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Life Cycle Assessment in an Ecodesign Process: A Pedagogical Case Study

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Abstract

To face environmental requirements in the design area, it is crucial to work on the education of younger generation to sustainable design. But literature shows there is a growing need for both teachers and learners to develop pedagogical support to help the integration of sustainable concerns and tools in the education. This article focuses on Life Cycle Assessment in the scope of an ecodesign process. Through a case study, the aim is to illustrate it with firstly a succinct version of the LCA of an electric kettle and then suggestions of ecodesign strategies based on the outcomes of the LCA.

Keywords: life cycle assessment (LCA), ecodesign, case study

1. Introduction

1.1. Challenges of ecodesign education

For a couple of decades there have been a growing need in the industry for new environmental knowledge and competencies. In the area of product design, the impact of each and every decision is major on the future environmental impact of the product. Indeed *"the developer significantly influences the environmental impacts of future products. During the development process, a product's function, its operating principles, shape and material are determined and with that, the most prevailing technical, economical as well as ecological product properties are specified"* (Kattwinkel et al., 2018). Therefore to meet legal requirements and to increase their competitive position, the development of sustainable products is a new challenge for companies.

Among strategies to enhance a company's environmental performance, ecodesign is one of the most studied in the literature by both academics and industries. Ecodesign is considered a sub-discipline of sustainable design and is defined as the integration of environmental concerns into the product development. Many advantages of ecodesign such as "*its quantitative approach or environmental target settings"* (Verhulst and Van Doorsselaer, 2015) make it attractive for industrials case. Therefore companies are in urge of students educated to sustainable issues and new practices and tools. Ecodesign is indeed promising on that matter as *"it offers the students knowledge, insights and skills on the environmental and economic part of the innovation and product development process"* (Verhulst and Van Doorsselaer, 2015).

However ecodesign currently is not fully integrated for both academic curricula and industrial practices. There exists a considerable variety of ecodesign tools and methods that have been developed in academia in the past couple decades but their isn't always the associated pedagogical content to enable beginners (may it be students or industrial designers that are not yet educated to ecodesign) to assimilate those tools and methods. This being the case of Life Cycle Assessment.

1.2. Life Cycle Assessment as an ecodesign tool

Life Cycle Assessment (LCA) assesses the environmental impact of a product throughout its entire life cycle. It has been studied since the 1970s. At the end of the 90s, the International Organisation for Standardisation (ISO) defined and wrote down the principles and frameworks of a LCA process and offers a descriptive methodology of LCA (ISO 14 040 and ISO 14 044).

LCA is a tool that is recognised in the literature as valuable in a ecodesign process. Indeed ecodesign needs to rely on quantitative approaches for target setting: "which of these impacts are deemed relevant for setting and measuring improvement targets?". It is an assessment methodology, which can be used to answer such questions. *"LCA enables the company to perform environmental target setting that is scientifically robust and make efficiency and transparency improvements."* (Alexandra Bonou et al., 2016). That is why *"Life cycle engineering has been adopted as baseline for the development of engineering courses oriented to ecodesign and became a consolidated trend in engineering Education »* (Favi et al., 2019).

As LCA is a key element in the companies' strategy to integrate ecodesign process, engineering education must meet the challenge of offering the appropriate pedagogical content to meet the demand while providing keys to promote questioning of the existing. The application and modelling of LCA framework in a study case of an ecodesign process is the main focus of this paper.

The aim of this paper is to illustrate the use of LCA for the redesign of a product in an ecodesign process, as pedagogical content addressed to beginners from any background. In the first section a literature review is conducted to understand the existing on LCA frameworks and its place in an ecodesign process and to pin down the lacks and main issues. The second section presents a pedagogical case study to illustrate the process and what could be the main steps and issues for a beginner. In a third section proposals are made on possible follow ups in the process. Afterward, discussion section goes over the specific learnings that this case study highlighted and we discuss the limitations of this case study for sustainable education. Finally conclusions are reached in the last section.

2. Literature review

2.1. Existing ecodesign frameworks

To understand the concept of ecodesign, there are plenty ecodesign frameworks that have been developed in the literature. Vallet et al. (2014) define an ecodesign framework as "*a research tool to help to develop awareness and communication on environmental issues. [...] meaning to be representative of the way of viewing ecodesign practice and processes in a sustainability perspective.»* Therefore it is a good representation for introducing general concepts and purposes of ecodesign.

In their article the authors reviewed several existing frameworks for implantation in industry on one hand and for education on the other hand. Then they developed their own ecodesign framework to provide students and practitioners a comprehensive multi-level -but nonetheless operational-framework. They represent ecodesign through 6 core dimensions. Each of them with different level of maturity. LCA in particular lies in the scope of the core dimensions of ecodesign: modelling lifecycle and choice and management of environmental criteria. In an ecodesign process, LCA is the mean of targeting the life cycle phases to act on by clearly defining the aim and scope of the study and the relevant criteria. It is considered as a rigorous tool to oversee shifting of negative impact (from a life cycle phase to another) or to prevent from going beyond the purpose of the study.

LCA is also framed and described in the norm (ISO 1404:2006). The ISO breaks down the LCA study into four distinct stages: goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA) and finally interpretation.

By defining the intended applications, the audience and the reasons to carry out the study, the goal and scope phase outlines the requirements and boundaries that we will have on the product system, on the data quality and on the interpretation.

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Following this initial set up, the LCI quantifies the relevant inputs and outputs of the product system in an iterative process (as the data are collected, the global comprehension of the product system increases and new concerns arise).

The LCIA translates this data inventory into environmental impacts. The level of detail, choice of the impacts evaluated and methodologies used depend on the goal and scope of the study.

Last but not least, the interpretation phase is to be carried out throughout the entire process. It evaluates the findings of the LCI and LCIA altogether, provides conclusions and recommendations while acknowledging the relativity of the approach and its limitations. The interpretation is consistent with the initial goal of the study and the form of its conclusions with the scope.

In the form of a mindmap, Ling-Ching et al. (2016) offer an extensive view of the concerns and requirements of each steps of LCA framework as it is defined in ISO 14040. It is a precious tool to expose with keywords what is behind each step of LCA framework. But despite its usefulness, it is a heavy amount of informations for beginners (may it be students or design engineers) as each point may not be relevant for everyone and it is not clear where to start. For instance, goal of the study will be basic for students as it is a study case made for itself. Or companies will seek for efficiency and shortcuts and won't want to go through an academical rigorous process.

2.2. Lacks in the current education

As ecodesign has been more and more implanted in engineering education curricula, Kattwinkel et al. (2018) operated a large review of sustainable courses in international curricula. This systemic review highlights the major topics that are needed to handle sustainable design. For ecodesign and LCA in particular, some of them are more relevant (manufacturing, energy efficiency, lightweight engineering etc.). Those fields cover several of the product lifecycle phases and are needed to understand the lifecycle as a whole. Holistic knowledge is needed to be able to come up with new solutions, to be critical and to identify and avoid the shifting of potential environmental burden between lifecycle phases that may occur. However difficulties remain to show this interconnection while lecturing each field separately. Moreover, a lack of continuum between courses and between the different level of education has also been highlighted in the French education system by Perpignan et al. (2020).

Also after reviewing international curricula Kattwinkel et al. (2018) highlighted that for *"all product lifecycle phases as well as the product development and the greater context"*, there were courses addressing those topics *"except for the usage phase"*. Given that *"For many technical products the usage phase is the most impacting of the life cycle phases."*, it is a substantial lack in education. This can be explained by the difficulty to approach the usage phase only with theoretical methods, as it is highly dependant on the case study and shifting of behaviour are often difficult to quantitatively evaluate and prioritize. Thus in depth case study are needed to fully apprehend the process of getting a grasp of the system or product and of the potential shifting of behaviour.

Verhulst and Van Doorsselaer (2015) emphasize the need of research to support integrating sustainable in education programs as some researchers did. Perpignan et al. (2020) identified skills needed to be developed in ecodesign teaching. Macris and Georgakellos (2005) offer a tool to support the development of training material for learners. They argue the importance of fostering autonomous data collection. "*Knowledge transfer […] can only be achieved if the trainee digs up some basic understanding of the bits of information, the relationships between them, and why they exist, thus enabling him or her to make sense of the topic that he/she studies*".

Coming from design backgrounds, frameworks and methods are not enough to educate oneself to ecodesign. There is a practical knowledge of the iterative process that is ecodesign that can not be shown only through the current frameworks of literature. When conducting a LCA, a substantial amount of time is dedicated to collecting data. May those data be available right away or research has to be made as well as hypothesis and simplifications. Ecodesign and LCA analysis of a specific product requires to gain knowledge on fields relevant with the product to be critical with the hypothesis made. Requirements of industrial designers for ecodesign tools have been studied by Lofthouse (2006). Surveyed designers *"asked for examples of ecodesign, to help them to "see" […] and to understand "the types of issues which can be considered"*. They also expressed that the process

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was too time consuming to be carried out on a regular basis as they were unaware of where to look for informations and no resources summarise relevant issue for industrial designers.
The benefits and eco-learning outcomes from LCA case studies have been proven by Favi et al. (2019) as it stimulates awareness on data to collect, issues to consider and can be used as a base for further reflections on ecodesign tips and best practices. Therefore in the next section we present a pedagogical modelling of a LCA process.

3. Modelling of a LCA process

3.1. Criteria for our modelling

Based on the requirements highlighted by Lofthouse (2006), we have identified a need for illustrating LCA process as well as the requirements on the form our study case should take: not too time consuming, highlights what to look for and gives precise resources, short and punchy lists and maximum use of graphics.
Consequently, we have conducted a case study on an electric kettle. We wanted a consumer good, easy to apprehend and common enough to be within reach for anyone. Following the ISO 14040:2006 on environmental management and lifecycle assessment, we will divided our LCA into four phases : the goal and scope definition (Subsection 2), the inventory analysis (Subsection 3), the impact assessment (Subsection 4) and the interpretation (Subsection 5).

3.2. Goal and scope definition

As presented in the introduction of this article, the goal of our study is to offer a comprehensive view (yet understandable for any background) of how a Life Cycle Assessment can be handled at a beginner level: what kind of data are needed, how to collect them and what hypothesis have to be set? The scope definition derives the requirements on methodology, quality, reporting, and review in accordance with the goal of the study. They are summarized in the following points (Table 1):

Table 1. Key points of the goal and scope definition of the study

Goal of the study			
Intended application		To present a pedagogical case study illustrating LCA as part of an ecodesign process	
Targeted audience (internal or public, technical or not)		Public, from any background	
Decision context (performance analysis, ecolabeling...)		To identify weak spots in order to redesign	
Scope of the study			
System of the product	Electric kettle + household consumption (water, energy)	*LCIA Method*	Impact 2002+
Functional unit	To warm up 20cl of water for a hot beverage (80-100°C) /day/year	*Types, quality and sources of data*	Experimental, external source, Ecoinvent 3.0 database

This case study being of pedagogical purpose and of beginner level for each discipline, assumptions and data simplifications have been made in order to keep the study clear and limit the amount of unnecessary informations. The whole study have been registered in a report but this article will only present a short overview.

3.3. Life cycle Inventory

The main purpose according to the norm is to "*quantify relevant inputs and outputs of a product system.*" (ISO 14040:2006). Despite being a quite common consumer good, the comprehension of our electric kettle offers us an interesting and multi-disciplinary study case. To quantify inputs and outputs, we need to study beforehand the different lifecycle phases of our product.
The following sections will present a succinct version of the study: the diverse phases then the modelling of the relevant data that has been made to carry out the LCA. The length allocated for each

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paragraph varies according to the significance of the calculated impact in the case of our kettle. The aim here is to illustrate the different considerations one may have when conducting a LCA, rather than being exhaustive in the data we present here.

3.3.1. Production phase

For this beginner level, we only discuss here the type of material chosen for the main body of the kettle. On the market there are two main materials' options: plastic (polypropylene) or stainless steel.
There are different considerations to have: mechanical/physical properties, impact on health, impact on the environment, aesthetic, costs, recyclability etc. Comparing two materials on one of these aspects separately is rather easy (Table 2). Yet when considered all together, things get messy. The challenge for any designers is to find a compromise in regards of the priorities set.

Table 2. Comparison of stainless steel and polypropylene

	Physical properties	Impact on health	Environmental impact*	Aesthetic	Recyclability
Stainless Steel	- : thermic isolation + : strength	Unknown	Heavier	Good	A priori equal in WEEE organisms
Polypropylene	+ : thermic isolation - : strength	Unknown	Lighter	Cheap looking	

* according Ecoinvent 3.0 database and the Impact 2002+ method

3.3.2. Use phase

Besides being a shortfall in current pedagogical content, the use phase was here also the hostpost of the environmental impact of our kettle. This paragraph is therefore more detailed.
To **model the usage phase**, it is useful to settle down a usage scenario that will define every user's action that we take into account. The usage phase can be divided into moments and each of theses moments comprehends different actions (Domingo, 2013). This tool is useful to go through every possibility (Table 3).
For the **measuring protocol**, the energy consumption of the kettle as well as its yields according different water volume can be easily measured. As the power is constant from on to off, the energy consumption is given by the time length of the heating. It is important however to note that the yield depends on our functional unit (heating to vaporising point or just to a certain temperature?).
When studying the use phase, one must not forget there is an irreducible gap between the ideal scenario and the **actual user's behaviour**. To foresee those *shiftings of behaviour*, we can rely on different methods and resources to analyse the user's behaviour (social science, institutional data, in vitro experimentation) and formalize it (persona, scenario, chronogram). These shifting of behaviour can be during an operating time or during maintenance (energy consumption, excessive waste generation, health and environment pollution…). An example is given below (Table 3).
In relation with our measure protocol, we have then to asses (quantitatively or qualitatively) the impacts of those *shifting of behaviour* (for instance xx additional kWh for xx cl of extra water or when the water has been forgotten for xx min). When highly likely to happen, it can be added to the data inventory for our functional unit.

Table 3. Assessment of potential shifting of behaviour

Moments	Shifting of behaviour	Potential effects	Likelihood
Operation : Pouring water	Heating more water than needed	Higher energy and water consumption	High
Operation : Turn on/off, wait during heating	Forgetting and needing to heat again	Additional energy consumption	High
End of life : Recycling	Discard in the wrong EoL branch	Loss of valuable material and incineration	Medium

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As we will see further in this article, those shifting of behaviour can inspire ecodesign strategies to tackle them. In Lidman and Renström (2011) model, adaptation can be operated to the product (to create new sustainable behaviour) or on the behaviour of the user (to limit negative behaviour).

3.3.3. Thermic behaviour

As the LCIA will later highlight, the energy consumption is the major environmental hostpost of an electric kettle. It was thus crucial for this product to study its thermic behaviour. The process is illustrated below (Table 4).

By modelling the thermic behaviour of the kettle according to its properties on a datasheet, we get a qualitative assessment of the impact of those properties on the energy consumption. The identified properties will be levers to act on when creating ecodesign strategies in order to reduce the impact of the use phase while evaluating the impact of their modification on the other phases of the lifecycle.

Table 4. Overview of the thermic study

Physical phenomenon	Impacting properties	Tools
Vaporisation Conduction Convection	Heating system (steam detection) Thermic behaviour (material, dimensions, thickness) Power Water volume	Basic thermic's formula Modelisation of the thermic behaviour according to the impacting properties value on a datasheet

3.3.4. End of life

The handling of waste are tightly connected to the territorial context and thus to the corresponding legislation. At the European level, the WEEE (Waste from Electrical and Electronic Equipments) directive makes mandatory the selective collect of EEE waste and makes the producer of EEE responsible for the financing.

In an ideal use scenario every waste material that can be recycled in the country is effectively recycled, thus minimising the actual impact of the end of life treatment of our kettle (stainless steel and polypropylene being theoretically recyclable materials). But to understand the possible end of life scenarios, some statistics are made available by organisms (such as Ademe in France). In the french example : EEE are handled by ecoorganisms that are accredited by the state and they publish their annual result. We learn there that it is during the collect phase that most of the waste are made (with only 52% of the thrown household appliances effectively collected in 2019 according to ADEME report (2019)). Those data show us that educating French consumer as well as rethinking the product system to preserve value and limit disposal are important levers in order to avoid the incineration and loss of valuable material.

Still on Ecosystem website (ecosystem.eco), helpful tips for an end-of-life friendly design are given such as facilitating the disassembly or avoiding certain materials or substances.

3.3.5. Inventory of the relevant data for modelling

Once the whole lifecycle (its different phases and their interaction) has been studied, we must quantify all the data according to our functional unit. The production phase is straight forward as it only depends of the knowledge we have of each material and of the more likely associated production and post-treatment processes (hypothesis to ignore the minor components can be made). The use phase and end-of-life are more complex as it depends on behaviour and socio-economical criteria. Percentage hypothesis can be made according to the likelihood of the identified shifting of behaviour. In the case of the kettle for tea making, we can assume that there is always 15% more poured water than needed or that 1 time out of 3 the user will forget the heated kettle and need another heating. For end-of-life scenario, national (or local) data are useful. For example in the french territory, we can consider only 52% of our kettles are effectively collected by ecoorganisms.

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3.4. Impact assessment

This step associates impact category and indicators with the inventory data. The norm (ISO 14040:2006) states that "*The level of detail, choice of impacts evaluated and methodologies used depend on the goal and scope of the study."* In our study the level of detail and the categories and indicators of impact are respectively determined by the chosen database (Ecoinvent 3.0) and methodology (Impact 2002+).

The *"quality assessment of the LCIA methods, assumptions and other decisions"* (ISO 14040:2006) are for a more advanced level that the one we target in our case study. To go futher ecodesigners should be aware of the various methods that has been developed in the literature. Each of them using different indicators and formulating impacts with different philosophy, it is interesting to compare their outcomes for a same product.

Optional elements of LCIA, such as normalising or grouping, can be used to simplify the following interpretation. Normalising enable to position the impact of the product compare to anthropogenic references (e.g average energy consumption of a European) but not to represent their impact. By grouping we aggregates several impact indicators into damage categories of impact but the weighting depends on the chosen method and is a social construction rather than environmental.

3.5. Lifecycle interpretation

With the results of the impact assessment, we can present results consistent with the defined goal and scope and reach conclusions. This starts by identifying which phase of the lifecycle and which components are the most impacting (for the kettle it was by far the energy consumption of the usage phase) then understanding which impact indicators are the most prevalent and why. Finally reach conclusions on actions needed to be taken (work on the yield of the kettle and improve its thermic behaviour) and recommendation on further approach (for parts that are still not clear or could not be further studied).

The interpretation phase of the LCA must acknowledge its limitations and subjectiveness to the uncertainties and the relevancy of the data. In line with the goal and scope of the study, collected data must meet quality requirements regarding technological, geographical and time-related representativeness and appropriateness. In our case study, we can question the regional average we chose on the Ecoinvent 3.0 database in accordance with our knowledge of the lifecycle of the product. Then conducting an uncertainty analysis consists to evaluate the range of uncertainties on the data and to what extent it impacts the conclusion of the LCA. For this pedagogical case study, we will not go deeper in the analysis of our data.

The conclusions of such a preliminary LCA offer a basis for ecodesign process and ecoinnovation. The next section is about follow ups we can do.

4. Further actions in an ecodesign process

4.1. Ecoideation

After this general assessment of the environmental impact of our product, the next step of an ecodesign process is to generate ideas and solutions to tackle the hostpost we have identified. Given that coming up with great ideas is not straight forward especially for beginners, ecoideations tools and sustainable innovation concept can be of great help.

The ecoideation phase is defined as *"the generation of ideas that reduce environmental impacts throughout the product life cycle of products"* (Bocken et al., 2011). Cluzel et al. (2015) give a review of associated methods and tools. For beginners, simple (although sometimes over simplistic) tools as the ecodesign strategy wheel (Brezet and Van Hemel, 1997) or eco-compass (Fussler and James, 1997) give guidelines and structures to organize ideas in terms of categories, lifecycle and level of innovation.

To spur new concept that are out of the box, one can also take a look at sustainable innovation concept. An already well known one is the circular economy (Esparragoza and Mesa-Cogoll, 2019). Because each and every components of our product do not have the same lifespan, it's about

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rethinking the model of the lifecycle of each major impacting components. That way "savings" can be made by spreading an initial production cost (plus the reuse/repair/recycling treatment) on several lifecycles. Circular economy is just an example of how an innovation concept can trigger ecodesign strategies. We can also mention economy of functionality or biomimecry.

4.2. Hostpost targets from our LCA

With the LCA of our electric kettle, we have concluded that the major environmental hostposts that we could act on were: the material and the thermic behaviour, the energy consumption in relation with the yield of the kettle (on an ideal use scenario) and the energy consumption in relation with the user's behaviour. Starting from there, we can suggest a list of ecodesign strategies (Table 5). But all those strategies must come with the foresight of potential negativ feedbacks (may they be environmental, economical or technical) and weighting them in a new LCA.

Table 5. Ecodesign strategies for the kettle

Ecodesign strategies	Concept	Potential negativ feedbacks
Prevent user's shifting of behaviour	Sonorous signal (inspired by Lidman et Renström (2011))	Weighing the impact of additional components to the energy savings
Take out the steam detection system (needing extra energy to vaporise water)	Redesign of the heating detection system	
Getting inspired of termite mound, polar bear and toucan for water volume control and thermic isolation	Biomimecry (see the Nautile Kettle (Design and innovation news, 2017))	Industrial feasibility of the concept and cost for the user

5. Discussion

Such case study provides specific learning we can highlight in the light of the UNESCO key competencies for sustainability (Rosén et al., 2019). In the LCA part, beginners develop systems thinking and critical thinking competencies as they collect and link data of the life cycle of a product and must assess the quality and the relevancy of those data. Favi et al (2019) emphasize the intakes of such a case study *"as it stimulates awareness on data to collect, issues to consider and can be used as a base for further reflections"*. On the further actions phase, the anticipatory and the strategic competencies are activated by assessing the hostpost of the product, providing ideas and solutions and foresee the potential shifting of environmental burden.

As this case study is addressed to beginners, the focus of the ecodesign process illustrated here has been on the redesign of an existing product (with data available) in order to be accessible to all backgrounds. However to be able to bring drastic changes, one should go back to the very initial steps of the design process. The further you step back from the existing, the more innovating and creative solutions you can come up with. This case study is an introductory education content, adapted to the competencies and knowledge of beginner from any background. To go further, ecodesign should stem from requirement clarification, conceptual design, embodiment design by using LCA as one of the decision-making support systems to guide through the different choices.

Yet we can question the relevancy of quantifying environmental impact with a "mathematical view" such as LCA and seeing environment just as another variable to adjust to. Lifecycle engineering is appealing for companies because it does not require radical change of the design paradigm. The optimisation of solution comes in the same way of designing product in a technical performance orientation. In order to bring significant changes to the production system, the new generation must be sensitized to fundamental questions of sustainability in order to be the instigator of new practices.

6. Conclusions

As the industries have to adapt to the public pressure for new environmental requirements, they need the current students to be trained to face the global challenge of their generation with ecosensitization, knowledge and methods. In this paper we have focused on LCA during an ecodesign process and we have highlighted a strong need of examples to illustrate the process for beginners. We have then

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presented a succinct version of the Life Cycle Assessment of an electric kettle, with the different concerns and resources one can have on each phases of the life cycle. Despite being a common consumer's good, the LCA of our kettle required to adapt the product for the comprehension of its lifecycle by the student (set hypothesis on the production and distribution, define a restricted use scenario, use such a complex database as Ecoinvent at a beginner's level). This study highlighted that for the analysis of a "simple" product, a strong preparatory work from the teacher was needed to enable students to deploy the research effort that will get them to structure their competencies and get to a more advanced level. In addition, we have discussed possible ecodesign strategies following that LCA to work on minimising the potential negative environmental impact of the product without shifting it to another life cycle phase. The aim of this article was to portray the use of LCA in an ecodesign process for a beginner level and to contribute to the pedagogical resources available in the literature.

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