LCA and ecodesign teaching via university-industry cooperation

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Abstract

Purpose – The purpose of this paper is to report on a life cycle assessment (LCA)-based ecodesign teaching practice via university-industry collaboration in an industrial engineering undergraduate course.

Design/methodology/approach – A new course was designed and taught in the Industrial Engineering undergraduate course of a Federal University in Brazil. The course comprised explanatory lectures and a practical project developed in a partnership between the university and an industry partner where students had to develop Ecodesign proposals based on LCA to improve the environmental profile of both solid and reticulated paint brushes. To that end, students used the LCA software tool Umberto NXT v.7.1.13 (educational version), where they modeled the life cycle of four plastic brushes and assessed it using the impact categories of climate change and resource consumption, and the Ecoinvent v.3.3 database. After course completion, students, professors and industry collaborators were asked to provide feedback on the project performance and expectations.

Findings – The course design used was welcomed by both students and the industry partner. Students found the novel approach intriguing and useful to their future careers. The results also exceeded the industry partner's expectations, as students formulated valuable insights. Professors observed that learning was made easier, as content was put into practice and internalized more easily and solidly. The approach was found to be a win-win-win.

Practical implications – Students acquired a fair share of knowledge on sustainability issues and potential existing trade-offs, which is valuable to industrial practices. The industry noticed the valuable contributions that academia can provide. The university profited from providing students with a real case challenging traditional teaching methods.

Originality/value – To the best of the authors' knowledge, this is one of the first case studies to show how LCA and ecodesign teaching practice can support sustainability learning in an industrial engineering undergraduate course.

Keywords Ecodesign, Life cycle assessment, Engineering, University-industry collaboration, Undergraduate teaching

Paper type Research paper

1. Introduction

One of the major areas in engineering is environmental engineering that addresses aspects of sustainability. Many universities are incorporating sustainability engineering into their curricula within engineering courses (Boyle, 2004). Engineers must be able to make decisions regarding economic, environmental and social aspects. The quest for

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sustainability is important and requires a systems thinking approach and their interactions are complex. Within this context, university is seen as a leader in the dissemination of thoughts, as they have the opportunity to raise the importance of sustainable development through academic and public discourses, as well as to provide the community of graduates with the knowledge and skills necessary to modify their workplaces and become responsible global citizens (Ferrer-Balas *et al.*,, 2008).

With regard to the environmental dimension, teaching life cycle assessment (LCA) can open doors and expand the knowledge portfolio in environmental terms. Teaching LCA includes providing concepts of processes, technical norms and computational tools. LCA is an environmental tool to account for and assess environmental aspects and potential impacts related to products, services or processes ISO (2006a) jointly with its whole or partial life cycle (Piekarski *et al.*, 2014). LCA is a well-accepted method for quantifying environmental impacts (Ingwersen *et al.*, 2012). Among the range of methodologies used to analyze the environmental profile of products, the most comprehensive and extensive method is the LCA and it can be characterized as the most important tool in the modern industrial environmental management (Löfgren *et al.*, 2011). Furthermore, LCA is a source of research and business opportunities that has recently been positively highlighted with environmental life cycle performance assessments (Barros *et al.*, 2018).

To advance knowledge in this area, the use of ecodesign and LCA can minimize the potential environmental impacts of a system. These tools allow to identify stages with greater or smaller impacts and to act on them (Zafeirakopoulos and Genevois, 2015). Ecodesign allows choosing alternative materials, seeking a better economic and environmental performance throughout the product life cycle (Ribeiro *et al.*, 2013). Ecodesign teaching combined with LCA covers a range of stages, from product development to the end of life (EoL). Opportunities for scientific and technological development that stimulate the options on EoL can generate opportunities to strengthen research, cleaner production activities and circular economy initiatives. It is possible to compare, by means of LCA, different options and scenarios of alternative materials for a product, using Ecodesign.

Ecodesign (also named as Design for Environment or DfE) refers to actions taken at the product development phase with focus on environmental impact reduction at the whole life cycle, such as material extraction and consumption, manufacturing, use and disposal (Johansson, 2002; Pigosso *et al.*, 2013). It is important to discuss here that Ecodesign does not mean that only environmental benefits are aimed to be achieved, but cost reduction, quality improvement and product aesthetics and ergonomics are also pursued (Johansson, 2002; Luttropp and Lagerstedt, 2006).

Ecodesign is also part of a broader context which is the Design for Sustainability (D4S). D4S, according to Crul *et al.* (2009), means that not only environmental aspects are considered into product development phases, but social and economic concerns as well. Both Ecodesign and D4S are included in product development by design practices (Pigosso *et al.*, 2013). Those practices vary from qualitative/quantitative and checklists/guidelines/matrix/software methods or tools, which add up to more than one hundred. Some examples include DfE Matrix, Environmental Effect Analysis (EEA), Environmental Quality Function Deployment (EQFD), Ecodesign Strategy Wheel, Ten Golden Rules and LCA (Pigosso *et al.*, 2013).

Moreover, to link the use and application of such concepts and put them into practice, more hands-on initiatives have to be included in the engineering curricula; therefore, more partnerships between the university and the industrial sector need to be arranged. The university-industry partnership is essential to leveraging student learning development within a university. This is especially true when it comes to sustainability, where it is perceived that universities around the world are engaged in activities related to the theme, development of special courses on sustainability, and opportunities for collaborative research (Ferrer-Balas *et al.*, 2008), such as partnerships with industries. By means of partnered projects, technical visits, real case studies, process improvement activities/tasks and internships, universities and industries are brought closer together. Universities are becoming increasingly proactive in managing collaborations with industry (Bruneel *et al.*, 2010) and this relationship results in bidirectional advantages. Industry strategies can benefit from research, development and innovation, besides knowledge generation and management offered by the university, whereas the university benefits from the access to real data from industrial activities.

Investigating the existing literature, it can be observed that few studies resembling the present approach have been developed (Cosme *et al.*, 2018; Gilmore, 2016), assessing the aspects of teaching LCA and Ecodesign. Examples include Cosme *et al.* (2018), who designed an LCA course combining theoretical teaching and practical assignments, including a screening LCA and a more targeted one. Gilmore (2016), in their turn, designed a course where students conducted LCA and Life Cycle Cost (LCC) on the design and operating parameters of a disinfection of wastewater system and were required to analyze the system's trade-offs. Although a few issues have been addressed, it can be noted a lack of investigation on applications of LCA-based education towards Ecodesign. Thereupon, this study sought to answer the following research question: what LCA-based Ecodesign teaching practices coupled with university-industry collaboration can assist in sustainability teaching and learning in an industrial engineering undergraduate course?

To answer this question, the aim of the present paper was to report on an LCA-based Ecodesign teaching practice via university-industry collaboration in an industrial engineering undergraduate course. To the best of the authors' knowledge, this is one of the first case studies to show how LCA and Ecodesign teaching practice can support sustainability learning in an industrial engineering undergraduate course. In addition, the theoretical contribution of this study refers to the approach used adjoined the use of LCA and Ecodesign towards introducing sustainability teaching in engineering courses, besides reporting on new experiences of hands-on activities and experiences with real cases. The study also corroborates with the United Nations (UN) Sustainable Development Goals (SDG). Among the 17 SDG adopted by UN (2015), this study contributes to SDG number 4 which aims to "ensure inclusive and equitable quality education and promote learning opportunities for all"; SDG 9 "build resilient infrastructure, promote sustainable industrialization and foster innovation", with a view to improving scientific research, improving the technological capabilities of industrial sectors in all countries, in particular developing countries, by encouraging innovation, and; finally, SDG 12 "ensure sustainable consumption and production patterns", because if society continues to consume exorbitantly, soon there might not be resources to meet society's needs, causing society to suffer from (e.g.) water, energy, mineral and food scarcity.

Having set the paper into context, to accomplish this study's objective, Section 2 will provide a brief literature review on LCA and Ecodesign teaching in engineering, as well as a few aspects of the university-industry collaboration and the implications of LCA and Ecodesign in this collaboration. Section 3 will provide the methods for course design and assessment. Section 4 will present the Results from the case study and Section 5 will lay a few Discussions, including the main considerations regarding the case study results and feedback from students, the industry partner and the professors. Finally, Section 6 will draw on the conclusions of the present paper.

2. The context of existing efforts on life cycle assessment and ecodesign teaching with industry partnering

2.1 University-industry collaboration

University-industry collaboration has been gaining prominence, acquiring and sharing knowledge about new technologies and adjoining skills that enable the creation of something innovative and useful (Wang, 2016).

The university-industry collaboration comprehends an interorganizational network where organizations unite to exchange information, resources and knowledge towards a common purpose (Steinmo and Rasmussen, 2018). The union of university and industry allows academics to access a broader set of resources and knowledge than they are used to, bringing the innovative industrial knowledge from industries to universities, who help mitigate the risks encountered in industrial activities (Lin, 2017). It is also known that empirical evidence supports that universities act as important means for technological opportunities to the private sector (Klerovick *et al.*, 1995).

According to Steinmo and Rasmussen (2018) the social capital can be particularly important in the university-industry collaboration, for it entails not only overcoming the differences between academia and industry but also the cooperation in complex processes such as technological innovation.

Moreover, the university-industry collaboration is currently considered a relevant economic factor, for the academia has specialized knowledge that aims to contribute to the development of regions or even entire countries. The transfer of knowledge and technology between universities and industries tends to stimulate technological innovation, since such collaboration many times combines very distinct pieces of knowledge (Rajalo and Vadi, 2017). On that same ground, the university may develop the ability to become a successful entrepreneurial organization, on top of performing entrepreneurial activities that maximize its contributions to society (Huang and Chen, 2017). In this context lies the possibility of using such collaboration towards more sustainable business practices.

2.2 Teaching life cycle assessment and ecodesign in engineering courses

Environmental education has been marked by numerous facts, which are bases for developments seen today (Leal Filho *et al.*, 2015), for example, the Industrial Ecology (IE) and some of its central concepts, such as Ecodesign and LCA, have been gaining worldwide importance (Boyle, 2004; Cushman-Roisin *et al.*, 1999; Sriraman *et al.*, 2017). Sustainability has been a key driver in the education of engineers (Lockrey and Johnson, 2013) for when they leave university they will be responsible for putting into practice all their learning towards cleaner and more sustainable practices in the conception, redesign, engineering and reengineering and management of products, processes and services.

As approximately 70 per cent of the total environmental impact of a product is determined at the design stage (Lewis *et al.*, 2001), Ecodesign and LCA must target early actions. However, often the design phase is environmentally overlooked, among other reasons, due to limited internal expertise (Lockrey, 2011).

In the "education in practice" context, learning-by-doing activities allow students to work with a range of other subjects (Lockrey and Johnson, 2013) and are fruitful ways to preparing students for future real-life situations (Cushman-Roisin *et al.*, 1999). With this regard, the presence of an industry partner, providing real cases, motivates students to participate in their course activities (Lockrey and Johnson, 2013). Furthermore, companies such as Steelcase, Herman Miller, Ford, and General Motors agree upon the importance of addressing such sustainability issues in tertiary courses, in light of the decision-making practice (Aurandt and Butler, 2011).

Aurandt and Butler (2011) argue that adequate addressing of sustainability issues has been neglected in undergraduate programs. Thus, new methods to address the topic seem of unquestionable importance, as only lecture-based approaches are not sufficient to provide students with the practical knowledge and experience necessary to deal with estimates, data gaps and uncertainties present in real-world situations (Sriraman *et al.*, 2017). Therefore, project-based learning is regarded as one of the most appropriate approaches.

To Ashford (2004), sustainability teaching in design and engineering should be addressed in a trans-disciplinary approach rather than in multi-disciplinary teaching. Furthermore, Ashford (2004) claims that it can assist opening up the "problem space" for engineers, that is, students can already be presented to the multitude of criteria faced in decision-making and the potential need for trading-off. One of the concerns of wanting to promote such transdisciplinarity in the academic universe, as reported by Boks and Diehl (2006b), is that including sustainable design into usual product development process courses at the university mostly brings about thoughts such as "as long as it does not affect what students really have to learn", "but not at the cost of my course" and "as long as I do not have to spend time myself to learn about environmental issues" (Boks and Diehl, 2006b, p. 933). Nonetheless, it is concluded by Boks and Diehl (2006a) that imitating real-life problems, in an integrative setting, is the most successful way to communicate sustainability criteria. Under this light, a few strategies already have been put into practice in higher education, as reported in the following section.

2.3 Developments to course planning and implementation

Education is an important means to further the sustainable development agenda, including higher education (Thürer *et al.*, 2018). However, little evidence can be found in the literature on cross interactions between LCA and Ecodesign teaching in engineering, hands-on activities and university-industry partnerships. In the few existing studies, though, some overlapping features can be observed, as reported hereafter.

Problem-solving-based approaches are seen in industrial design engineering courses (Boks and Diehl, 2006a; Boks and Diehl, 2006b; Lockrey and Johnson, 2013), where students usually work in teams addressing a specific real practical problem. Boks and Diehl (2006a) present a series of course designs, which integrate sustainability issues into industrial design engineering.

Some authors report on project-based approaches, defending it to be the most appropriate means to bringing real-world cases to teaching future engineers. Designing entirely new subjects, some choose to give a well-established system for students to work on the environmental, and sometimes economic, assessment, giving them the task to account for uncertainties and data gaps over defined boundaries.

Filion (2010), who voraciously defends the idea of incorporating sustainability issues to engineering courses or having entire subjects dedicated to the theme, reported on the course design in a Civil Engineering course, leading students through the design of a water transmission pipeline and the assessment of its environmental impacts. Students had to conduct LCC and LCA of the referred system. As some information was given to them, students wished having had more autonomy to research it themselves. Overall feedback was quite positive, with great wish to have a follow up course, as a sequence of what they had learned.

Gilmore (2016) designed a course on LCA aimed at teaching from undergraduate to master's students. The course design included conducting an LCA on the design and operating parameters of a disinfection of wastewater system. Besides that, students were required to conduct LCC and analyze trade-offs in initial and ongoing states for different scenarios.

Leaning towards a different approach, other authors defend the idea of giving students broader tasks, as from having them choose their own systems to work with, or at least giving them certain freedom towards it.

Lockrey and Johnson (2013) proposed a product design curriculum where students were given a problem (a component/product, provided by an industry partner, to be used as the main component of a new product/solution) and then encouraged to come up with new products/solutions having that as the core component. Students were assisted by tutors in their proposals and during the project, students used the LCA Greenfly tool to conduct a streamlined LCA to assess the environmental aspects of their products and compare it to benchmarking alternatives (if there were any existing in the market).

Sriraman *et al.* (2017), in their turn, adopted a hybrid approach involving project-based and problem-based learning. The authors reported on the development and assessment of a graduate course based on sustainable engineering and IE where students were required to conduct an LCA of a product of moderate complexity chosen by them. The students reported the learning approach to be better than courses based on in-class activities.

Approaches of quicker application can also be seen, as the one of Cushman-Roisin *et al.* (1999), who developed a board game, having the automobile industry as the theme. The game comprised the consideration of costs and impacts during the production, use and disposal phases of the vehicles' life cycle, requiring participants to perform a quick LCA along with cost strategies, considering from obtainment of raw materials, to production, to disposal/recovery. Feedback from engineering students was overwhelmingly positive, as it allowed them to think quickly and critically and have an integrated view of the complex life cycle.

Others yet, as Aurandt and Butler (2011), worked on the entire redesign of existing courses. The authors worked on the redesign of three engineering courses for undergraduate students to include sustainability issues and shift their approaches to include sustainable design by means of using tools such as Ecodesign and LCA.

Moreover, Luttropp and Lagerstedt (2006) report on students using the Ten Golden Rules of Ecodesign on squeezer, mini chopper and clipper projects for Ecodesign education proposals, justifying its choice for an Industrial Engineering course. In this sense, students were able to think about opportunities to minimize environmental impacts caused by a product available at the company.

All forms of addressing Ecodesign and LCA in engineering education proved to be effective and showed no way back to traditional learning, as they conquered students' approval and support. Learning was boosted as the more practical experience consolidated students' knowledge and rendered them more prompt to answer to actual sustainability issues.

3. Methods

This case study is framed around the LCA and Ecodesign teaching practice based on university-industry cooperation in an industrial engineering course. For this purpose, the following activities were carried out:

- identification of a partner industry and case study preparation;
- course design;
- description and assumptions of the case study;
- student assessment and feedback planning;
- organization of the final workshop with presentation to the industry partner.

Through the identification of the company (Activity 1), there was a visit to the industry to define the case study that would be carried out. To do so, the professors of the course considered: availability to perform the product LCA, low or intermediate level for difficulty in modeling the product system, availability of company data, and the real opportunities for Ecodesign improvements in the product. With this, the teachers collected the process data and the LCI data to allow the course to progress according to the activities described hereafter.

3.1 Course design

The course pedagogical principle comprised the adjoined use of theoretical lectures and a "learning-by-doing" approach, that is, at the same time students learned the theory they would already put that into practice as a way to demonstrate to tutors their understanding of the acquired knowledge; and laboratory practices, where students aimed at knowing and applying Ecodesign fundamented on LCA to a specific product. That was a distinct practice from which the engineering students were used to, based on explanative lectures, given by the professors.

Ecodesign was presented to the students at the classroom. At that time, concepts about Ecodesign, its proposal, and some design practices were presented and discussed with the students. Three design practices can be highlighted here: ten Gold Rules, EEA and LCA. The first one is a prescriptive practice, i.e. it is composed of ten generic rules to help designers to improve product's environmental performance, which is easier to students understand some applications at the first moment.

Then, EEA (Lindahl, 2000) was introduced, a design practice based on Failure Mode and Effect Analysis (FMEA). FMEA is a well-known tool by students since it is widely applied in other disciplines, such as Quality Management. EEA is more complex than the Ten Gold Rules, embedding qualitative-quantitative analysis and opportunities along the product's life cycle.

The course project was based on a real case study where the students conducted investigations on the environmental improvement of products throughout their entire life cycle (both solid and reticulated plastic brushes). These brushes can be seen in Figure 1. All was done in partnership with an industry collaborator, here called industry partner. A technological project was signed between the Federal University of Technology - Parana (UTFPR) Ponta Grossa Campus (university) and a Painting Tools Company (industry partner). The project was also registered as university extension at the Industrial Engineering Course.

Assisted by an LCA software tool, students investigated the potential environmental impacts of the products, from the extraction of raw materials to their final disposition, identifying the production stages where most of the negative impacts occurred, thus, enabling suggestions for improvement to be presented to the industry partner.

The course project was conducted according to the following steps:

- Step 1: *Lectures*. Lectures were delivered to present the definitions and meanings of LCA and Ecodesign, the methods and software tools that could be used in an LCA study.
- Step 2: *Data gathering*. Specific data of each product and the products themselves were obtained and given to students with the assistance of the industry partner. The products were painting brushes, named: solid brush n.2, solid brush n.3, reticulated brush n.2 and reticulated brush n.3.

Figure 1.
Differences between solid base/reticulated base and the polyethylene terephthalate (PET) filaments

Source: Own Authorship (2019)

- Step 3: *System modeling and impact assessment*. In teams, students started working on the practical phase of the project, which took place at a laboratory where the LCA software was available for them to use.
- Step 4: *Preliminary results*. The results obtained from each group were presented in graphical form and compared to identify potential divergence of data and, thus, conclude which brush (either solid or reticulated) had the least environmentally-impacting profile and show which production stage was the most impacting throughout the product life cycle.
- Step 5: *Ecodesign proposals*. A few changes were suggested to the product, identified from Ecodesign opportunities, such as weight reduction, volume reduction, material recovery and, substitution of materials by more sustainable ones.
- Step 6: *Final presentation*. A meeting was held to present the Ecodesign proposals based on LCA of the products (solid and articulated brushes) to the industry partner management personnel.

3.2 Description and assumptions of the brush case study

The university and the industry partner (producer of paint brushes), partnered to identify the environmental impacts caused by the solid and reticulated brushes throughout their life cycles, from the extraction of raw materials to the products' final destination.

Thereby, the aforementioned case study became the final project of the LCA course, where the students were challenged to elaborate and identify Ecodesign proposals based on LCA. This study was based on LCA Standards ISO 14040 (2006a) and ISO 14044 (2006 b). By means of the LCA software tool Umberto NXT v. 7.1.13 (educational version), students modeled the life cycle of the four types of brushes and analyzed them using the impact categories of Climate Change and Resource Consumption under the Life Cycle Impact Assessment (LCIA) methods IPCC 2013 and ILCD 1.0.8 2016, respectively. The LCIA was obtained by means of the database Ecoinvent 3 (version 3.3).

Thereafter, the impact results obtained for each brush type were presented in charts for comparison and selection of the product with the best environmental profile given the selected impact categories. After having checked the data, students presented the Ecodesign proposals to reduce the identified impacts. Among the proposals were the reduction of the use of virgin raw materials and reduction of brush dimensions. All proposals were welcomed by the industry partner.

3.3. Student assessment and feedback

Students' assessment was given in three partial deliveries:

(1) 1st. delivery: Objectives, scope and Life Cycle Inventory (LCI);

(2) 2nd. delivery: LCIA and Interpretation; and

(3) 3rd. delivery: Final report, comprising the Ecodesign proposal based on LCA.

After each delivery, students received prompt feedback from professors on their performance in the respective task. Feedback delivery was provided collectively (when the same flaws were spotted in most teams' pieces of work) and individually (when flaws were spotted only in certain teams). Once students were finished with all partial deliveries, a reassessment was done by the professors before the final presentation where the proposals were presented to the industry partner.

At the end of the course, students were polled, by means of a questionnaire, to assess the course design and students' performance throughout the semester. The main parameters in the assessment included:

- whether students had previous knowledge on LCA, its phases and standards;
- whether students had previous knowledge on the productive process of the brushes, products which were the target of the LCA study they conducted;
- to what extent the course had contributed to their knowledge on LCA;
- whether the teaching methods had encouraged their active participation;
- to what extent the learning had been challenging;
- to what extent the partnership with an industry partner, bringing a real case, had made learning easier; and
- which topics had been the easiest and the hardest to manage.

Having such information enabled identifying how satisfied each student was, concerning the teaching methods and the entire project posed by the course (university and industry).

3.4 Final presentation to the industry partner

In this step, students were entitled to prepare a presentation to the industry partner, aiming to present the project results, showing the parameters used in the deployment of the LCA investigations and explaining the results for the selected impact categories, thereby, pointing the best option for each brush type.

The students were divided into teams to work on the LCA investigations and were reunited as one group during the presentation, presenting collectively the results to the industry partner. The presentation comprised LCA definitions and principles as well as the results of all LCAs conducted by each group considering the selected impact categories.

One student from each team was elected within the team itself to explain the team's results. Notwithstanding, when presenting the ecodesign proposals, all students were present to defend the idea and reiterate its feasibility. After the students' presentation, the industry partner representatives discussed their perspectives regarding what had been presented and firmed new partnerships with the university.

4. Results

The base-design was provided to students by the professors. Each team was, then, in charge of making adaptations and assessing each product system (solid brushes 2 and 3 and reticulated brushes 2 and 3), using the impact categories of Climate Change (using the IPCC method) and Resource Depletion – mineral, fossils and renewable (using the ILCD method).

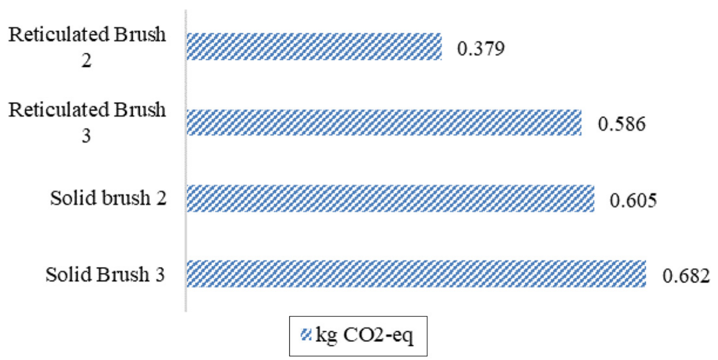
The results among teams showed little variation. The teams' averaged results can be seen in Figures 2 and 3.

As it can be concluded from Figures 2 and 3, overall, the reticulated brushes have a better environmental profile than the solid brushes. Reticulated brush 2 is the least impacting of all 4, whereas the most impacting one is the solid brush 3. Reticulated brush 3 and solid brush 2 have a very similar environmental profile both in terms of climate change and resource depletion, considering the LCIA methods used.

Students, then, had the impacts broken down into processes and materials. Having identified the environmental hotspots, students were told to formulate Ecodesign proposals so as to improve the environmental profile of one or more brushes. The teams presented the proposals shown in Figure 4.

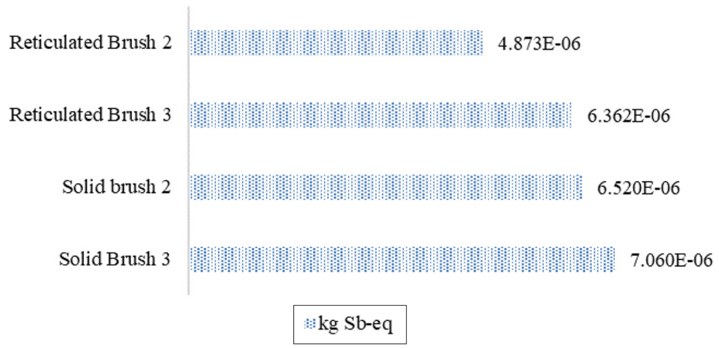
Some teams had similar proposals, culminating in overlapping results, which corroborated the possible options for improvement.

The product improvement proposals related to Ecodesign (Figure 4) were elaborated based on contents of previous courses, market research and information provided by the



Source: Own Authorship (2018)

Figure 2.
Averaged results for the category of climate change using IPCC



Source: Own Authorship (2019)

Figure 3. Averaged results for the category of resource depletion using ILCD

industry partner, always emphasizing product quality and efficiency and reduction of environmental impacts. Some examples are:

Group 2: The proposal based on reverse logistics arose from contents of previous courses in which the students participated and the information made available by the industry.

Group 6: Searching for the practicality of the brush users, the proposal developed to elaborate a Kit containing the base, cable and a refill of the bristles, was to think about the possibility of reuse of part of the product that is not affected by the use, changing only the bristles damaged. The idea came from Internet research and the foundations of the subjects observed during the course, with the aim of benefiting the environment and reducing costs for the consumer.

As it can be seen in Figure 4, some proposals comprised similar insights. During the final presentation, the proposals were presented to the industry partner, who later on gave feedback on the project's expectations and actual results. Students were also asked to give feedback, which is hereafter presented.

5. Discussion

5.1 Students and industry perceptions

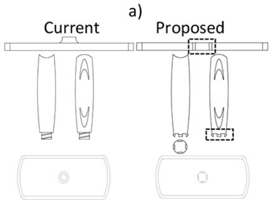
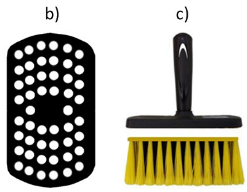
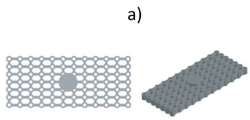
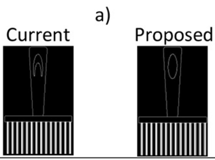
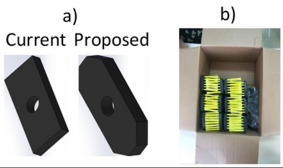
After completing the course, first, the students were surveyed by means of a questionnaire, which addressed subjects related to their knowledge before the course application and the subjects they found easy and/or difficult during the course.

Figure 5 shows the amount in per cent according to each student's response. In addition, a small chart is shown next to the answers.

The first question shows that a few students had previous knowledge on LCA; however, the overwhelming majority did not have knowledge on the process of the brushes. However, 100 per cent of the students reported that after completing the course, they have come to understand how an LCA study works.

In addition, most students fully agreed reporting they had felt more comfortable developing the study, and all students agreed that a technical visit to the company, to witness the production processes they were to deal with, would have influenced their learning experience.

Most part of the students (62 per cent) affirmed having had difficulties defining functional units and reference flows and using the software for LCA, whereas 29 per cent of them struggled with inventory analysis and Ecodesign concepts. The reasons for their

Team	Proposal	
Team 1		a) Replacing the mechanism for attaching the cable to the base - the current mechanism comprises a screw thread. The students proposed replacing it with a mechanism composed of plastic claws.
Team 2		a) Reverse logistics: returning a used brush - the consumer could return a used brush and get a discount on a new one. This would ensure correct destination of the old one; b) The more reticulated the better - Increasing the amount of holes would reduce raw material consumption up to 15.6%; c) Separating the filaments from the base - a new process was proposed where a hot tool would approach a set of filaments during the cut and thus create a plastic base with the filaments' material. This new base could be fitted into an adaptation of the current base. This would enable design for disassembling, where the set of filaments could be a stand-alone product and sold as refills.
Team 3		a) Redesigning the base - a new base was proposed in order to reduce raw material consumption; b) Selling cable and brush separately - this could enable reusing materials that still did not reach their end-of-life; c) Designing a reusable base - the focus would be replacing only the filaments, whereas the base could be kept.
Team 4		a) Redimensioning: reduction of PP - Redimensioning the cable would reduce raw material consumption
Team 5		a) Base redesign - this would reduce raw material consumption b) Box size redimensioning - changing the way the brushes were placed in the boxes for transport would, could significantly reduce the volume they take. This would result in either (i) reducing the box size to transport 16 brushes instead of 12 in the current way, thus for every 3 boxes, one would be spared, or (ii) increase the box size to transport 24 brushes.
Team 6		a) Replacing polypropylene (PP) with polyhydroxybutyrate (PHB) - PHB is a bio-derived and biodegradable plastic and could be composted. It would be an alternative for substituting PP; b) Printing barcode on the brush - barcode would be printed directly on the brush, rather than using a sticker; c) Reusing the cable - promote reuse of materials by, for example, giving discount selling the brush with no cable; d) Selling kits - develop a system where the set of filaments could be a stand-alone part, apart from the base and the cable, and sell kits with a spare set of filaments.

Source: Own Authorship (2019)

Figure 4.
Ecodesign proposals formulated by the six teams

Questions	(--)	(-)	( )	(+)	(++)	Chart
I had previous knowledge on LCA (phases and norms) before the course	24.0%	29.0%	19.0%	19.0%	9.6%	
I had previous knowledge on the productive processes (brush) that involved the LCA study	52.4%	33.3%	14.3%	0.0%	0.0%	
The course contributed to my learning on LCA	0.0%	0.0%	0.0%	33.3%	66.7%	
The teaching methods encouraged my active participation	0.0%	0.0%	4.8%	47.6%	47.6%	
The professors created a good continuity among the different teaching techniques (lectures, case discussions, use of software, tutorials)	0.0%	0.0%	9.5%	38.1%	52.4%	
The learning was challenging	0.0%	0.0%	14.3%	33.3%	52.4%	
The contact with an industry's real case made learning easier	0.0%	4.8%	9.5%	9.5%	76.2%	

Notes: (–) Totally disagree, (-) disagree, () neutral, (+) agree, (++) totally agree
Source: Own Authorship (2019)

Figure 5. Questions and answers given to the students

difficulty were no previous knowledge on the subjects of Ecodesign and LCA, lack of time availability to focus on the project/course, little or no knowledge of the LCA software and low course workload.

On the other hand, among the subjects students found easier to learn and assimilate were: LCA (concepts and application) (67 per cent), objective and scope definition (62 per cent), interpretation (52 per cent), Ecodesign (43 per cent) and impact assessment (38 per cent). The most recurring reasons supporting these results were reported by students as being: previous knowledge on the specific subjects from previous courses such as Waste Management and Environmental Management; practical activities/classes conducted during the subject; the approach used by professors during classes making learning easier with clear explanations and examples and; in-class discussions.

One of the main appraisals students highlighted was the performance of professors when explaining and exemplifying the topics, which were enriched by class discussions on every step of the way, yet, facilitating the later phases of impact assessment and interpretation.

Students were also asked to give an overall rate to the course according to:

- professors' performance;
- balance between in-class and at-home activities;
- student's own performance;
- acquired knowledge and;
- having the course lectured by two professors.

The results showed a very positive feedback from students on all aspects of the subject showed the used approach to having been welcomed and effective, with students being overwhelmingly satisfied or very satisfied.

When students were asked to point the positive and negative aspects of the subject, on the one hand, as most recurring positive aspects regarding the course as a whole, students reported: working on a real case and having practical assignments, taking them closer to the industry reality; the relationship UTFPR-industry partner; having the opportunity to present their results to the industry partner; break of a "traditional teaching system"; encouragement of creativity via the ecodesign proposals; having different views with two professors lecturing; teamwork; a dynamic approach and; pace of teaching. On the other hand, as most recurring negative aspects regarding the course as a whole, students reported: low course workload; insufficient practical classes/activities; lack of data on the productive system when modelling and conducting the LCA; not having someone with knowledge on the software to help with it at the times the laboratory was available to use; little time to work on the software tool.

A questionnaire was also applied to the industry manager. The first question relates to the level of satisfaction with the design of LCA based Ecodesign solutions carried out with the university. On a Likert scale, it was answered that the expectations were exceeded.

Furthermore, "bringing innovative solutions through students" was the answer given to indicate the strengths of university-industry partnership. In view of this, the industry partner replied that they would like to continue the project in the coming semesters, where LCA could be applied to other products or processes in the factory.

The manager reported availability of | more than 4 hours per month to assist students in the next semester. Therefore, when the course is offered again, the students can clear the doubts with the company in terms of product, process, materials and others. According to the company, other products can be studied revealing great potential to reduce raw material consumption and improve design.

The feedback from industry was satisfactory. They were interested in continuing the project in the following semesters. Thus, the university-industry relationship is important and positive. The application of a case study has benefited both parties.

5.2 Reflections from professors

From the feedback given by the students and industry over the semester, the professors were able to make several considerations about the benefits of teaching LCA.

First, students were more engaged with the project than in the past Industrial Engineering courses. This is due to the fact that ecodesign and LCA promote deep applicability related to industry's environmental problems. Students had to organize themselves in teams to collect data, analyze results and propose solutions. Although the initial classes were theoretical, most of the class time was spent in a real industrial problem case.

Numerous final assignments of undergraduate students are being developed, after the LCA course conclusion, correlated to the course's theme, which proves that ecodesign and LCA brought an increasing interest on students for research in the area. In a near future, LCA teaching could improve the number and the quality of Master's and PhD students in environmental research projects at UTFPR and in Brazil.

Students were also in touch with industrial practices which are, many times, far from the students' academic reality. Classes on environmental management tend to be theoretical, encompassing more concepts and applications than solving real problems at the industry level. Teaching LCA was an opportunity given to students to be involved with industrial problems, practices, products, processes and decision-making.

Ecodesign demands innovation and creativity at the companies' products and processes throughout the whole life cycle. Students were required to develop innovative solutions based on LCA results, which demanded them a search for sustainable materials, production processes, transportation and materials properties.

A large number of students' enrollment was also identified. Initially, the course was defined to be attended by only 22 students due to the restriction of software licenses at the university laboratory. For an elective subject, a high demand was observed, requiring to establish some criteria to select potential students to attend the course, for example, choosing only students with the highest Grade point average (GPA). It is also important to highlight that using LCA software tools and databases require some previous knowledge on ISO 14040 (2006a) and ISO 14044 (2006b) principles, mass balance, environmental management systems and other subjects. Therefore, to attend the course, students were required to have already taken other subjects on environmental management.

Strengthening the industry-university relationship was one of the most important benefits observed throughout the course. The industry offered a case, with information about products and data, while the university (professors and students) developed ecodesign opportunities for better environmental performance that could be implemented. The product manager, employee of the industry partner, declared interest in taking part in further courses the following year, assisting students with more technical information about products, materials, processes and data.

An innovative teaching-learning methodology was used, resulting in important contributions towards sustainability issues in higher education. Although the methodology of this case study has opportunities for improvements and adaptations, it certainly can be applied in different educational contexts and replicated by other professors or institutions.

Finally, students' awareness about their environmental responsibility was increased, since one of the professors' major concerns was related to the contributions of future engineers from UTFPR to sustainable development.

5.3 Further discussions

Innovative teaching practices that promote sustainability and relationships with companies can be an alternative for the modernization of curricular structures. Currently, there is great availability of academic information on the internet, and there are great challenges to enhance learning and involvement of students in curricular units. This paper presented an option that enhances students' and professors' learning, generates practical and real-world interaction with the corporate environment, stimulates creativity and problem solving and build a deeper basis for technical skills for sustainability, life-cycle thinking and ecodesign.

Regarding the course outcomes, it can be mentioned that the major challenges are related to the course planning. It is necessary to build a consistent theoretical basis on LCA and Ecodesign, and software learning in a short time. Students needed time to learn about the real-world case and be creative to promote green solutions.

The process and results of the projects regarding sustainability impact can be observed in the three spheres of sustainability. The products should have better environmental performance after Ecodesign solutions and potential environmental impact measurement. The education and students' skills were improved. The university's interaction with industries promotes social and regional development. Using real cases, students are encouraged to think about the feasibility of technical implementations that promote competitive advantage and economic development.

To finish, as potential drawbacks are the limitations on finding products and companies that may be partners in the course. Not all companies are available and willing to participate in this type of partnership (university-industry). Moreover, it is not any product that can be used as a course case. As recommendations it is suggested to use products and processes from manufacturing companies with real and practical potential for changes in design and production processes, for example. Industries that use injection and extrusion processes, textile products, and product design companies are options recommended by the authors.

6. Conclusions

This paper offers a valuable real-world example of introducing LCA with ecodesign considerations into an industry-collaboration at an engineering undergraduate course.

Revisiting the research question, "what LCA-based Ecodesign teaching practices coupled with a university-industry collaboration can assist in sustainability teaching and learning in an industrial engineering undergraduate course?", in summary the authors provided the following option. One seemingly effective way to incorporate LCA-based Ecodesign into teaching practices to assist sustainability teaching and learning in industrial engineering undergraduate courses is by developing a partnership between the academia and an industry partner and bringing real-world cases from the industry partner to be solved within the engineering curriculum, involving students and industry managers in the same project, giving students freedom to develop creative problem-solving skills and having them receive real direct managerial feedback on their ecodesign proposals to solve the problem or provide improvements on the issue. That can be done providing students with theoretical knowledge and freedom to practice LCA studies as a guide for environmental profiling assisted by LCA software tools and existing inventory databases. Furthermore, the approach included constant feedback and assistance from professors with expertise on LCA and ecodesign.

Besides the description of the teaching approach, this paper also presents feedback and follow-up reflections on students' and the industry partner's perceptions, and it is an interesting contribution to various professors, managers and developers in higher education. The results were found to be satisfactory and recommended to other engineering courses and universities.

The study evaluated by LCA tool the solid brushes 2 and 3 and reticulated brushes 2 and 3 using the impact categories of Climate Change and Resource Depletion – mineral, fossils and renewable. The solid brush 3 represented the greatest potential environmental impact for the two impact categories. To students and industry perceptions some questions were asked for them. As a result, all students and managers answered the questionnaire. It was noticed that the knowledge acquired by the students at the end of the course was substantial. To reflections from professors was observed that the students were more engaged with the project than in the past Industrial Engineering course.

One the one hand, it is observed that there are researches around the world using approaches based on teaching in the areas of LCA and Ecodesign in engineering education, there being different forms and pedagogical techniques to teach sustainability. On the other hand, barriers and pedagogical problems are faced in engineering education, however, research as the one presented in this paper is important to contribute to sustainability in higher education development and promotion. Projects in the area of LCA and Ecodesign can also contribute, in pedagogical terms, to engineering teaching. Awareness to environmental responsibility has increased in the last years, thus student engagement in the environmental aspect of sustainability is essential. This engagement begins to be formed in the classroom and directly reflects the performance of the student in the industrial sector.

The project proved that the academia-industry connection enhanced students' engagement and led to results that exceeded the industry partner's expectations. This study corroborated the idea that practicing while learning content is an effective way to teach the undergraduate student. The theoretical and practical LCA and Ecodesign contents alignment made learning easier and more quickly absorbed by students. The students were faced with a real case study that took place in partnership with a company to promote innovations and sustainable solutions. In this sense, the university-industry relationship can be seen as a win-win, once both institutions profited from the partnership. It needs to be highlighted that the teaching approach was the university's initiative and not the industry's demand. To the industry partner, collaborating with the university was a means to improving their Ecodesign practices.

As the experience was positive for both parties, the partnership remains open for future collaboration and opportunities in Ecodesign.

The concepts of life cycle thinking, LCA and Ecodesign prepare engineering students to face the sustainability challenges in the near future. Developing LCA and Ecodesign skills by students is critical to the success of engineering practice and to achieving sustainable professional commitment. In this sense, the study also intended to encourage further approaches, new forms of LCA and sustainable learning, tightening the ties between industry and university.

The implications of the study move toward the teaching engineering more efficient and the students can learn a discipline by applying a real case study to an industry. In addition, the study intends to show that the university-industry relationship can generate significant results for both sides. It is an interesting contribution to various teachers, managers and developers in higher education.

Furthermore, the work suggests opportunities for further studies. Universities and research institutes may apply a similar technique reported here to generate comparability and mainly, to develop the teaching LCA and Ecodesign in engineering courses.

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