CASE STUDY: LCA THREE WAYS

INTRODUCING INDUSTRIAL DESIGN UNDERGRADUATES TO FAST-TRACK LIFE CYCLE ASSESSMENT

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PAPER ABSTRACT: Life cycle assessment is one of many tools a designer can use to design products for the circular economy. Unfortunately, commonly used software that offer comprehensive life cycle assessment (LCA) presents a challenge for students to use in design without extensive training. This case study discusses the use of three different fast-track LCA tools with 4th year industrial design students. A small-scale survey revealed that each student found at least one tool approachable enough to use in future design work.

Keywords: sustainability, fast-track life cycle assessment, circular economy, product systems.

1. INTRODUCTION

It is estimated that 80% of the environmental impact of a product is defined at the early product development stage (McAloone & Bey, 2009). This means that designers bear the responsibility of advocating for environmental protection and as such, need to have competency in many skills and methodology centered on sustainable design. Educating the next generation of designers who embody the confidence to design for the environment is critical. Recently, Watkins at al. (2021) surveyed academics from the United Kingdom, Australia, Denmark, the Netherlands, and the United States to understand the state of sustainable product design education. Through their reflections on teaching and research practices, they determined that life cycle assessment (LCA), life cycle design, sustainable product design strategies, and systems thinking are essential in undergraduate and graduate design curricula. If the goal of sustainable design is ultimately to eliminate landfill waste, then designers need to carefully think about how they utilize 10R design strategies (Reike et al., 2018), and how they are sealing that fate into the product at those early development stages.

Life cycle assessment is a decision-making tool which can help designers prioritize the reduction of environmental impact across different points of the entire product life cycle using quantitative measures (Jolliet et al., 2015). Designers can focus on the impact of primary versus secondary material use, evaluate the impacts of using a different material entirely, or assess alternative end of life scenarios. There are plenty of ways to conduct a full LCA using various software such as GaBi (Sphera, n.d.), SimaPro (SimaPro, n.d.), and openLCA (openLCA, n.d.), but without thorough training, the process can be intimidating and confusing. In this case study, students were introduced to a simplified approach whilst still honouring the ISO standard (ISO, 2006), referred to as 'fast-track LCA' (Vogtlander, 2014). The fast-track LCA approach is centred on comparing the overall environmental impact of design alternatives with one impact score, rather than calculating each emission to air, water, and soil and how they impact human and ecological health. Also referred to as 'streamlined' or 'simplified' LCA, these approaches use generic data to save time and expenditure compared to a comprehensive study (McAloone & Pigosso, 2017). Reverse LCA's take a similar approach, starting with the analysis of a generic product, then determining what the optimal 'green product' might be if designed for the user and environment in tandem (Graedel, 2011). In a similar teaching approach to Suppipat et al. (2021), this case study explores the student experience of using different tools to generate fast-track LCA data which was used in evaluating existing, then redesigning consumer electronic products. Two categories of tools were taught: calculation by hand, and calculation through software.

2. CONTEXT AND APPROACH

Fast-track LCA was taught across two 4th year courses in the Industrial and Interaction Design program at Syracuse University. The first, Product Systems, is a required course and the second, Advanced CAD, is an elective that a handful of the 4th year students were concurrently enrolled. The Product Systems course was centered on teaching students about the environmental impacts of design choices within the current cradle-to-grave consumption model. Students were challenged to think about the gravity of their impact on the environment and work towards a circular economy design strategy. They were tasked with the redesign of consumer electronic products (countertop kitchen devices, handheld power tools, clothes irons, etc.) for a circular future. As is customary in LCA methodology, students calculated the baseline impact of the current product and create alternative scenarios by which to compare the impact for their proposed ideas. Students were informed that small consumer electronic products are not recycled in Onondaga county and unless they are resold, the assumed end of life was landfill.

In the Advanced CAD course, students were taught to use data insights to improve the carbon footprint of their products. For example, students were introduced to plastics simulation which models injection molding behaviors that can be used to reduce short shots and air traps. Coupled with the *Sustainability* software add-in in SolidWorks, students were asked to consider the redesign of plastic components specifically for disassembly and recycling. They were also tasked with determining whether there were better material and product geometry choice that could be made while still satisfying the product's performance criteria.

Prior to calculating an LCA, students were primed with lectures and discussions on life cycle thinking through case studies (de Sadeleer & Lyng, 2022; Dormer et al., 2013), literature written for design students and practitioners (Penty, 2019) and LCA researchers (Jolliet et al., 2015). To generate an LCA, material extraction, material processing, transportation, inputs to use the product, and end of life outcomes need to be mapped. Figure 1 shows the protocol that students followed in building their LCA.

Product lifetime and a functional unit need to be determined so that a comparison can be made across product redesign scenarios. For example, over a two-year product lifetime, 750 cups of coffee were made, or over a 5-year period a rechargeable battery was charged 100 times.

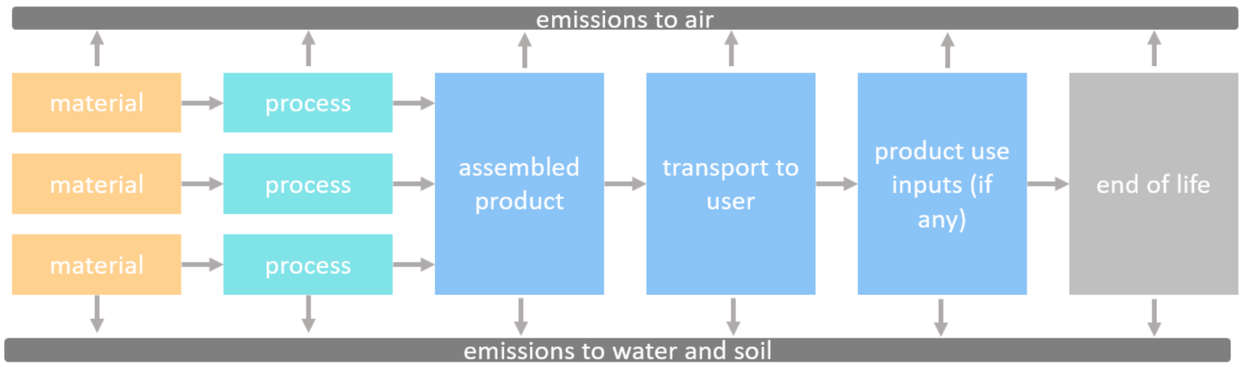


Figure 1. Impact points were calculated for each stage of the cradle to grave process. In the baseline product example, end of life was set to landfill which corresponds to the region's protocols for small electrical products.

CALCULATING BY HAND

Two approaches we used for calculating overall product impact in the Product Systems class:

1. The Okala Practitioner (White et al., 2013) which provides a lookup table and examples of how to calculate impact;
2. Idemat 2021 which provides a programmed spreadsheet hosted by the VentureWell website (VentureWell, n.d.).

These methods follow a similar workflow for impact calculations (from different source data), however Okala relies on the students calculating by hand whereas Idemat has a spreadsheet with programmed equations and graphing output. The other important difference is that Okala uses imperial measurement input (lbs, inches, miles) and Idemat uses metric (kgs, mm, kms). The students learned both methods and were given the choice to use either in their individual project. The baseline impact scores were built using the following information and look-up tables from Okala and Idemat:

- **Bill of Materials (BOM) from the product breakdown**. Material assumptions were required based on product research and material suitability. Weights for each component and material type were captured. Individual elements of the electronics and battery composition were not considered but were included as subassemblies and calculated as such.
- **Materials processing**. Students used their knowledge of product manufacturing techniques to determine how each component was made.
- **Transport to the user**. The exact location of product assembly was difficult to determine, therefore was approximated. For example, if the product was manufactured in China, students selected a city in China that has established manufacturing industry. This location was used as the starting point for calculating transport impact. From here, the product travelled from port to port, then by rail to a product distribution centre and finally by truck to the School of Design.

- **Product use inputs**. Students calculated the inputs needed to use the product over their defined product lifetime. This included electricity for running the product or charging the battery, water for the iron and coffee machines, and number of single serve coffee pods or quantity of loose coffee. They did not calculated maintenance such as water or soap for cleaning.
- **Functional unit**. The impact was summed across the categories and divided by lifetime to give the impact per functional unit e.g., impact score divided by 10,000 hours of use equals impact per hour.

This process was repeated for each design alternatives to assess their new product impact. Strategies used included product light weighting, using recycled materials, eliminating redundant features, optimizing the design for repair and battery replacement, reducing material types to maximize recovery through destructive recycling, and making it simpler to recover internal components such as batteries, water pumps and motors before the product shell is recycled. Product packaging was also considered in the LCA. Many students opted to remove environmentally damaging materials and reduce overall packaging size.

CALCULATING THROUGH SOFTWARE

SolidWorks Sustainability (SolidWorks, n.d.) was used to evaluate the impact of consumer electronics plastic shells. As stated, approximately 30% of the students in the Product Systems class were also taking Advanced CAD. At the point in the semester when LCA was taught in CAD, these students were already calculating impact with Okala and Idemat. A refresher lecture was given about the importance of LCA in reducing design impact on human and ecological health. In the software, fewer calculations were required from the user and the focus was on injection molded components. The inputs were:

- **Materials.** SolidWorks provides an exhaustive list of plastics for injection molding, thus students selected one that made sense for the product parts that were analysed.
- **Materials processing location**. Only the continent was selectable for this analysis.
- **Transport to the user**. The exact route was not required. Students selected a continent, and the software automatically populated the mode of transport and number of miles.
- **End of life**. The program adjusts end of life percentages (recycle, incineration, landfill) based on the continent of use. These were adjustable to reflect the actual end of life scenario in Syracuse.

In this process, there were no impact scores, rather total carbon footprint, energy used, air acidification, and water eutrophication metrics were given. The software allows for the comparison of one scenario with the baseline and the output was reviewed on screen as percentages, or as actual quantities in a downloadable report. Strategies employed by the students to decrease the environmental impact of injection molded plastics were light weighting the design, selecting a different plastic type, and manufacturing in the continent of product use to reduce transportation distance.

DATA CAPTURE

To capture student opinion on the three LCA tools, a two-question survey was distributed to the seven students who were enrolled in both courses. They were firstly asked to rate how much they disliked or liked on a 5-point semantic differential scale (dislike to like) and secondly whether they would use each of the tools again in future design work. The students contributed anonymously.

3. RESULTS AND DISCUSSION

The semantic differential question revealed that Okala rated more highly with all students scoring the approach positively (moderately like, and like) with Idemat scores ranging from moderate dislike and neutral feelings to a small percentage stating that they moderately like the method (Figure 2A). When asked if they would use each of the tools again for future design work, the results closely matched their opinions on how much they liked the tool. All students stated that they would use Okala again, and five of the seven said that they would not use Idemat again (Figure 2B). Interestingly, Okala is the most labour-intensive method to calculate impact as students needed to manage the calculations themselves, either on paper or in their own spreadsheet. The benefit of this tool over Idemat is that the user has complete control over the format in which the data is organized and gave the students perhaps more perceived freedom to explore how they wanted to visualize the data. It may also be due the usability of the impact look-up table; Idemat had significantly more columns of information to search through compared with Okala. Perhaps student preference for Okala over Idemat was due to way it was taught. Olaka was taught directly by the professor, whereas Idemat required that they watch an online instructional video to supplement the professor's introduction to the method. This is not to say that industrial design students will always favour one method over the other; different cohorts may have differing preferences.

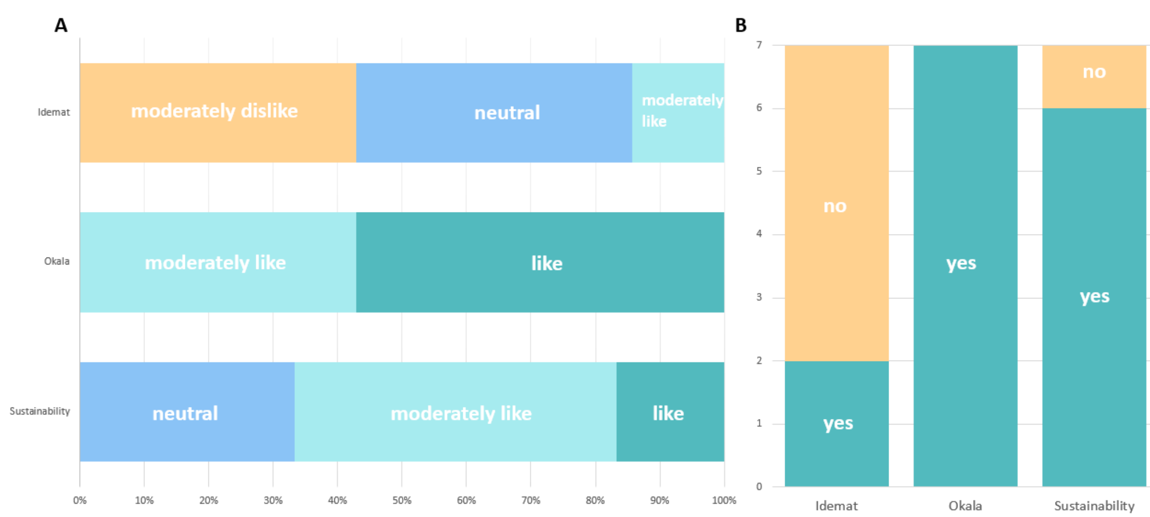


Figure 2. Results from student survey on LCA calculation. (A) Rating on a 1 to 5 scale, 1 being dislike, 5 being like, to what extent they liked the calculation method. (B) Results for whether they would use each method again for calculating LCA.

SolidWorks Sustainability add-in was well received by students (Figure 2A). Although perhaps not directly comparable to Okala and Idemat due to the need for a CAD model to generate impact scores, it did offer students an opportunity to measure unit-based impacts, such as kilograms equivalent of carbon dioxide. Linking through to the Solidworks website, students could visualize what the amount of carbon dioxide meant by comparing it to the number of kilometres you could drive a hybrid car and produce the same quantity of emissions. Perhaps best used specifically for CAD-based product refinement, students mostly reported that they were likely to use this calculation tool again (Figure 2B).

SUCCESSES IDENTIFIED IN STUDENT WORK

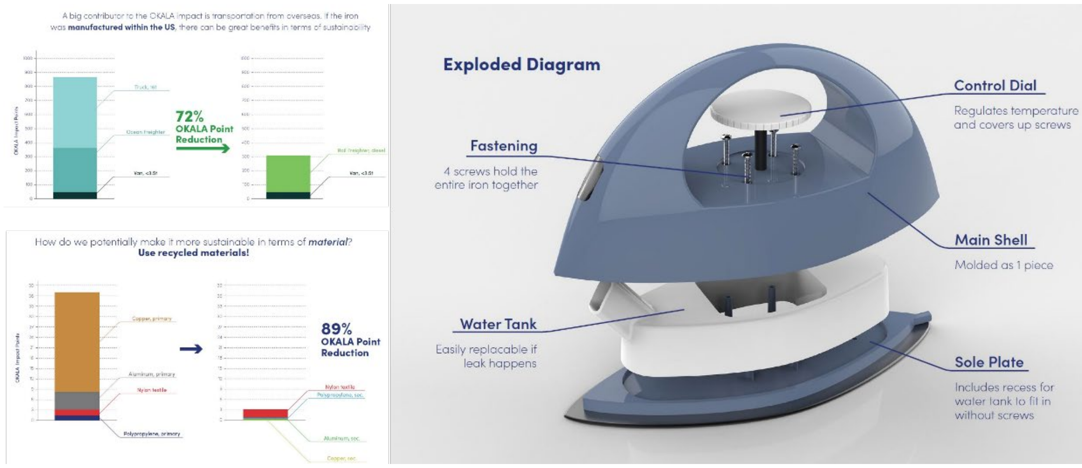
From an instructor standpoint, successful application of LCA to understand environmental impact in design choices was evident in student work. Figure 3 shows samples of LCA outcomes being used in the ideation process. As discussed, students needed to fully understand the impact of the current product (albeit with some assumptions on the exact materials for some components) and work to redesign their product to have lower environmental impact and fit in to the circular economy. Showing LCA calculation in their process books was a course requirement, but the level of detail and exploration shown by many students exceeded expectations. Similarly to observations by Suppipat and colleagues (2021), fast-track LCA gave students the opportunity to innovate within this product category catalysed by reducing environmental impact.

OBSTACLES IN FAST-TRACK LCA APPLICATION

When comparing new designs to the baseline product, you need to have the same information to calculate impact, and this primarily means the mass of each component for the new product. There were two ways this problem was solved by the students: from a physical or from a digital prototype. Low/medium fidelity cardboard prototypes were produced by each student to show basic product functions that illustrated design for the circular economy (e.g., ease of component access for repair or replacement). The new mass of redesigned components could be roughly calculated by using the model geometry and the proposed material density. Students who modelled their design in CAD were able to retrieve mass information through the software. Both approaches were time consuming but necessary to complete the scenario comparisons to the baseline product impact.

The other obstacle for students was end of life characterization and accepting that at least in Syracuse, consumer electronic products end in landfill and that it will take time for infrastructure to exist to change this disposal outcome. Many students opted to work to the idea that one day, recycling systems will accept consumer electronics. As such, many designers decided to ere on the side of optimism and designed their products with simplified internal organized to optimize the recovery of electronic components and maximise recyclability of the outer shells.

A



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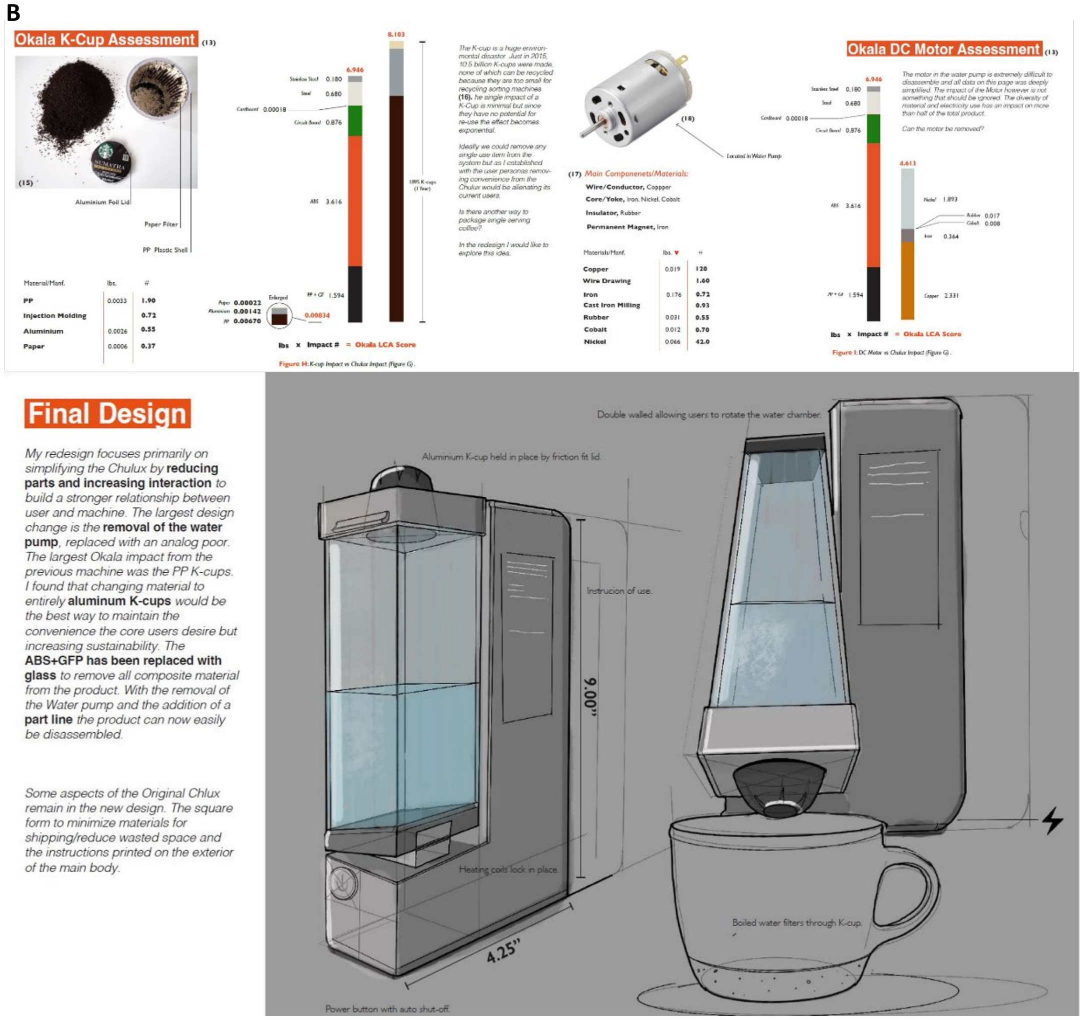

Figure 3. Two examples of student work in Product Systems. (A) Redesign of a budget clothes iron with a focus on using secondary materials and extended product lifetime through simple part replacement. (B) Redesign of a single serve coffee pod machine, exploring coffee pod materials and a powered versus gravity fed water system eliminating the need for a motor.

4. CONCLUSION

This case study describes how 4th year industrial design students were introduced to fast-track life cycle assessment in two courses in the same semester. In both courses, students needed to justify their design choices for reducing environmental impact and explain what the LCA data meant. The fast-track approaches of Okala, Idemat and SolidWorks Sustainability helped to make LCA more approachable by giving designers accessible tools without extensive training to decide on appropriate strategies for the circular economy. It was important for students to recognize that this is just one tool of many to help guide their process and that as a fast-track approach, they must acknowledge and document the assumptions, estimations, and omissions made in generating single impact scores. This case study shows that across the students surveyed, everyone selected at least one approach that they liked enough to use in their coursework and in future design work.

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