushes them to go further into their thinking, once they need to define users, the value proposition, resources, partners, client relationships, distribution channels, costs, and revenues.

3.2. Course evaluation

After finishing the course, we assessed it with a questionnaire. It was composed of the following affirmatives that should be evaluated using a Likert Scale from 1 to 4, in which 1 meant "I do not agree at all" and 4 meant "I agree a lot".

i. The support material was clear, and it helped me to understand the subject.
ii. The activities were interesting to me.
iii. The project helped me to comprehend CE.
iv. The activities had a good duration.

In the end, there was also a space where the students could make free comments regarding the course.

4. Results

In this section, we present the results of each step of the course methodology. Additionally, we show the responses from the students' questionnaire evaluating the course.

4.1. Course methodology: results

In this subsection, we describe how the activities were conducted, and the student's project development from discovering the problem to delivering solutions, using prototypes, service design and industrial operations.

4.1.1 Discover: results

The students disassembled the masks and goggles, taking pictures of the final result: the separated components (Figure 5). Next, using the Unlinear Method, they made a scheme (Figure 6) in which each hexagon represented a component, describing its function and material. The hexagons were connected by lines, in which they described how the components were assembled. We noted that the cheapest the products, the fewer components the product had.

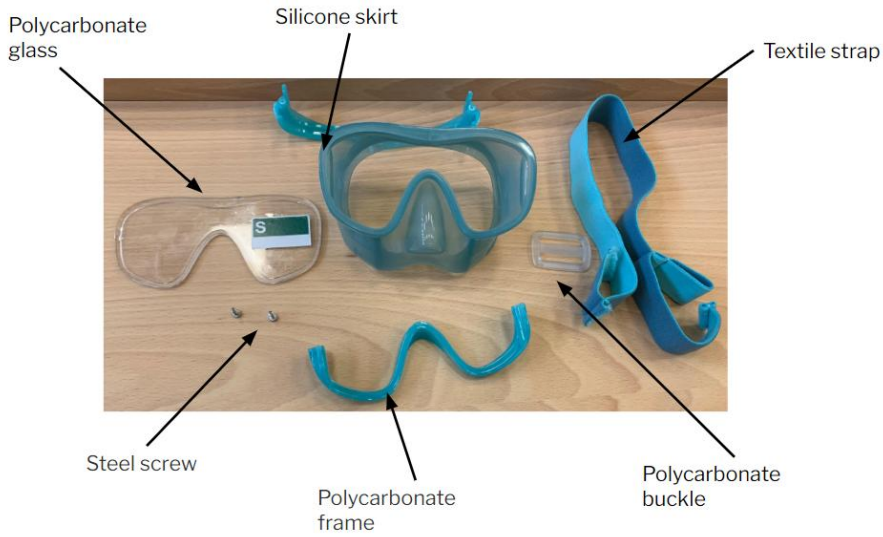

Figure 5. Disassembled mask

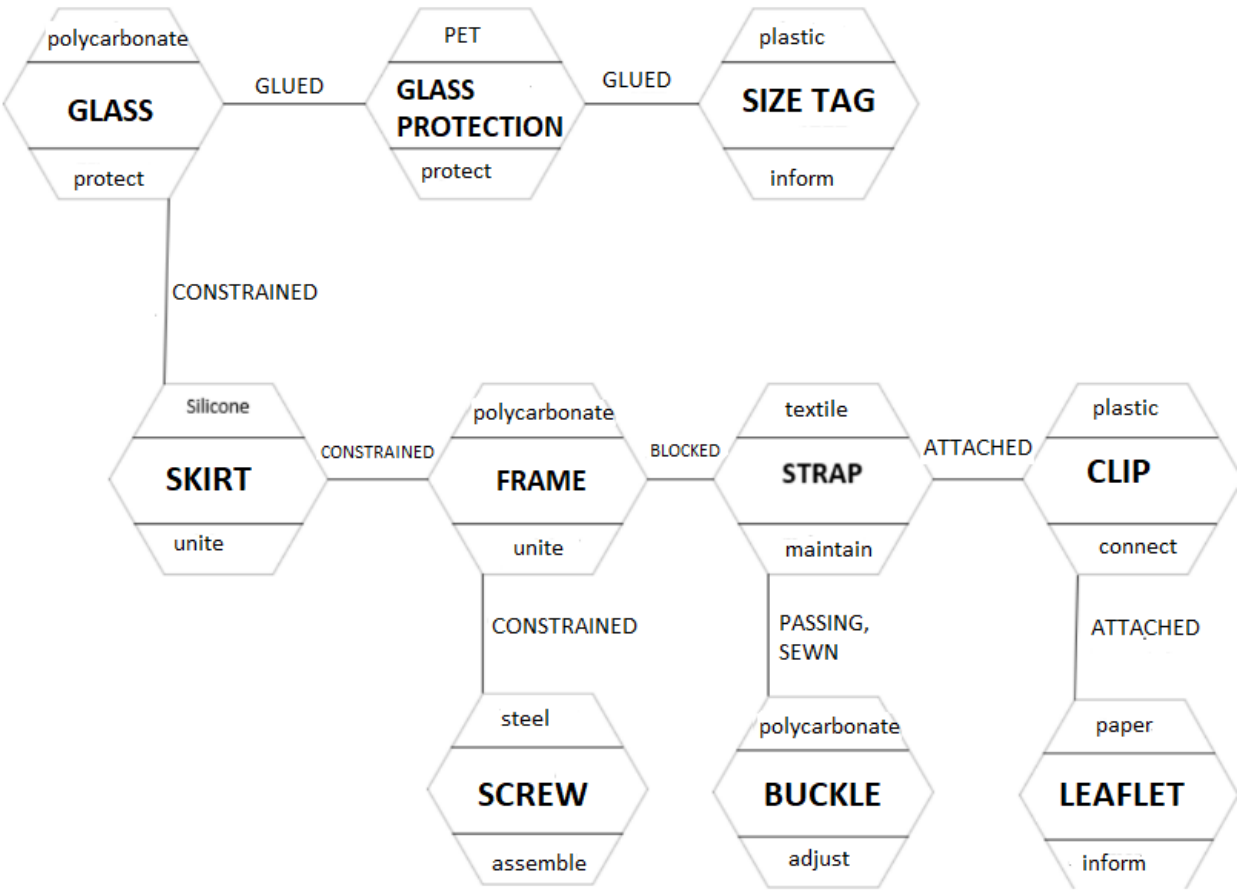

Figure 6. Unlinear Methodology for a mask (translated)

4.1.2 Define: results

With the knowledge that was acquired in the previous class, students had to imagine different kinds of disassembly processes. Next, in another level of the mindmap, they described the resulting components, and what kind of circular strategy they could apply to it. For example, if they decided to

crush the product, they could envision downcycling all materials together or recycling certain materials (e.g. polycarbonate) after sorting. On the other hand, if they disassembled the product without degrading it, they could reuse the spare parts in a repair strategy. In Figure 7, we show part of a translated mindmap that was created by a group.

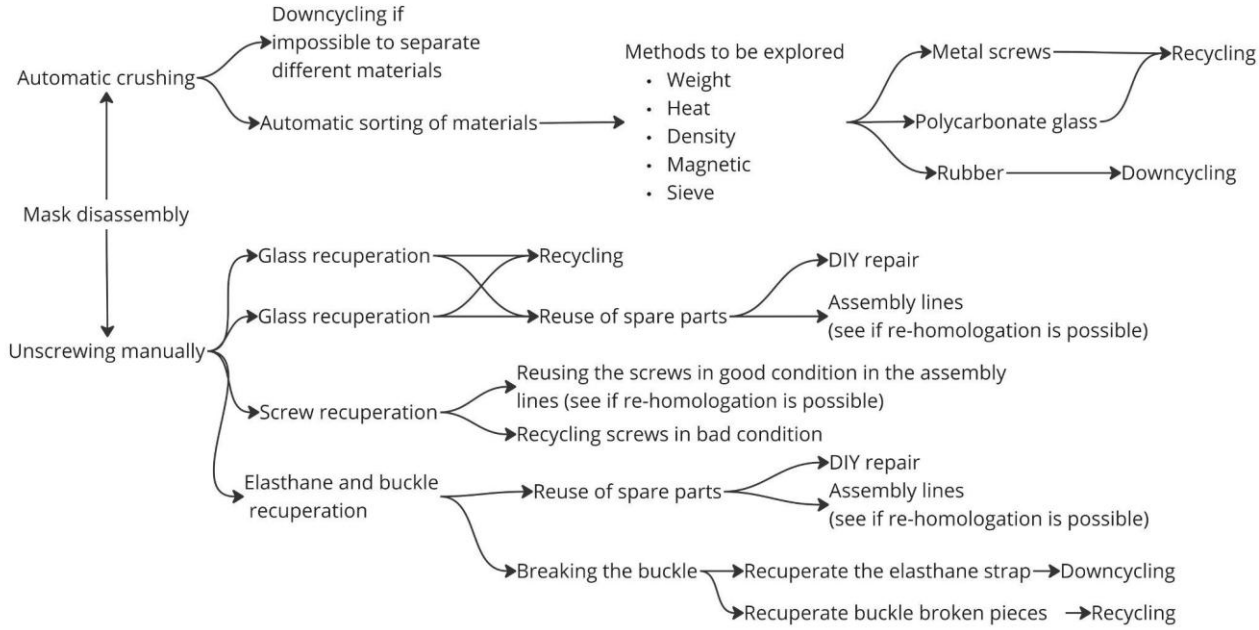

Figure 7. Example of a translated mindmap

Afterwards, they selected one of the items they have mapped. For example, another group decided to focus on manual disassembly. In Table 1 below, they detailed the defined problem to be developed.

Table 1. Framework for problem definition—mask manual disassembly

What is the issue you are trying to address and why is it important?	Who is it a problem for?	What social or cultural factors shape this problem?	What evidence do you have that this is worth the investment?	Can you think of this problem in a different way? Can you reframe it?
The chosen solution is the manual disassembly of the mask, it is important because we need to be able to recover all the components of our mask without damaging them.	We have encountered a problem disassembling the button. It is a problem for all users.	Lack of the necessary equipment for the manual disassembly of this part, moreover the fact of inciting the users to bring back to the store to be able to reuse the reusable parts.	The investment is worth it because millions of these products are sold, allowing us to reuse millions of non-defective parts to limit the ecological impact and at the same time save money.	From a different perspective, we can say that the problem comes from the design of the button that cannot be disassembled without a tool. It forces us to destroy this piece. One solution to this issue would be to redesign the part so that it can be disassembled and reassembled very easily without the help of a specific tool.

				The solution chosen has been to develop a tool that people can use directly in the shop.

4.1.3 Discover: results

Some groups explored the spare parts flow and interactions from masks' end-of-life to the reuse phase of some spare pieces in repair. They focused on searching the ways to engage clients in this CE business. It is the case of the group that created the scheme from Figure 8 below.

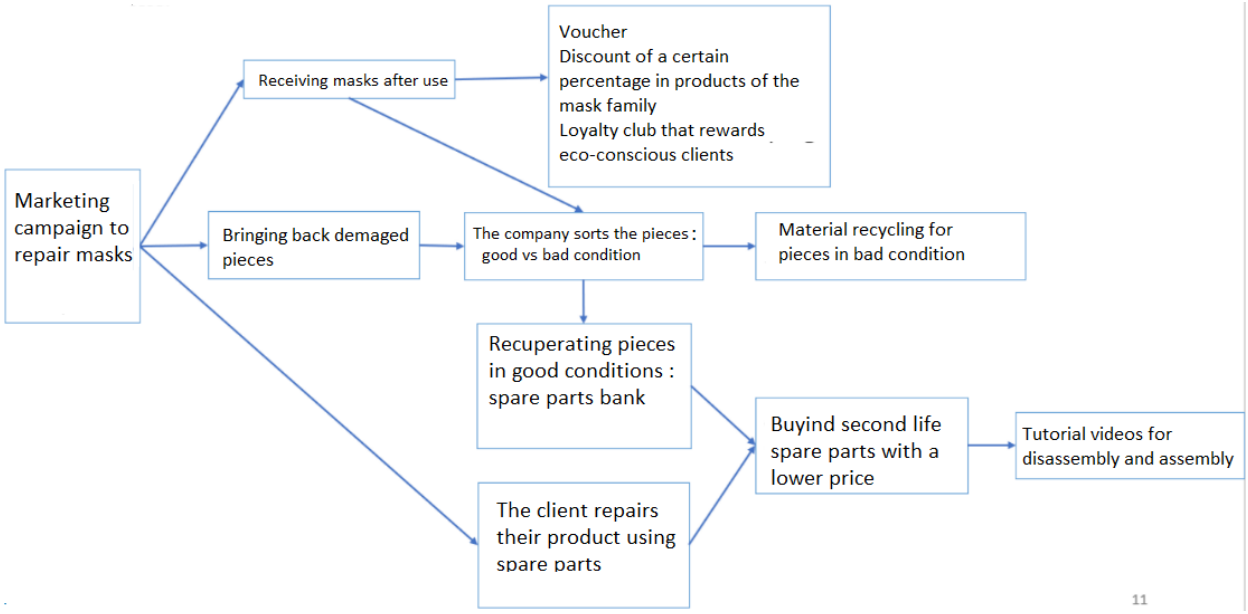

Figure 8. Interactions from the end-of-life to the reuse of spare parts

Another group created a design for machinery that could cut the straps automatically, as shown in Figure 9. A third group designed a tool, presented in Figure 10, that could help disassemble the mask by triggering a button, which would avoid damaging the product.

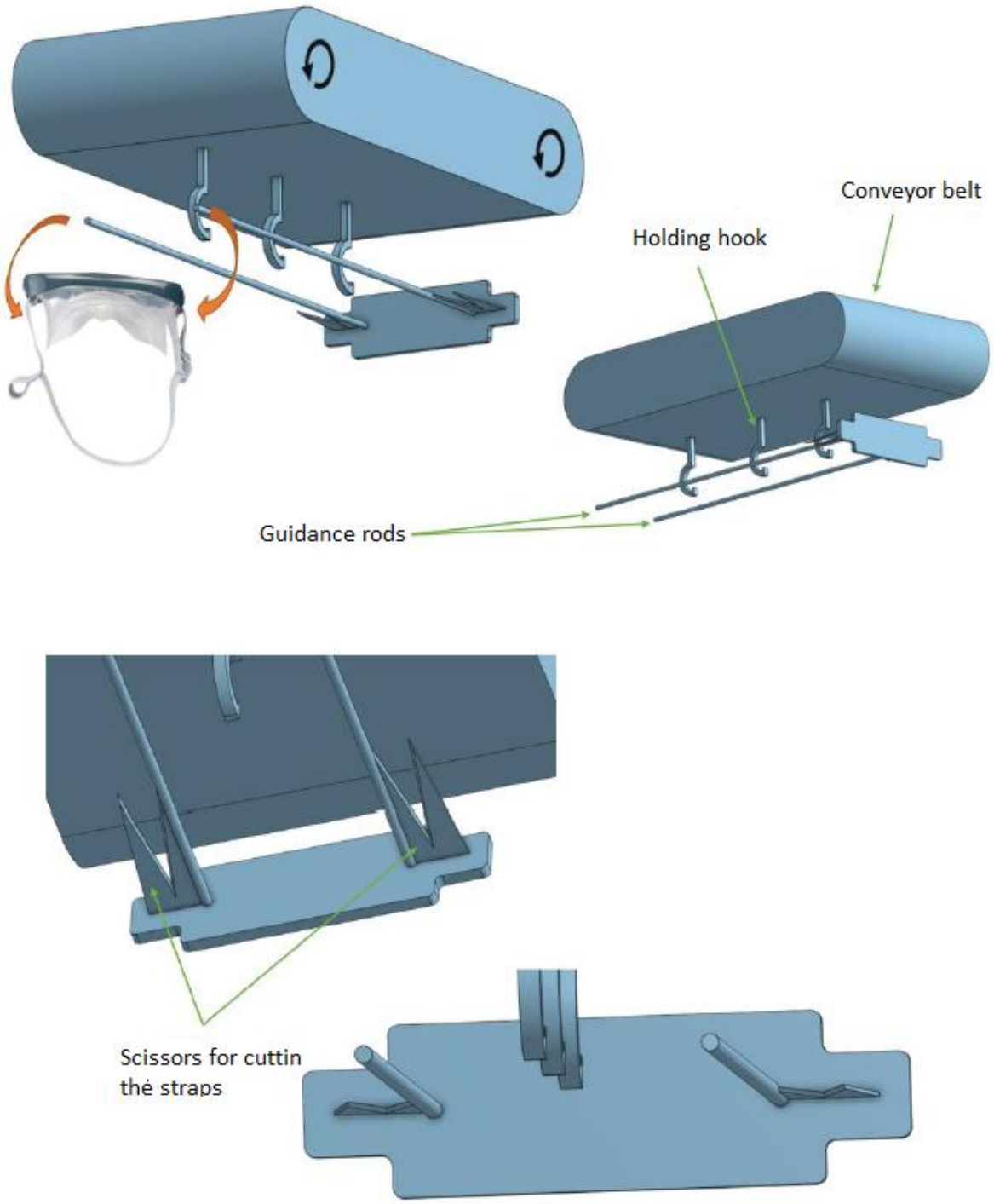

Figure 9. Machinery to automatically cut straps

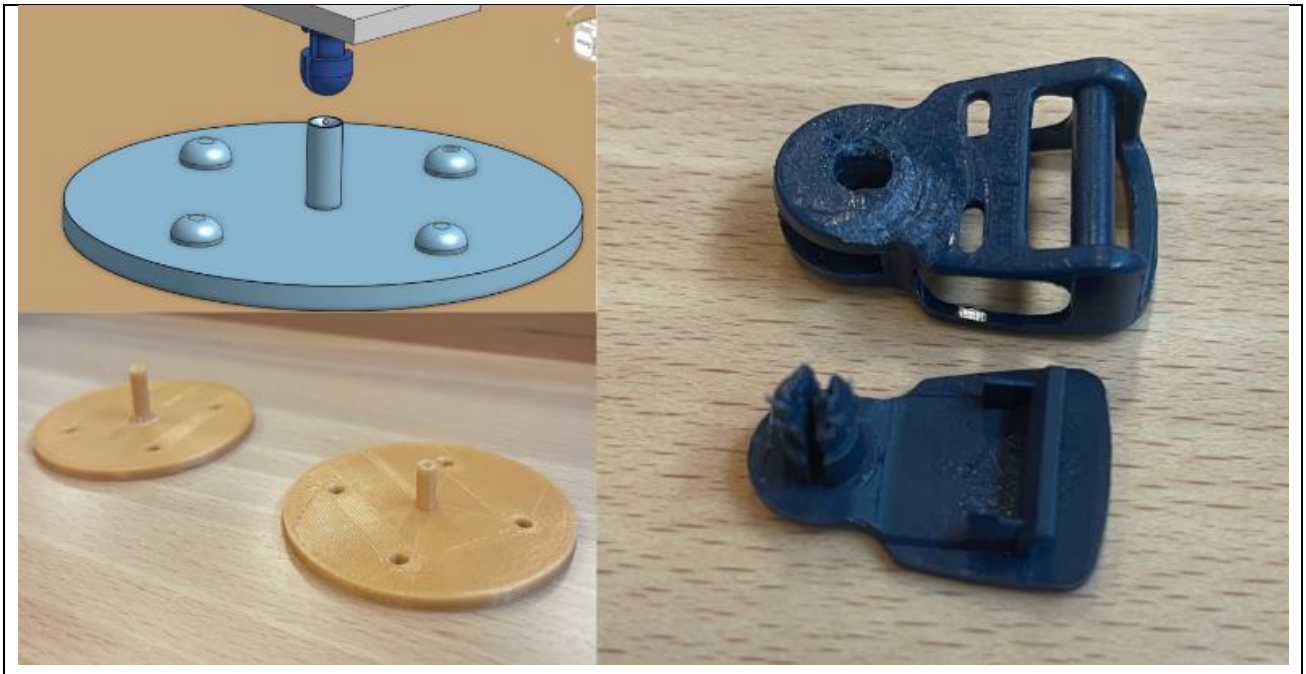

Figure 10. Tool for triggering the mask button

4.1.3 Deliver: results

Each group created a BMC that would be adapted to their solution. For example, in Figure 11 below, we present the BMC from the group responsible for the tool above (Figure 10).

KEY PARTNERS	KEY ACTIVITIES	VALUE PROPOSITIONS	CUSTOMER RELATIONSHIPS	CUSTOMER SEGMENTS
Companies specialized in material recovery for recycling Marketing companies	Marketing campaign to aware clients Demonstration stand for disassembly/assembly	Financial economy, once the client avoids buying a new product Environmental footprint reduction Awareness about the company's environmental engagement	Salesperson After-sales service Tutorials	B2C: private customers B2B: swimming clubs
	KEY RESOURCES Employees dedicated to mask disassembly and sorting		CHANNELS Website Social networks	

COST STRUCTURE	REVENUE STREAMS
Marketing campaign, employees' salary	Sale of spare parts, investments from external partners

Figure 11. BMC considering on tool-based solution

4.2. Course evaluation: results

From the fifty-two students, 46.15% responded to the questionnaire. The graphs below present the result of their perception of affirmations about this course. In this context, 1 meant "I do not agree at all" and 4 meant "I agree with it a lot".

i. The support material was clear, and it helped me to understand the subject (Figure 12).

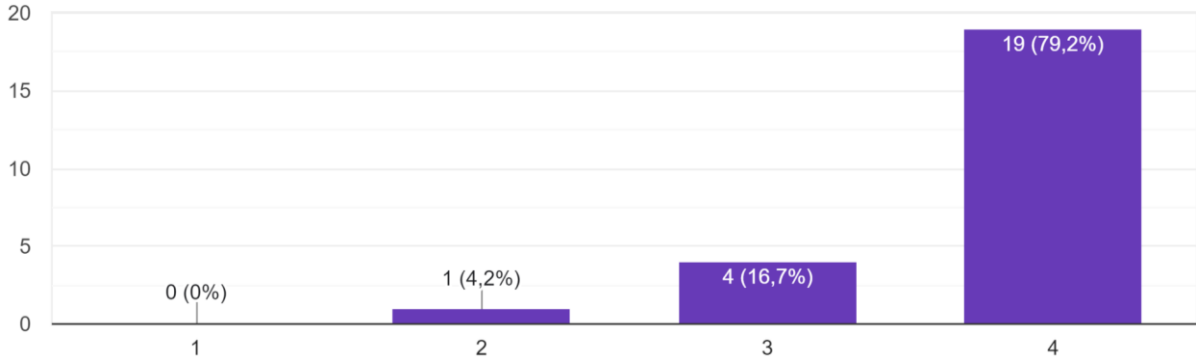

Figure 12. Evaluation of the class' support material

ii. The activities were interesting to me (Figure 13).

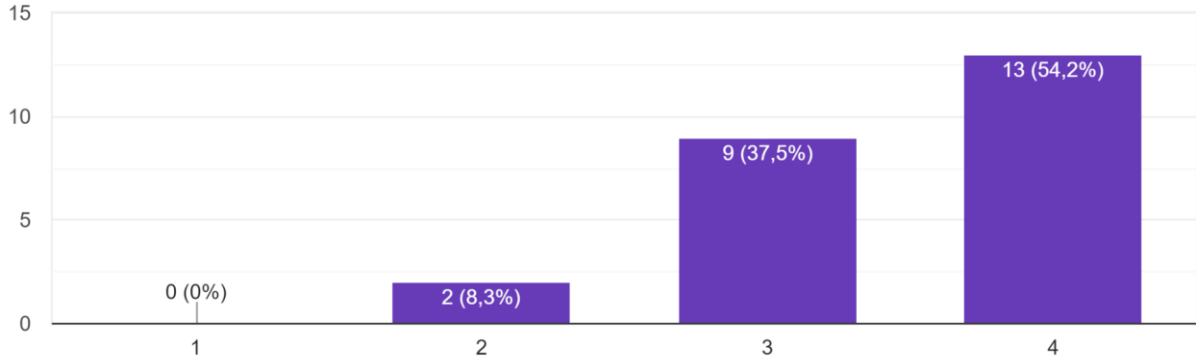

Figure 13. Evaluation of the student's interest regarding the course

iii. The project helped me to comprehend CE (Figure 14).

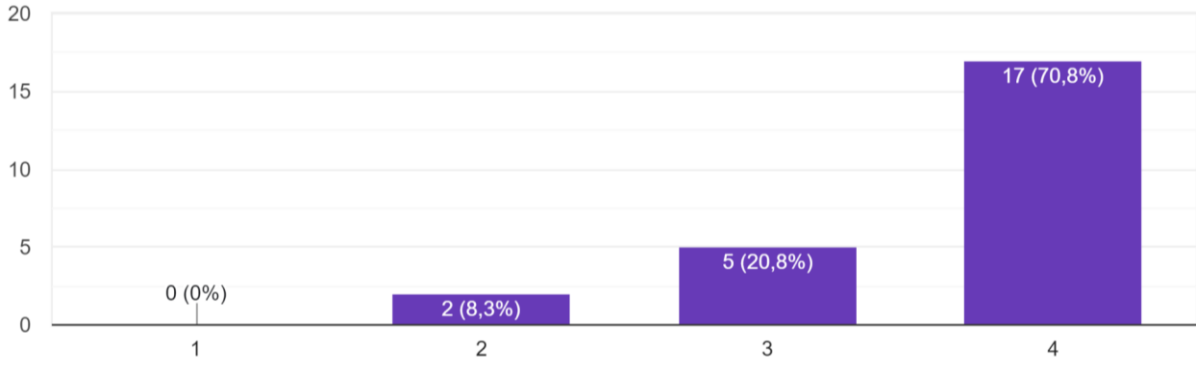

Figure 14. Evaluation of the student's comprehension regarding CE

iv. The activities had a good duration (Figure 15).

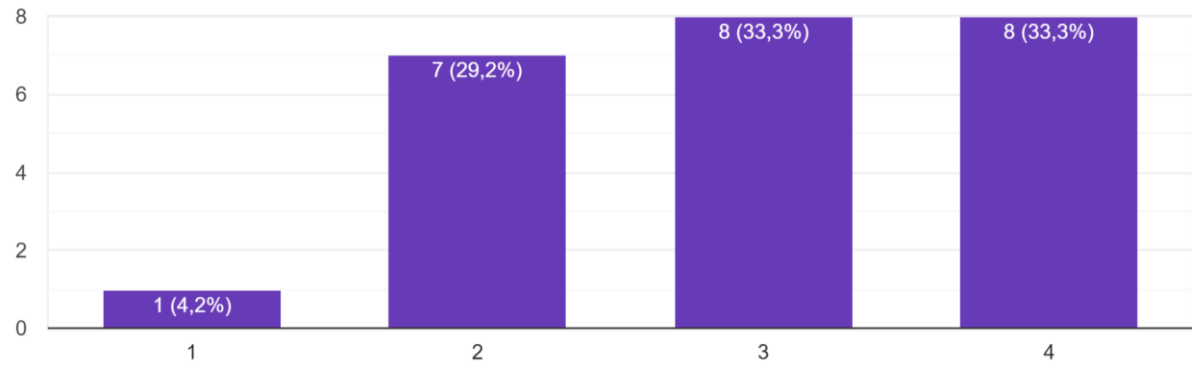

Figure 15. Evaluation of the activities' duration

We also received a comment, saying there was not enough time to develop the required activities.

5. Discussion / Conclusion

The students realized that in most of the cases, it was difficult to dismantle the masks and goggles by hand. Sometimes, even with general tools and their engineering background, it was not possible and some pieces had to be broken. The Unlinear Methodology (Demarcq et al., 2022) proved to be useful to analyse the assembly of different components. However, it raised doubts regarding assembly pieces, such as screws: should they be analysed as a component (represented by a hexagon) or a connective (represented by a line)?

When defining the problem, there were two major subjects: automatic disassembly by crushing and then recycling, or manual disassembly to reuse spare parts for repair loops. Regarding the framework for problem definition, most of the students had difficulties when filling in the required cases (Table 1). Instead of choosing one of the mapped elements, the issue they addressed was masks and goggles circularity in general, lacking focus in the problem definition. This could affect the project's evolution, once it causes a more superficial analysis. Yet, one common element was when asked to reframe the issue, most of the groups mentioned the importance of designing for circularity to prevent disassembly difficulties in the end-of-life.

In the explore phases, there was a diverse range of solutions. Some groups developed machinery designs, others tool prototypes, and also service designs. It shows that circularity could be approached from different perspectives, considering products' characteristics, such as price. For example, cheaper products had fewer chances of being repaired, so circular solutions were based on recycling.

Then, in BMC, marketing campaigns were a central point in customer relationships to raise awareness among customers. Also, students explored the role of employees in disassembling, which could increase operations costs. Finally, private clients in a B2C model were the main customer segment, but they also saw an opportunity with companies that worked directly with swimming and diving clubs.

We had promising results when analysing the course evaluation. On a scale from 1 to 4, we see that most of the students thought the support materials were clear (3.75 average), that the activities were interesting (3.46 average) and that this course helped them better understand CE (3.63 average). Yet, the activities had a very limited time (2.29 average): only four 2 hours long classes to develop the projects were not enough to deepen the project's solutions. However, this course was a good initiative to educate students of their future role as engineers in the context of CE.

6. References

Alves, A. C., Moreira, F., Leão, C. P., & Carvalho, M. A. (2017). Sustainability and circular economy through PBL : Engineering students' perceptions. In *WASTES – Solutions, Treatments and Opportunities II*. CRC Press.

Crawley, E., Malmqvist, J., Ostlund, S., & Brodeur, D. (2007). *Rethinking Engineering Education : The CDIO Approach* (p. 5). https://doi.org/10.1007/978-3-319-05561-9

De los Rios, I. C., & Charnley, F. J. S. (2017). Skills and capabilities for a sustainable and circular economy : The changing role of design. *Journal of Cleaner Production*, *160*, 109‑ 122. https://doi.org/10.1016/j.jclepro.2016.10.130

Demarcq, B., Masson, D., Legardeur, J., & Millet, A. (2022). Towards a Circular Product (Re)Design Methodology : Proposition of the Unlinear Method to Foster Circularity. *Tehnički Glasnik*, *16*(2), 246‑ 251. https://doi.org/10.31803/tg-20220410142313

Ellen MacArthur Foundation. (2013). *Towards the Circular Economy Vol. 1 : An economic and business rationale for an accelerated transition | Shared by Business*. https://emf.thirdlight.com/link/x8ay372a3r11-k6775n/@/preview/1?o

Framework for Innovation : Design Council's evolved Double Diamond. (s. d.). Consulté 24 novembre 2022, à l'adresse https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/

Jacometti, V. (2019). Circular Economy and Waste in the Fashion Industry. *Laws*, *8*(4), Art. 4. https://doi.org/10.3390/laws8040027

Jang, E.-Y. (2006). An Analysis on Cases of Fashion Collaboration Strategy. *Journal of Fashion Business*, *10*(6), 110‑ 121.

Kirchherr, J., & Piscicelli, L. (2019). Towards an Education for the Circular Economy (ECE) : Five Teaching Principles and a Case Study. *Resources, Conservation and Recycling*, *150*, 104406. https://doi.org/10.1016/j.resconrec.2019.104406

Lee, Y., & Park, J. (2012). Modern sports-inspired fashion through active sportswear development history. *The Research Journal of the Costume Culture*, *20*. https://doi.org/10.7741/rjcc.2012.20.5.635

Menu, B., Jenny, F., Valérie, L., & Jean-François, B. (2019). From Product to Dust : Looking at the Ways to Regenerate Value in Product Life Cycle. *Proceedings of the Design Society: International Conference on Engineering Design*, *1*(1), 3321‑ 3330. https://doi.org/10.1017/dsi.2019.339

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*, *93*(3), 223‑ 231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Prince, M. J., & Felder, R. M. (2006). Inductive Teaching and Learning Methods : Definitions, Comparisons, and Research Bases. *Journal of Engineering Education*, *95*(2), 123‑ 138. https://doi.org/10.1002/j.2168-9830.2006.tb00884.x

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