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# Environmental service-learning approach in higher education - a descriptive case study on student-led life cycle assessments of university cafeteria meals

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## Structured Abstract:

**Purpose** – This study aims to share experiences of an easy to adapt service-learning approach in a graduate course on life cycle assessment (LCA). Specifically, it reports on how students helped the university's cafeteria to assess meals by conducting an LCA for 25 meals and identifying environmental hotspots.

**Study design/methodology/approach** – A descriptive case study of a graduate course at Ulm University is presented. The course included lectures and problem-based exercises, both theoretical and software assisted. A course evaluation was conducted during the course and one year after completion in order to poll improvement potentials as well as its impacts on students' everyday life.

**Findings** – It was found that although it was the first LCA for all students, the resulting LCA information of 25 different meals were homogeneous, comparable to the scientific literature, and beneficial to the cafeteria's sustainable development strategy. The concept of service-learning had a higher impact on students' motivation than a good grade, and active-learning is explicitly requested by students. The course design sensitized students to the real-life problems of LCA and made their consumption patterns more elaborate and ecological. Furthermore, this digitization of higher education could be carried out with only minor changes in the present COVID-19 pandemic situation.

**Originality/value** – As the subject of service-learning in natural sciences is still expandable, we present an easy to adapt case study on how to integrate such an approach into university curricula dominated by traditional learning. To the best of the authors' knowledge, this case

study presents the first published LCA university course explicitly describing and evaluating a service-learning approach. The topic touches every-day lives of students, allows comparisons between different student groups, is easily scalable to different group sizes and credits, and supports learning both how to work in small groups and cooperation between groups to ensure comparability of LCA results.

**Keywords** case study, life cycle assessment, LCA, sustainability, higher education, service-learning, problem-based learning

**Paper type** – Case study

## 1 Introduction

The seventeen Sustainable Development Goals (SDGs) set in 2015 by the United Nations General Assembly and concretized by specific targets and indicators in 2017 provide orientation for a more sustainable world by 2030 (Sachs *et al.*, 2019). The provision of food touches to a greater or lesser extent on almost all of the SDGs. It affects, among others, nutrition, health, water use, land use, life on earth, and climate, as well as decent work and responsible consumption and production (Rocha and Spagnuolo, 2019). Though relationships are often complex, and the impacts of a food product are sometimes rather hidden, the awareness of sustainable lifestyle choices regarding food production and consumption, like vegetarianism and veganism, increases (Kamble *et al.*, 2020). A number of people are also willing to pay more for sustainable and/or more healthy food (Ha-Brookshire and Norum, 2011; Zhou *et al.*, 2016). However, judging whether a given food product can be considered "sustainable" or just "environmentally sound" is challenging as—similarly to other commodities—information about the circumstances of the food production is lost. Eco-labels aim at overcoming this information asymmetry, but typically are only process-based, e.g. prohibiting the use of chemical fertilizer, but do not provide information about the corresponding impact (Horne, 2009; van Amstel *et al.*, 2008). Furthermore, in order to boost sales, a large amount of greenwashing by meaningless labels takes place (Northen, 2011; Zanasi *et al.*, 2017; Gephart *et al.*, 2011).

Therefore, it is necessary to integrate ecological awareness into degree programs. This case study addresses these pressing problems by describing an easy to adapt graduate course making use of the didactic method of service-learning, with the aim of inspiring teachers to replicate the approach. Combining service-learning with an LCA graduate course may have been already applied in higher education, but to the knowledge of the authors, no detailed description, instruction, or analysis exists in scientific literature. The paper closest to this approach (Cosme *et al.*, 2019) does not focus on an evaluation of the service-learning approach, but instead explains and reviews the collaboration with companies in an LCA teaching context in general. We aim to fill this gap by giving detailed background information about the service-learning approach and how it impacted the course, the participants, and the learning outcomes, while giving lecturers guidance for how this approach can be applied at their university.

The "Studierendenwerk" (student services running the cafeteria, cafés, and student accommodation at Ulm University, Germany) introduced a new meal-line called "Prima Klima" (good for climate) in the campus dining facility (in German "Mensa", a cafeteria offering several hot meals for lunch at reasonable prices; in the following termed "cafeteria"). The "Prima Klima" meal-line is focused on regional suppliers and seasonal products, while being meat-free. This step was taken in a general effort to make the Ulm University more sustainable. The meals and ingredients were chosen according to common knowledge about sustainable food production and consumption and advertised accordingly. But the cafeteria was unsure about the scientific soundness of their advertising and needed help finding newly introduced meals that were not as environmentally friendly as other "Prima Klima" meals or established meals with or without meat. At the same time, the authors planned to revise their graduate course "life cycle assessment and sustainable product evaluation" for master students of "Chemistry and Management" and "Sustainable Corporate Management" by integrating a service-learning concept which revolves around a student-made life cycle assessment (LCA) of a product. This approach is aimed at teaching the students critical thinking on sustainability issues. By reaching out to the "Studierendenwerk" it was realized that a win-win-win situation (Berson, 1993) for the cafeteria, the students and the course leaders could be created. Through advertising the goal and the cooperative background of the course beforehand, the number of participants tripled compared to the average level seen in previous years.

Therefore, a service-learning course design was developed to analyze, using the method of LCA, whether the newly developed meal-line of eco-friendly food was as environmentally friendly as advertised, and, if possible, to propose options for improvement.

The aim of this paper is to share the experiences and lessons learned from the LCA case study, focusing on the topic of service-learning. By doing so we hope to encourage others to adapt this active-learning approach for higher education.

# 2 Background

## Sustainability in higher education

Teaching sustainability in higher education encountered many barriers (Ávila *et al.*, 2017) but sustainability literacy is a topic gaining in importance (Thomas, 2009; Rath and Schmitt, 2016; Colucci-Gray *et al.*, 2006; Winter and Cotton, 2012), since every student must make decisions based on economic, environmental, and social aspects in their professional, as well as their private lives (Luppi, 2011; Moura and Aires, 2018; Chen *et al.*, 2018). LCA will help with this by engaging the student in problem-based learning (Thomas, 2009; Biberhofer and Rammel, 2017) through thinking about the whole life cycle of the product, as well as its inputs and outputs. The industry is in need of employees with the necessary knowledge and skills regarding sustainable development and management, since the requirements related to a sustainable business strategy are ever-changing (Chen *et al.*, 2018). Higher education can play a vital role in contributing to the individual development of sustainable thinking and behavior of students. A recent study of European and Turkish university students' perceptions of sustainability found not only that the consciousness level of students needed to be further enhanced, but also that students wanted to have sustainability as a part of their university education (Sertyeşilışık *et al.*, 2018). Moreover, studies on 13 to 16 year old Europeans found that pupils are increasingly well informed, but that knowledge, awareness and willingness to act differs substantially, (Kuthe *et al.*, 2019; Oliver and Adkins, 2020) something to which teaching must adjust itself in the future.

Brundiers *et al.*, 2010 differentiated three key competence clusters in sustainability: The strategic knowledge cluster, the practical knowledge cluster, and the collaborative cluster. In the course we present, all clusters are addressed so that students will be enabled to act more sustainably. The strategic knowledge cluster, which includes understanding the status quo and

past developments, is targeted by the lectures on sustainability issues in LCA and their scientific basis. The practical knowledge cluster is addressed by linking the "knowledge-action gap" (van Kerkhoff and Lebel, 2006; Brundiers *et al.*, 2010) and by giving hands-on experience through the performance of an LCA study. Finally, the collaborative cluster which involves "to work in teams and in different knowledge communities" (Brundiers *et al.*, 2010) is addressed by pairing two or three students for each LCA study, as well as by mixing two completely different degree programs within one course. While one of the degree programs (Chemistry and Management, MSc) is focused on linking science and management, the other (Sustainable Corporate Management, MSc) is focused on shedding light on the importance of sustainability in a management context. It is important to emphasize that, while Chemistry and Management is a consecutive bachelor's and master's degree, Sustainable Corporate Management is only a master's degree consisting of students from many different undergraduate programs, from tourism to economics. Therefore, though interdisciplinary and transdisciplinary teaching are important and interesting topics (Lindvig and Ulriksen, 2019), they will not be the focus of this study, as this course design is laid out to work with nearly every graduate degree program.

## Service-learning in higher education

Service-learning is an active learning method (Goldberg *et al.*, 2006). It uses fundamentals from project-based as well as inquiry-based learning, and therefore can be seen as a subcategory. Table 1 summarizes these learning concepts to highlight the similarities and to provide a common theoretical ground to expand from.

*Table 1 Comparison between learning concepts related to service-learning, with the aim of highlighting the similarities as well as differences and to provide a common theoretical ground to expand from.*

| | **Active learning** | **Project-based learning** | **Inquiry-based learning** | **Service-learning** |
|---|---|---|---|---|
| **Connection between the learning concepts** | "Any instructional method that engages students in the learning process" (Prince, 2004) | "Project-based learning is one of the active learning methods"(Derevenskaia, 2014) | "IBL is a form of active learning"(Ernst *et al.*, 2017) Could be grouped as problem-based, project-based and case-based teaching (Aditomo *et al.*, 2013) | Involves active learning opportunities (Goldberg *et al.*, 2006) "Project-based service learning is a form of active learning where students work on projects that benefit a real community or client while also providing a |

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| | | | | rich learning experience" (Bielefeld *et al.*, 2009) |
| **Role of teacher** | Creating a constructivist learning environment (Anthony, 1996) | Engaging students in investigation by giving them a project to work on. The assignment is usually broad and complex while the outcome must not be predetermined (Blumenfeld *et al.*, 1991) | Pose the initial question or problem to students, then facilitate them in discovering answers by posing further questions (Aditomo *et al.*, 2013) | Supportive, enabling a democratic environment (Deeley, 2015)<br>Manager, facilitating the cooperation between students and organization |
| **Role of students** | Students actively interpret and impose meaning through the lenses of their existing knowledge structures (Anthony, 1996) | "Students pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analyzing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artifacts." (Blumenfeld *et al.*, 1991) | Investigate and solving problems (Aditomo *et al.*, 2013) | "Students engage in activities that address human and community needs together with structured opportunities for reflection designed to achieve desired learning outcomes" (Jacoby, 1996) |
| **Framework or phases** | Too broad to define common a framework | Setting goals, planning, monitoring and evaluating progress, and producing and revising artifacts (Blumenfeld *et al.*, 1991) | Orientation, conceptualization, investigation, conclusion, and discussion (Pedaste *et al.*, 2015) | Kolb's experimental learning-cycle: experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984; Salam *et al.*, 2019) |
| **Educational objectives** | Shift from passive to active learning.<br>Activating students, promoting student Engagement, improve learning outcomes (Prince, 2004) | Motivate students, promote real life skills like problem-solving (Blumenfeld *et al.*, 1991).<br>Practice applying knowledge (Aditomo *et al.*, 2013) | Critical thinking and problem solving (Aditomo *et al.*, 2013)<br>Developing students' skills in communication and collaboration (Aditomo *et al.*, 2013) | "Students' active engagement in learning facilitates thinking critically, questioning assumptions, considering varying perspectives, and appreciating the civic purpose of their profession" (Goldberg *et al.*, 2006) |

Research on service-learning in higher education is readily available in textbooks (Deeley, 2015), in systematic literature reviews (Salam *et al.*, 2019) and in papers on selected topics (Glover *et al.*, 2013; Gillis and Mac Lellan, 2010). However, a recent systematic literature review found that only 5% of the analyzed studies on service-learning can be attributed to the field of natural sciences, whereas most applications were found for the more practical disciplines like health science and nursing (Salam *et al.*, 2019). Therefore, we aim to contribute

to the growing field of service-learning in natural science education with the description of this teaching experiment.

Service--learning is defined as "a form of experiential education in which students engage in activities that address human and community needs together with structured opportunities for reflection designed to achieve desired learning outcomes" (Jacoby, 1996). According to Kolb, 1984, whose model is widely adopted by service-learning scholars (Salam *et al.*, 2019), an experimental learning cycle consists of the four phases of concrete experience, reflective observation, abstract conceptualization, and active experimentation. Key characteristics of service-learning are real-world student learning and civic engagement (Deeley, 2015; Kenworthy-U'Ren, 2003) and therefore generating a synergy between subject-specific and generic skill development, as well as taking social responsibility (Halberstadt *et al.*, 2019). It is emphasized that service-learning should not be "for the community", but rather "with the community" (Ward and Wolf-Wendel, 2000). Research found that projects, like the hereby presented case study, benefit from a clarity of purpose (Keen and Baldwin, 2004) and increase students' civic engagement (Bringle and Hatcher, 2002; Parker *et al.*, 2009). By engaging students in service-learning, it was suggested that the development of values related to diversity, poverty, social change, and social responsibility, can be positively impacted (Bowman *et al.*, 2010; Parker *et al.*, 2009), likely also depending on the concrete service provided. Detailed information on how service-learning in higher education with a sustainability context can be found in Brundiers *et al.*, 2010, and broader information about service-learning in general is available in Deeley, 2015 and Salam *et al.*, 2019.

Service-learning supports the switch from passive learning to active learning. Effects of active learning on learning outcomes are highly discussed, as studies either found similar results for active and passive learning students (Michel *et al.*, 2009) or better scores for those who used active learning (Hackathorn *et al.*, 2011; DeNeve and Heppner, 1997). Nevertheless, students reported positively regarding satisfaction, perceived learning, motivation and effectiveness of the method (Riley and Ward, 2017; Michel *et al.*, 2009; Celio *et al.*, 2011). Moreover, a meta-analysis found that service-learning strengthens civic engagement and social skills (Celio *et al.*, 2011). This is particularly important since in a recent analysis of the 2018 PISA assessment among 15 years old pupils, Germany performed worst of all countries by the "number of actions taken by students for collective well-being and sustainable development"

(OECD, 2020). Hence, using a combined approach of a passive lecture and an active learning-by-doing approach should be to the benefit of students and their learning outcomes.

In the underrepresented service-learning context of higher education in the natural sciences literature a wide range of applications exist, and diverse topics are discussed. Molderez and Fonseca, 2018, for example, analyzed survey data on how students perceived to have developed sustainability competences for different learning activities. Pearce, 2009 described how a service-learning experiment was used to coordinate a sustainability-focused outreach campaign to retrofit stop lights using an online-tool, and Najmr *et al.*, 2018 explained how a chemistry course employed a service-learning approach by having the students design and teach chemistry experiments to pupils. It is likely that service-learning is more widespread in use in the natural sciences, but apparently not frequently published.

## Life cycle assessment

Life cycle assessment (LCA) is a standardized and widely accepted method to identify and assess environmental impacts over the whole life cycle of a product or service. ISO standards 14040/44 as well as the European Commission's ILCD handbooks provide guidance and are used in academia and industry and for support in policy making (DIN EN ISO 14040; DIN EN ISO 14044; EC-JRC, 2012, 2010b, 2010c). An early engagement of students with LCA, as well as sustainability, are indispensable for a deeper understanding of this ever-growing topic. In recent years, the topic of sustainability and LCA has become increasingly important, so much so that entire curricula have been designed around it (Olsen *et al.*, 2018) Yet scholars still report a lack of concrete examples of teaching LCA in scientific literature (Mälkki and Alanne, 2017) This case study aims to help fill this perceived gap by sharing our teaching experiences from the case study.

Generally, LCAs of meals served in school canteens (Laurentiis *et al.*, 2019; Benvenuti *et al.*, 2016; Ribal *et al.*, 2016; Saarinen *et al.*, 2012) or university cafeterias (Chen *et al.*, 2016; Graham *et al.*, 2019) as our students have made, are found in literature. Also, literature on the aspect of teaching students to do their own LCA to further the understanding of eco-design (Duin *et al.*, 2015; Marques, 2014; Mulder-Nijkamp *et al.*, 2018) and implement environmental education (Bezbaruah and Lin, 2008; Gilmore, 2016; Hawkins and Matthews, 2009; Lin *et al.*,

2012) is available and refers to a variety of implementation options. But LCAs in higher education are mostly done for the sake of gaining hands-on experience and not to work for a client or in a real-world application. Bevilacqua *et al.*, 2015, for example, followed a gamification approach of teaching LCA by letting the students cook and assess their own meals, which were then scored by professional cooks for tastiness and by LCA experts for environmental impacts and the level of detail of the students' LCA. It must be emphasized that the topic of teaching LCA hands-on while cooperating with industries or other organizations can be dated back at least 20 years (Cosme *et al.*, 2019). Still, scholars plead for more studies to share LCA experiences between university teachers, and also to motivate them to use LCA as a learning tool for environmental awareness (Mälkki and Alanne, 2017; Olsen *et al.*, 2018). Therefore, this case study uses the lessons learned by Piekarski *et al.*, 2019 who recently implemented a course for industrial engineering students on the ecodesign of a paint brush, thereby assisting the industrial partner, as well as by Cosme *et al.*, 2019 who shared insights in their long experience with teaching LCA with industry cooperation in order to develop an easy-to-adapt service-learning LCA approach helping the local university's cafeteria assess the environmental impacts of their meals. Refer to Mälkki and Alanne, 2017 (in particular their table 3) and references therein, as well as Gallego-Schmid *et al.*, 2018 (their table 1) for more detailed information and examples on LCA studies in educational environments. In addition, a recently published paper about teaching LCA in higher education gives a structured overview of LCA teaching contents and related competencies for the first time and identifies a literature body of 28 studies that are focused on teaching LCA in higher education (Viere *et al.*, 2020). They also found that only a few studies presented the content of the lectures, the learning outcomes, or teaching methods, as is an objective of this case study.

## 3 Methodology

This descriptive case study (Zainal, 2007) follows a narrative approach (McDonough and McDonough, 1997) to provide detailed descriptions of the course, the service-learning approach, and the lessons learned, in order to provide direction to educators.

A descriptive statistical analysis is conducted as the case study was evaluated using the mandatory online evaluation questionnaire of Ulm University. Since the mandatory evaluation

was performed after roughly three quarters of the course, the evaluation cannot provide a final feedback from students. Therefore, the students were engaged again one year after the course using a much shorter online questionnaire.

The mandatory online questionnaire of Ulm University uses the EvaSys platform. The items were derived from Rindermann's work (Rindermann, 2001, 2002, 2003a, 2003b, 2009; Rindermann and Kohler, 2003). The questionnaire aims to derive students' opinions on structure, interaction, demand, material, teaching methods, students' knowledge, interest, and communication using 31 items on a 6-point Likert scale, as well as two open-ended questions. A detailed explanation of Ulm University's course evaluation concept is available online (Dresel *et al.*, 2006).

The online questionnaire one year after the course serves to check the impacts of the course on the everyday life of students, and how they perceive the course and the applied active learning method one year after completion. Both English-translated questionnaires and the resulting data are available as supplementary material.

## 4 Description of the case study

The course "Life Cycle Assessment and sustainable product assessment" for master students of "Chemistry and Management" and "Sustainability Corporate Management" was revamped to feature a service-learning approach. The course took place at the Ulm University, Ulm, Germany, where about 10.000 students are enrolled in 62 study programs led by 215 professors (Ulm University, 2019) in four faculties: Engineering, Computer Sciences and Psychology, Mathematics and Economics, Medicine and Natural Sciences. No degree program is specifically laid out to focus on environmental problems.

The course took part from 14.10.2019 to 15.02.2020 and is valued with 7 ECTS (European Credit Transfer and Accumulation System) corresponding to a maximum student workload of 210 h. This corresponds to level 3 (minor specialization) of the "LCA learning and competency framework for higher education" of Viere *et al.*, 2020, which was derived using Bloom's taxonomy of learning (Bloom *et al.*, 1956). This competency framework describes the goal of a level 3 study program as "LCA practitioners […] [are] able to conduct and interpret LCA

studies" and the learning outcomes as "design and partial performance of a full-fledged LCA study, incl. analyzing and evaluation the validity of specific steps, the quality and reliability". Our case study will use these suggestions as well as the six levels (knowledge, comprehension, application, analysis, synthesis, evaluation) of the cognitive domain of Bloom's taxonomy (Bloom *et al.*, 1956) as a base line for case-study evaluation. See Table 2 for more information.

Throughout this paper, a detailed description of the case study is given, in order that others have little difficulty seeing the same phenomena in their own experience and research (Dyer and Wilkins, 1991). While the weekly 90-minute lecture remained mostly the same, the corresponding weekly 90-minute exercise was completely restructured. The core of the restructuring was the inclusion of student-made LCAs of 25 different meals prepared by the Ulm University's cafeteria. The 53 participating students were assigned to groups of two or three to create their first own LCA study. A schedule of the course is illustrated in Figure 1.

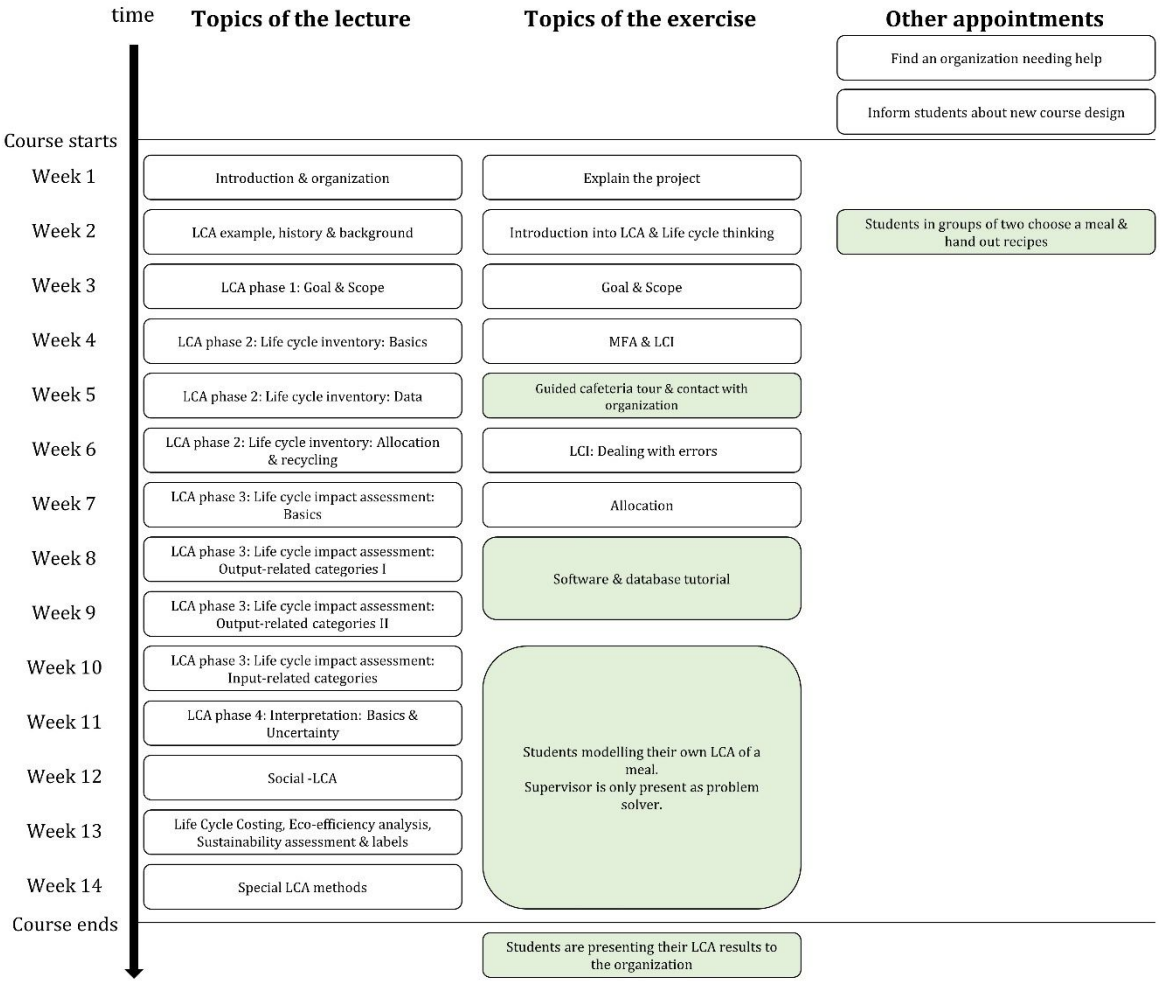


*Figure 1 Schedule of the master's degree service-learning LCA course that can be taught in one semester. The course is divided into a weekly lecture and exercise of 90 minutes each. 90-minute active-learning exercises are highlighted in green. MFA for material flow analysis, LCI for life cycle inventory.*

In the first exercise, students were introduced to the practical task of analyzing the life cycle of a meal to help the cafeteria with creating a more environmentally sound meal plan. Theoretical 90-minute exercises with general training exercises coupled to lectures on topics such as basics of LCA, material flow analysis, uncertainty, and allocation were done to sensitize the students for problems that occur when conducting an LCA. In brainstorming sessions coupled to the current topic of the exercise, students gathered ideas on the goal and scope definition, inventory analysis, impact assessment, and interpretation of the LCA. The recipes for the meals, provided by the cafeteria, were distributed shortly after the beginning of the course. To improve the understanding of the cafeteria's current sustainability issues, the students were given a tour through the cafeteria. First, the deputy head of the "Studierendenwerk" held an introduction, that consisted of background information on

purchases, regional suppliers, and current issues with implementing a new climate-friendly meal-line. One main concern regarding the climate friendly meal-line was the advertised reduced climate impact. Afterwards students were invited to a walkthrough of the kitchen. The tour focused on meal preparation processes and the highly automated kitchen appliances, as this differed the most from the cooking the students are familiar with at home. Given that the students already knew which meal they had to analyze, questions could be asked about the preparation processes that students could not deduce from the recipe itself.

After six lectures, exercises on LCA, and the exchanges with the cafeteria staff, the students were introduced to software-based modelling of an LCA in the exercises. The course used the open source LCA software openLCA 1.09 (openlca.org) for modelling. OpenLCA describes itself as "the world's leading, high performance, open-source Life Cycle Assessment software". It uses third party databases, which users need to model the life cycle of a product or service. The databases consist out of processes (e.g., a tomato farm) which in turn consist out of thousands of mass and energy flows to describe the inputs and outputs (of the tomato farm). Therefore, the user does not need to have detailed data about every process in the supply chain but can use average data called background data. Using the openLCA software, the user can connect database processes with own data (called primary data) to model all relevant inputs, outputs, and emission of a product's life cycle. These thousands of data points are then automatically processed by the software to calculate the potential environmental impact resulting from the life cycle. The primary data of the study came from the cafeteria as well as from suppliers contacted by the students. The background data was mainly derived from ecoinvent 3.3 (Wernet *et al.*, 2016) with some agricultural data derived from Agribalyse 1.03 (Colomb *et al.*, 2015). Under supervision, the students studied the modelling and use of the software with a tutorial of a plastic bottle's life cycle (GreenDelta, 2019) by themselves. Afterwards, the students were able to adapt their knowledge to their specific LCA case. Under supervision, the students constructed their own LCA over the course of five weekly exercises over a period of nearly two months. One supervisor per 25 students was needed to satisfy the constant demand for help and information. If any questions or problems occurred outside the weekly exercises, an online messaging board implemented in the university's teaching platform making use of Moodle (moodle.org) was available. The messaging board was used to facilitate communication among students and between students and supervisors. Moreover, the platform allowed students with similar meals to exchange ideas and data.

The functional unit was discussed at an earlier brainstorming session and was defined as one serving of a meal in order to simplify the comparability for the cafeteria. The students were instructed to focus on finding environmental hotspots, as well as on giving advice on how to make the meals more environmentally friendly. The system boundary of a cradle-to-plate assessment (see Figure 2), chosen in the brainstorming sessions, fits best into the area of operation of the Studierendenwerk, as their main interest laid in the use of eco-friendly ingredients and not on the question how to dispose leftovers in a particularly environmentally friendly way.

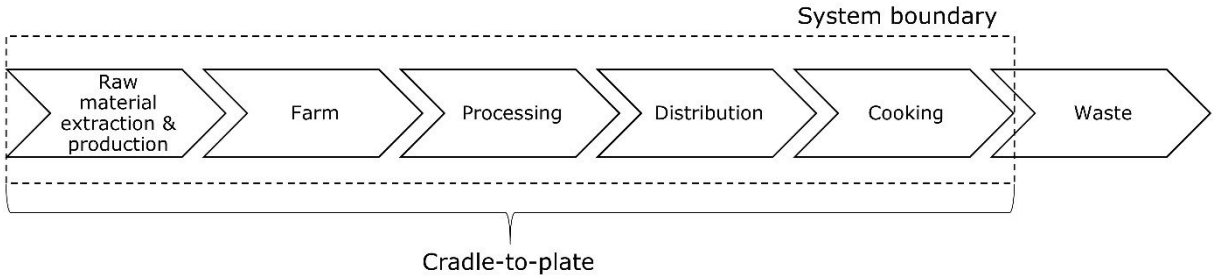


*Figure 2 Streamlined illustration of a generic cradle-to-plate Life Cycle Assessment as used in the presented service-learning LCA course. Modeling the ecological impacts of the generated waste and/or recycling processes is outside the scope of the study.*

To compare the LCAs with one another, the highly diverse impact categories (EC-JRC, 2010a) had to be made comparable. The ReCiPe life cycle impact assessment model (Huijbregts *et al.*, 2017) at endpoint level was chosen as it allows to aggregate the results to one final point score and therefore facilitates the understanding of complex results by the cafeteria staff. Note that aggregation always comes at the cost of information loss (Pizzol *et al.*, 2017). The LCA results were uploaded to a data-sharing online platform to let students compare their LCAs before the final presentation. In a meeting with the cafeteria heads, the students held 10-minute presentations of their results. This event had several functions: it underlined the interest in the outcomes of their work providing additional motivation, it forced students to think about how to present their results in front of an audience that had no experience with LCA, and to set an ultimate deadline. Furthermore, the single LCAs were systematically brought together for the first time, which only then allowed a larger picture and an answer to the question of which meals perform better, and which really deserve the label “Prima Klima”. Therefore, everybody was curious. However, the presentation event also posed a particular challenge to the students: meals were rather similar, and the number of groups was so large, that students knew they had to focus on the particularities of their meal under study to gain attention.

A summarizing enumeration of the students' tasks and learning outcomes is provided in Table 2 below. The table is classified into the six levels of Bloom's taxonomy of learning to fall in line with preceding publications (Cosme *et al.*, 2019; Viere *et al.*, 2020; Marconi and Favi, 2020).

*Table 2 Using Bloom's taxonomy of learning to structure students' tasks and learning outcomes of the presented service-learning LCA course into six cognitive levels.*

| **Bloom's taxonomy** | **Students' tasks and learning outcomes** |
|---|---|
| I – Knowledge | • Know basic terminology, principles, concepts, and problems of the LCA methodology |
| II – Comprehension | • Understand the iterative approach of conducting an LCA<br>• Understand the used LCA software and databases using a tutorial |
| III – Application | • In joint discussions in the exercise a common ground to expand from was outlined by:<br>  ○ Defining a common goal and scope<br>  ○ Defining system boundaries<br>  ○ Defining a functional unit<br>• Identifying and requesting missing information of the recipes, for example, asking suppliers about detailed ingredient data for processed food and asking the chef about preparation processes<br>• Modeling the whole life cycle of the meal from cradle-to-plate. First on paper, then using openLCA<br>• Finding the necessary data in the databases |
| IV – Analysis | • Identifying environmental hotspots of their meal<br>• Identifying potentials for improvement |
| V – Synthesis | • Compare LCA results with others<br>• Prepare LCA results and the presentation |
| VI - Evaluation | • Critically reflect the LCA results<br>• Put the LCA results in a wider context |

| | |
|---|---|
| | • Present findings in a 10-minute presentation in front of the heads of cafeteria, the supervisors and interested researchers of the department |

# 5 Results

## Results of the LCA case study

The cafeteria of Ulm University tasked the students to evaluate whether the new "Prima Klima" meal-line was in fact environmentally superior to typical, mostly meat-containing, meals. The results of the students LCA are shown in Figure 3. It should be emphasized, that this data is not to be published for the sake of understanding or studying LCA results, but rather to help in imitating the described teaching approach and to understand the learning results.

The aggregated final ReCiPe point score shows distinct and explainable differences between certain meal types, while no outliers exist. The meals containing meat or high amounts of milk-products ranked the highest, while vegan and vegetarian meals containing mostly plant-based ingredients ranked the lowest and were therefore most environmentally friendly.

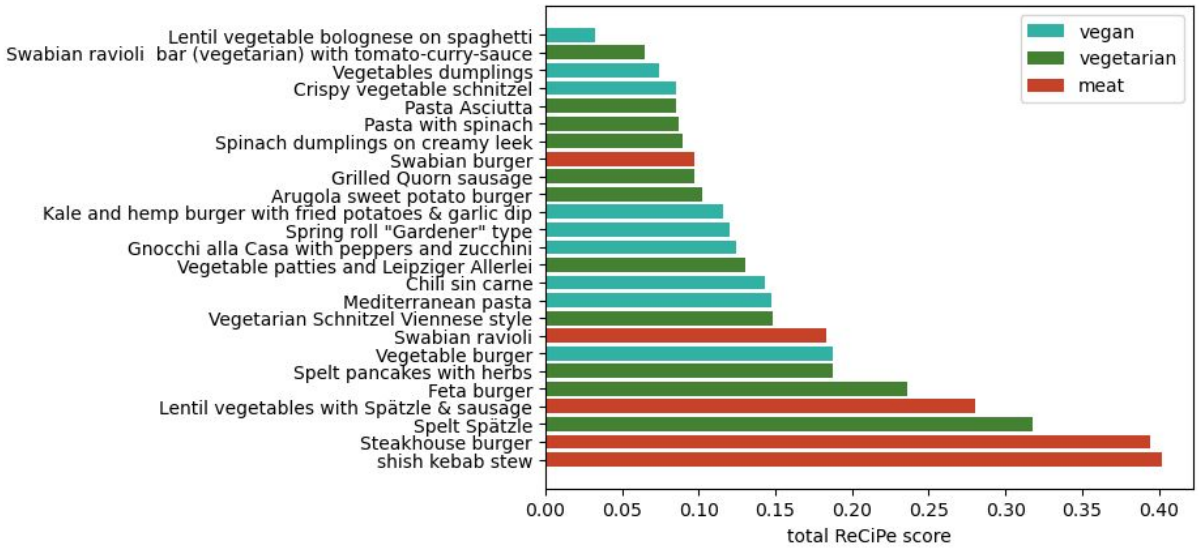


*Figure 3 Results of the 25 LCAs performed by the students. The higher the total ReCiPe score, the higher the potential ecological impact of the respective food. On average, meat-based food performed worse than vegan or vegetarian alternatives.*

To further help the cafeteria's decision-making, students identified environmental hotspots in their respective meals and proposed alternative ingredients or processes. For example, it was found that cream and cheese in the "spelt Spätzle", as well as a generally large meal size, resulted in a relatively high ReCiPe score, an aggregated indicator value indicative for environmental impacts, for a vegetarian meal. Therefore, it was proposed to test whether the amount of food or milk products required for this meal, i.e., cheese, could be reduced. An exemplary substitution product was found for the "vegetable schnitzel Viennese style", where the use of organic potatoes could reduce the ecologic impact by 29%.

## Results from the service-learning approach

After three quarters of the course the students were asked to take the mandatory feedback questionnaire of Ulm University (n=24, participation: 45%). In the following some statements of students are quoted (after translation) in order to evaluate the aspects that the students perceived as positive and aspects that needed to be improved. While the "practical application of the learned knowledge in the meal LCA" and "the alternation of exercises, theory and examples" were highlighted positively, some students also found that the "workload for the life cycle assessment of the cafeteria meal is too large". Another often heard point of criticism is that the "available data for an LCA is insufficient". This highlights the expectations of students regarding LCAs. Even though data acquisition and availability problems are taught in the lecture and exercise, it seems that only the experience of the case study enabled students to understand the extent of the problems concerning data issues in LCA. It must be emphasized that the time restrictions did not allow for extensive modelling of background data, and that consequently estimations and assumptions had to be made. While helping students with problems, we found that working with estimated data was especially inconvenient for students with a natural science background.

On a Likert scale of 1 to 6, the statement "After the course I know a lot more than before" averaged at 4.6 (SD 0.9), while the statement "The course stimulates my interest in the subject material" was evaluated with a 4.0 (SD 1.0) on average. "I understood the most important contents very well" scored a 4.4 (SD 0.5).

Coming back to the three competence clusters by Brundiers *et al.*, 2010, the case study design targeted all three clusters in a verifiable way: The strategic knowledge cluster, was checked by the final exam, which every student passed. The practical knowledge cluster was checked

by grading the LCA presentation with the heads of cafeteria. Due to privacy, the heads of cafeteria were left out of the grading process, but an argument for including them can be made. Here, all students provided plausible LCA results, and could competently answer questions from the auditorium. The collaborative cluster, however, could be checked by closely observing and guiding the students to their first LCA.

The students' performances during the exercise were as widely distributed as the results from the presentation and the written exam. No influence of the degree program on the study outcome could be identified. While most students were highly engaged since the start of the hands-on exercises, pondered problems with fellow students, and requested feedback on their solutions from the supervisor, few students remained passive. This behavior included trying to solve problems on their own, which most of the time wasn't time-efficient since other groups most-likely already encountered and solved the problem. As the appointed time for the presentation drew nearer and the social pressure of delivering acceptable results grew, every group at least asked for a review of the results by the supervisor. The presentation showed that, while every student adhered to the requirements of performing an LCA and identifying hotspots, some students went the extra mile and performed sensitivity analyses or took a deep dive into the background data to explain their results.

We found that, while the students in Chemistry and Management excelled more in natural science- and mathematics-based subjects such as mass and energy balances, screening scientific papers for data, or solving complex problems, the students in Corporate Sustainability Management were stronger in providing a macroscopic view of the problems-to-come as well as on general sustainability issues that should be focused on. Together, a heterogenous group of students complemented each other, and an educational environment was created that endorsed cooperation as well as the sharing of knowledge and data.

One year after the completion of the course, students were questioned about the impacts of the course on their everyday life (n=11, participation: 21%). The statement "Conducting the LCA has positively influenced me in my ecological thinking and actions in everyday life" scored a 4.8 (SD 0.6) on the 6-point Likert scale. Students were also asked to give examples. Nearly every student mentioned that he or she is more aware of what food they buy and eat even resulting in vegetarianism or veganism. It was also mentioned that the exercise helped with getting an internship, as practical experience was already obtained.

The statement "I would like to have more courses for my university education that promote active learning" scored a 5.8 (SD 0.4). This again shows the demand for a change of the higher education teaching status-quo.

"The cooperation with the Studierendenwerk has positively influenced the exercise" was evaluated with a 4.9 (SD 0.9), showing that service-learning, next to the active learning approach, is highly valued by the students, as a social bond and interaction with an organization is established. This also showed the 4.3 (SD 1.7) of the statement "The goal of helping the Studierendenwerk improve their recipes influenced me more to deliver a good LCA than the goal of getting a good grade".

## 6 Discussion

Through the gathered experience, multiple positive effects for the participating groups of the service-learning approach can be formulated, resulting not only in a win-win situation as experienced by Piekarski *et al.*, 2019 and Cosme *et al.*, 2019, but in a win-win-win-scenario through including the faculty members in the evaluation. The following threefold structuring of the discussion in students, community needing support, and faculty members is based on the review of service-learning benefits by Salam *et al.*, 2019. But first, the importance of selecting the right product for an LCA, as well as the four phases of an experimental learning cycle (Kolb, 1984) are evaluated in the context of this case study.

The selection of appropriate assignments is an important part of preparing a service-learning course (Gujarathi and McQuade, 2002). The topic of conducting an LCA of a meal was selected since prior courses on LCA showed that students heavily underestimated the workload of conducting an LCA. The approach of analyzing a meal, when primary data was readily available from the cafeteria, was beneficial, since most industrial products like a plastic water bottle (Gallego-Schmid *et al.*, 2018) or a painting brush (Piekarski *et al.*, 2019) look like an easy to model product until industrial production data is needed. But if no industrial partner, as in Piekarski *et al.*, 2019, can be found, this data is most likely confidential and not readily available to the public. In contrast, most meal ingredients do not rely on company secrets as they are not as highly processed and a list of ingredients must be available, while background data in common LCA databases are mostly usable. Exemplary exceptions of easily acquirable data were Quorn, a trademarked meat substitute derived from fungus (Finnigan, 2011) or the

pre-packed Swabian ravioli. Depending on the meal, the LCA differed in complexity. But the decision about the level of complexity was at the discretion of the students and an important part of problem solving. Each group could decide for themselves if they wanted to model the ingredient as detailed as possible with the limited data available, and when to use alternative processes for substitution. Moreover, students had to decide if, according to the LCA standards, a cut-off of ingredients with limited shares and impacts was justified. As a result, students did not have to spend their time budget on researching data, but instead could spend most of their time budget on the modelling itself, thereby experiencing the decisions and problems an LCA-modeler has to face themselves. Another advantage of conducting a meal based LCA is that students generally know the procedures of cooking a meal and have a general knowledge about the climate impacts of food. Hence the students are able to estimate data if needed and assess the modelling results on the validity. Choosing a cradle-to-plate LCA simplified the modelling process, as no data for waste management had to be gathered. The LCA results show that, given the harsh time-constraints, students were able to generate data relevant to practice, which is essential for the organization's acceptance of service-learning. Choosing the university's cafeteria as the organization needing help also reduces potential preparation time for the lecturer before the start of the exercise, as external organizations are likely harder to reach and to convince of the advantages, they would receive from participating in the teaching method. Regarding the time constraints given by the length of the semester, we also see a possibility in the application of this approach as a block event over the course of one to two months. When adapting our approach, one also has to keep the costs in mind. We already optimized the cost structure by using open-source options as often as possible. While there are open access textbooks (Matthews *et al.*, 2016; Margni and Sonnemann, 2015), software (openLCA, Brightway2) and databases readily available, we found that only database with costs such as ecoinvent satisfied the need for the broad spectrum of background data. A particular LCA database for food products might be advantageous if more reliable results should be obtained since broad databases such as ecoinvent sometimes lack data for more particular food ingredients and processes. Still, it was found that the students' LCA result were comparable to scientific findings. They showed that meat-based meal options tend to have twice as high of a ReCiPe score (see Figure 3) compared to vegetarian and vegan alternatives. This agrees with the findings from Laurentiis *et al.*, 2019, who found that meat-based meals also had the highest ecological impact with a similar distance to vegetarian food on the water

and carbon footprint. However vegetarian and vegan meals performed mostly indistinguishable in both studies.

The four phases of an experimental learning cycle which are, according to Kolb, 1984, concrete experience, reflective observation, abstract conceptualization and active experimentation have also been targeted in the presented case study. The concrete experience, as the basis for observation and reflection, was provided in the hands-on experience in modelling an LCA. Constant observation and reflection from the students were needed in order to iteratively construct the LCA. Abstract conceptualization in form of adopting different perspectives and analytical capabilities were also constantly proven by the students through solving problems regarding data availability or modelling errors. The accumulated knowledge proved useful in the phase of active experimentation, as the theoretical knowledge from the lecture and exercises could be supplemented with individual experiences. This results in the so called "accommodative knowledge" (Kolb, 1984) about LCA and starts a new learning cycle.

## Students

Students made first contact with the method of LCA and gathered important knowledge in the field of sustainable product evaluation. By modelling their first LCA, they had to engage in the ever-present subject of sustainable food consumption and learned through numerical facts which ingredients to look out for and why. Students learned about the composition of food, the supply chain of ingredients and how much (or how little) the transportation of food impacts the LCA in comparison to other parameters such as heating a greenhouse or organic farming. The learning-by-doing approach increased the eagerness to learn, as noted by Cosme *et al.*, 2019, and taught them to ask the right questions of the right people in order to progress their LCA. The self-assessment in the feedback questionnaire revealed that students obviously spent a lot of time on the course and report high knowledge gains. However, no difference in learning outcome was found in the exam compared to the years before. Analogous findings of indifferent learning outcome have been reported by Michel *et al.*, 2009. This might be interpreted in that competencies learned in the LCA study do not correspond to what was asked in the exam. Cosme *et al.*, 2019 notes that a written exam "can only be considered as a large step backwards, as it would invalidate the fundamental pedagogical principle behind the current course design (i.e., learning-by-doing)". We agree with the presented argumentation

and suggest a focus on grading the presentation as well as the LCA model. Still, students themselves did not specifically argue against a written exam, as the statement "I would have liked an exclusive performance evaluation of the LCA results and presentation (without a written exam) better than the grading of the LCA results and presentation and written exam that took place" only scored a 3.6 (SD 1.5, n=11).

By performing the LCA, the students learned system-thinking, to work iteratively, as the LCA is an iterative method (DIN EN ISO 14040, 2009), and got a deeper understanding of data issues, which likely also affect how they will perceive other LCA study results. By using an open access LCA software, general digitalization soft skills were increased, and important hands-on experience was gained. The social interaction with the cafeteria staff increased the willingness to learn as students saw their chance to help the university and expressed their commitment to the cause. The students improved their social skills by working in small groups and as parts of a bigger unit that strived for the same goal. They thereby honed their skills in acquiring information, researching data, and cooperation with suppliers and clients. By shifting their consumption patterns to a more vegetarian or vegan diet the students' social responsibility was positively impacted. This underlines the findings of other service-learning studies (Bowman *et al.*, 2010; Parker *et al.*, 2009). In addition, the individual students' and curriculars' strengths were combined by engaging in an interdisciplinary teaching model. Still, we firmly believe that this service-learning approach will also function without the curricular diversity.

The students' greatest pitfalls in performing an LCA were found to be understanding the logic structure of the software and databases used, deciding which background process best applies to reality, and making independent assessments of which simplifications should be made. These pitfalls are typical for an LCA beginner and should be kept in mind when designing and running the course.

Finally, the presentation taught them how to break down their scientific findings and communicate these in an easily understandable manner for a non-scientific audience. While we think that a presentation fits the style of information generation and transportation the best, a poster exhibition where students present their results would also be feasible. To generate a degree of comparability between the individual LCA results, it is important that students follow the same goal and analyze the meals within the same framework. We found that using guided brainstorming sessions to let the students define an LCA framework

including goal and scope, functional unit, system boundaries, life cycle impact assessment method, and impact categories, led to a similar framework to what the supervisor would have used for the course. Generally, analytical, and problem-solving skills were utilized on several occasions throughout the exercises.

The goal of the level 3 study program of the competency framework (Viere *et al.*, 2020) that "LCA practitioners […] [are] able to conduct and interpret LCA studies" was fulfilled. Viere et al. also proposed learning outcomes: "design and partial performance of a full-fledged LCA study, incl. analyzing and evaluation the validity of specific steps, the quality and reliability", which was also achieved. In conclusion, service-learning provides students with many different and invaluable practical skills which, in the traditional method of passive learning, cannot be taught as easily. With the master's degree and a starting career in sight for most students, these skills will be beneficial throughout their career (Salam *et al.*, 2019). We are confident that we have contributed to reducing the gap in sustainability deduction between industrial need and academic education (Chen *et al.*, 2018).

## University's cafeteria in the role of a community needing support

The cafeteria benefitted from the generated results as the theory of service-learning lays out. By interacting with the students, the "Studierendenwerk" received ideas for new, more sustainable recipes. Moreover, the discussion of the results in further university intern conferences involving cafeteria staff and the supervisor indicates the cafeteria's efforts in pursuit of a green strategy and becoming more sustainable. This could lead to more students eating in the cafeteria because they know that environmentally sound food is served there. Moreover, the initial goal of the "Studierendenwerk" to assess the climate impact of the meals, was surpassed by the all-encompassing environmental assessment using LCA and the ReCiPe impact assessment method. Received feedback from the "Studierendenwerk" therefore aligns with the findings from Piekarski *et al.*, 2019, that the results exceeded the partner's expectations. Though not analyzed, we are also convinced that the staff of the university cafeteria learned about LCA, too, and are now enabled to make better judgements when being confronted with such information from food suppliers.

The "Studierendenwerk" took not only the role as a provider of primary data, but also as a contact point for detailed questions as well as a university department which cares about sustainability and therefore their students. The "Studierendenwerk" was involved in every part of the LCA study. This strengthens the argument made by Ward and Wolf-Wendel, 2000 that service-learning should not be for the community but with the community.

## Faculty members

Those who design and teach the course can be easily forgotten in a service-learning approach (e.g., in Keen and Baldwin, 2004) but are nevertheless essential (Kenworthy-U'Ren, 2003; Kawabe *et al.*, 2013; Salam *et al.*, 2019). It is the responsibility of the faculty members to design a suitable service-learning course by achieving the academic, institutional, students' and community members' goals (Voss *et al.*, 2015; Salam *et al.*, 2019). In restructuring the exercise, the supervisor and corresponding author achieved his goal to ensure a sustainable and more motivating learning experience, which can be useful for further courses. Moreover, in establishing a trusting relationship with the "Studierendenwerk", future projects in the field of LCA and sustainability are made possible.

Literature argues that service-learning enhances the supervisor's ability to teach and the productivity of teaching as one actively participates in the study (Kinloch *et al.*, 2015; Salam *et al.*, 2019). Literature also found that service-learning can lead to a new sense of commitment and determination for the instructor and lead to a change in university culture (Molderez and Fonseca, 2018). We want to underline that supervisors tend to teach the same courses over and over, and a detailed reflection on the topic resulting from the restructuring to include a service-learning approach certainly emphasizes these findings.

For the faculty it is important to offer interesting and modern courses, in order to prepare students for a modern professional life and attract more students. Advertising for the new service-learning approach via email before the start of the course tripled the number of participants compared to the constant level of previous years. This shows the demand of the students for something new, and perhaps also for a learning environment that has a different goal than just a grade.

It can be summarized that adapting service-learning into some of their courses should be in the self-interest of the faculty.

# 7 Conclusions

LCA has proven to be a powerful tool for research and practice to assess products from an environmental perspective but LCA bears a high degree of complexity, too. Teaching LCA in higher education can be supported by selecting real case studies, possibly making use of a service-learning approach. The paper reports on a graduate course on LCA in which students helped Ulm University's cafeteria to assess meals by conducting a LCAs for 25 meals and identifying environmental hotspots. Students who had their lunch in one of the university cafeterias for up to 5 years, likely without having thought about the sustainability of the food they ate beforehand, explored the cafeteria with its processes, employees, suppliers, and meals. A number of outcomes can be drawn from this experience.

While the preparation and planning of this service-learning approach was very time consuming, the results exceeded our expectations and have thereby encouraged us to continue on this path, as well as to suggest others to try out this service-learning approach.

To achieve the LCA results, it took a strong commitment from the students to be able to perform an LCA for the first time while working under time pressure and with new software. Specifically motivating for the students were the meetings with the cafeteria staff, their indication that the students' results are valuable for the staff, and that the students' time and efforts are appreciated.

Adapting the different phases of the course to the stages of Bloom's taxonomy of learning (Bloom *et al.*, 1956) helped to develop a didactically challenging service-learning approach. Using Kolb's experimental learning cycle (Kolb, 1984) illustrated the students' cognitive development. The influences of active-learning, project-based learning and inquiry-based learning blended to create a successful service-learning case study in which all parts of Brundier's key competence clusters in sustainability (Brundiers *et al.*, 2010) are targeted. The proposed goal and learning outcomes of the "LCA learning and competency framework" (Viere *et al.*, 2020) were achieved.

Key findings of this case study are:

- Service-learning is a welcome change for students from the otherwise passive-learning dominated courses

- Direct social interaction with a community needing help is an important part of the service-learning approach, as it engages the students in the topic and motivates them
- Food-based LCAs are suitable for students as a first entry point to software-based LCA modelling
- Food-based LCAs positively influenced the students' everyday food choices
- By being able to contact the supervisors over the whole LCA modelling process, even the first LCA results of the 53 students are intrinsically valid and comparable to scientific findings

Limitations of the case study result mainly from the methodology of conducting an LCA with students. As mentioned, the LCA results don't meet the requirements of the standards (DIN EN ISO 14040, 2009; DIN EN ISO 14044, 2018), as too many simplifications and assumptions had to be made to ensure results in this limited time span. Moreover, since this teaching experiment was performed for the first time and no detailed information about a LCA service-learning approach in higher education was found, improvements to the course structure, procedure and learning outcome determination are necessary and already included in the course design of Figure 1. Through the course of this paper the reader was informed about our findings and potentials for improvement. Lastly, a more in-depth evaluation after the end of the course will help with retrieving a more neutral students' perspective. Still, the students have been sensitized to the subject of sustainability and are able to integrate their knowledge into future jobs, which will have a positive impact on the environment.

It should be emphasized that, even just by modelling their own LCA, students can experience the core issues of an LCA. By experiencing the possibilities of changing the outcome of the LCA with one "little" assumption or choice, the students are now more aware when analyzing an LCA and therefore understood the method much more deeply than when only using textbooks as a source of knowledge. Moreover, students' everyday behavior was changed in the long-term to more eco-friendly behavior.

This case study aimed to inspire others to incorporate a service-learning LCA course in their curriculum. Our approach is easy to adopt and fast to setup, since data for meals are most likely readily available at each university. Also, by the literature requested, we contributed to filling the gap of specific examples of LCA teaching approaches including learning outcomes, curriculum, and a detailed schedule.

## 8 Outlook

Using the students' LCA data as a base for further analysis, as well as the selling price, daily selling amount, and nutritional value of the meals, more detailed decision-making support for the cafeteria was provided. It was shown that cheaper meals tend to be more climate friendly, meat containing meals were more popular than vegetarian or vegan options, and cheaper meals tend to be more popular. This means that the cafeteria should focus on selling vegetarian and vegan meals at a lower price to encourage students to act more environmentally friendly. Also, it was advised to lessen the amount of meat and milk products in various meals. Since this part of the evaluation was performed after the course was finished, detailed data will not be presented here, as it is not the focus of this case study.

Nevertheless, the success of this service-learning approach as well as the feedback of the students convinced us to continue making use of an integrated service-learning approach within this course. The cafeteria already assured further cooperation, since many more meals need to be assessed. Further extensions to social LCA, Life Cycle Costing, and Life Cycle Sustainability Assessment are possible. Of course, it is not reasonable to run similar studies continually for years, as the topic wears off if it becomes routine for cafeteria staff, teaching staff, and students. With experience gained through the years, and more information made available from previous rounds, more accurate LCA studies could be achieved by the students, but the learning outcomes would shift from basics to specialized questions. Therefore, LCA of university cafeteria meals is a service-learning target for a few years only, with the possibility of offering an advanced course where special topics of the food LCAs like seasonality, regionality, storage times, organic production, end-of-life scenarios, and other parameters can be a focal point.

Service-learning is continuously in need of finding new endeavors and organizations which could benefit from such a course. A challenge remains in how to assess students in a service-learning environment. In our case study the additional learning outcomes didn't register in the written exams, indicating the need for different questions or different exam formats. Oral marks are difficult to grade in the context, even more so from the perspective of the faculty

members, who will only grasp the tip of the iceberg of the students' activities. Another option would be an (additional) grading based on activities like social media such as ResearchGate (researchgate.net) do, which scores their members for their activities and feedback from other members. Whereas implementation would seem possible for such a course like the one in the case study, it is not clear whether this would draw too much attention away from the LCA study, and if it would result in fair grades or simply reflect personal relationships between the course members. A further option could be a mandatory and transparent self-assessment of and within groups (Boud, 1989; Taras, 2010; Steinke and Fitch, 2007).

Note that, due to the COVID-19 pandemic, changes to the course had to be made to run the course completely digitally. Fortunately, this service-learning based course in principle offers the possibility to be performed completely online. By using a virtual private network to log into the university's PC with preinstalled LCA software and databases, students could generate a similar LCA. Since most of the course's materials are available online and digital tools, such as messaging boards and data share points are already in use, a fully online exercise would be possible without larger efforts. The framework and model for such a course could be based on Bourelle, 2014.

Lessons learned for the next service-learning LCA courses include the provision of additional LCA background data for several ingredients, planning extra time slots for LCA modelling, giving students a more detailed view of what to expect from this course, and to further embrace of the learning-by-doing methodology by replacing the written exam with a more fitting format.

Finally, it can be said that LCAs of food is a well-suited point of entry for the natural and environmental sciences into the field of LCA. Care must be taken to not exceed the time budget as defined by the credit points, since creating a LCA for the first time is a very time-consuming task. The students' detailed LCA results, as well as models and product systems, are available on demand for interested lecturers.

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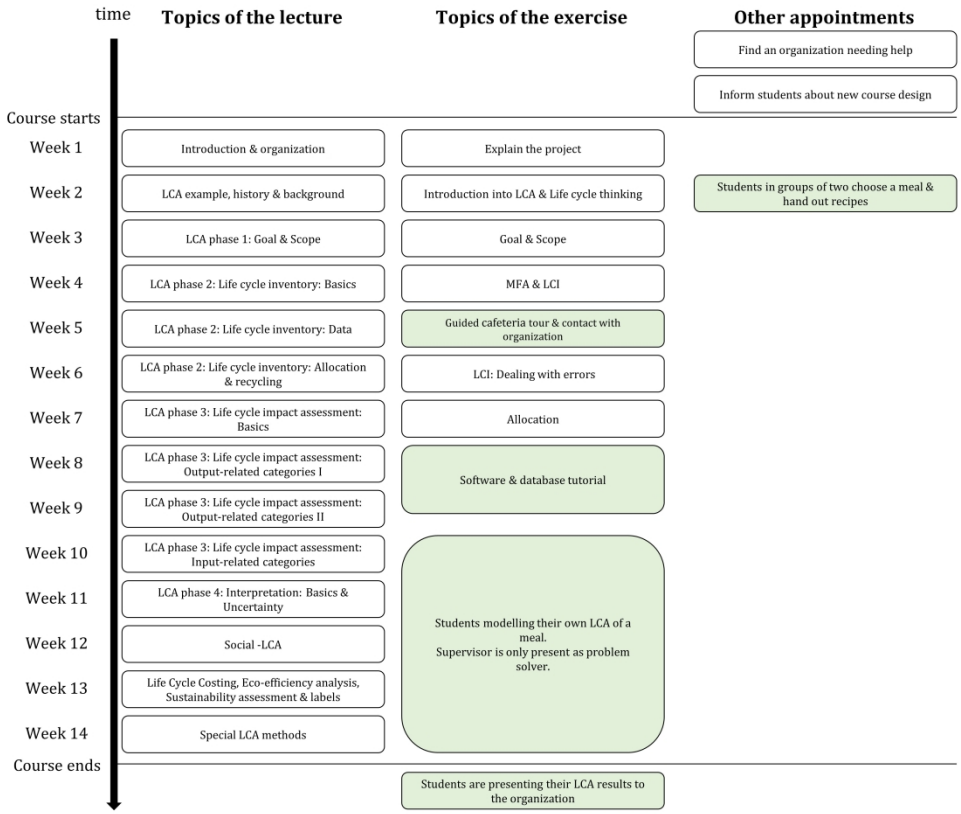


Figure 1 Schedule of the master's degree service-learning LCA course that can be taught in one semester. The course is divided into a weekly lecture and exercise of 90 minutes each. 90-minute active-learning exercises are highlighted in green. MFA for material flow analysis, LCI for life cycle inventory.

190x159mm (600 x 600 DPI)

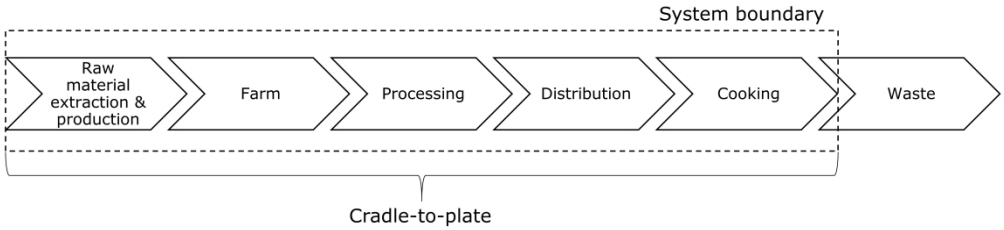


Figure 2 Streamlined illustration of a generic cradle-to-plate Life Cycle Assessment as used in the presented service-learning LCA course. Modeling the ecological impacts of the generated waste and/or recycling processes is outside the scope of the study.

248x60mm (600 x 600 DPI)

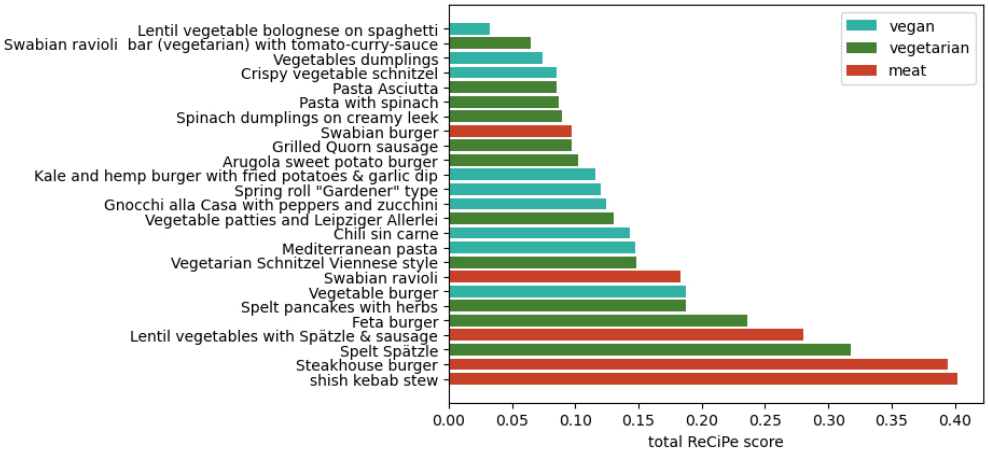


Figure 3 Results of the 25 LCAs performed by the students. The higher the total ReCiPe score, the higher the potential ecological impact of the respective food. On average, meat-based food performed worse than vegan or vegetarian alternatives.

235x109mm (100 x 100 DPI)

*Table 1 Comparison between learning concepts related to service-learning, with the aim of highlighting the similarities as well as differences and to provide a common theoretical ground to expand from.*

| | **Active learning** | **Project-based learning** | **Inquiry-based learning** | **Service-learning** |
|---|---|---|---|---|
| **Connection between the learning concepts** | "Any instructional method that engages students in the learning process" (Prince, 2004) | "Project-based learning is one of the active learning methods"(Derevenskaia, 2014) | "IBL is a form of active learning"(Ernst *et al.*, 2017) Could be grouped as problem-based, project-based and case-based teaching (Aditomo *et al.*, 2013) | Involves active learning opportunities (Goldberg *et al.*, 2006) "Project-based service learning is a form of active learning where students work on projects that benefit a real community or client while also providing a rich learning experience" (Bielefeld *et al.*, 2009) |
| **Role of teacher** | Creating a constructivist learning environment (Anthony, 1996) | Engaging students in investigation by giving them a project to work on. The assignment is usually broad and complex while the outcome must not be predetermined (Blumenfeld *et al.*, 1991) | Pose the initial question or problem to students, then facilitate them in discovering answers by posing further questions (Aditomo *et al.*, 2013) | Supportive, enabling a democratic environment (Deeley, 2015) Manager, facilitating the cooperation between students and organization |
| **Role of students** | Students actively interpret and impose meaning through the lenses of their existing knowledge | "Students pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analyzing data, drawing conclusions, | Investigate and solving problems (Aditomo *et al.*, 2013) | "Students engage in activities that address human and community needs together with structured opportunities for reflection designed to achieve desired |

| | | | | |
|---|---|---|---|---|
| | structures (Anthony, 1996) | communicating their ideas and findings to others, asking new questions, and creating artifacts." (Blumenfeld *et al.*, 1991) | | learning outcomes" (Jacoby, 1996) |
| **Framework or phases** | Too broad to define common a framework | Setting goals, planning, monitoring and evaluating progress, and producing and revising artifacts (Blumenfeld *et al.*, 1991) | Orientation, conceptualization, investigation, conclusion, and discussion (Pedaste *et al.*, 2015) | Kolb's experimental learning-cycle: experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984; Salam *et al.*, 2019) |
| **Educational objectives** | Shift from passive to active learning. Activating students, promoting student<br><br>Engagement, improve learning outcomes (Prince, 2004) | Motivate students, promote real life skills like problem-solving (Blumenfeld *et al.*, 1991).<br><br>Practice applying knowledge (Aditomo *et al.*, 2013) | Critical thinking and problem solving (Aditomo *et al.*, 2013)<br><br>Developing students' skills<br><br>in communication and collaboration (Aditomo *et al.*, 2013) | "Students' active engagement in learning facilitates thinking critically, questioning assumptions, considering varying perspectives, and appreciating the civic purpose of their profession" (Goldberg *et al.*, 2006) |

*Table 1 Using Bloom's taxonomy of learning to structure students' tasks and learning outcomes of the presented service-learning LCA course into six cognitive levels.*

| **Bloom's taxonomy** | **Students' tasks and learning outcomes** |
|---|---|
| I – Knowledge | • Know basic terminology, principles, concepts, and problems of the LCA methodology |
| II – Comprehension | • Understand the iterative approach of conducting an LCA<br>• Understand the used LCA software and databases using a tutorial |
| III – Application | • In joint discussions in the exercise a common ground to expand from was outlined by:<br>  ○ Defining a common goal and scope<br>  ○ Defining system boundaries<br>  ○ Defining a functional unit<br>• Identifying and requesting missing information of the recipes, for example, asking suppliers about detailed ingredient data for processed food and asking the chef about preparation processes<br>• Modeling the whole life cycle of the meal from cradle-to-plate. First on paper, then using openLCA<br>• Finding the necessary data in the databases |
| IV – Analysis | • Identifying environmental hotspots of their meal<br>• Identifying potentials for improvement |
| V – Synthesis | • Compare LCA results with others<br>• Prepare LCA results and the presentation |
| VI - Evaluation | • Critically reflect the LCA results<br>• Put the LCA results in a wider context<br>• Present findings in a 10-minute presentation in front of the heads of cafeteria, the supervisors and interested researchers of the department |

| Questionaire # | Compulsory | Interest | Lecturer | Examination | Written exam | Relevant topic |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 0 | 0 | 1 | 0 |
| 5 | 1 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 1 | 0 | 1 | 0 | 0 |
| 7 | 1 | 1 | 0 | 0 | 1 | 0 |
| 8 | 1 | 1 | 0 | 1 | 1 | 1 |
| 9 | 0 | 1 | 0 | 0 | 0 | 1 |
| 10 | 1 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 1 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 1 | 1 | 0 |
| 13 | 0 | 0 | 0 | 1 | 1 | 0 |
| 14 | 1 | 0 | 0 | 1 | 0 | 0 |
| 15 | 1 | 0 | 0 | 1 | 0 | 0 |
| 16 | 1 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 1 | 0 | 0 | 0 | 1 |
| 18 | 0 | 0 | 0 | 0 | 1 | 1 |
| 19 | 0 | 1 | 0 | 0 | 0 | 0 |
| 20 | 0 | 1 | 0 | 0 | 1 | 0 |
| 21 | 0 | 0 | 0 | 1 | 1 | 0 |
| 22 | 0 | 0 | 1 | 0 | 0 | 1 |
| 23 | 1 | 1 | 0 | 0 | 0 | 0 |
| 24 | 0 | 1 | 0 | 0 | 1 | 1 |
| Arithmetic mean | | | | | | |
| Standard derivation | | | | | | |

| | | | | Structure, Interaction | | |
|---|---|---|---|---|---|---|
| How much tim | The course fol | The time prov | The lecturer a | Participants ca | I feel very wel | The assistance |
| 3 | 4 | 2 | 3 | 3 | 2 | 3 |
| 2 | 4 | 4 | 5 | 5 | 3 | 5 |
| 4 | 5 | 5 | 5 | 6 | 5 | 5 |
| 4 | 5 | 3 | 4 | 5 | 4 | 5 |
| | 1 | 1 | 1 | 4 | 1 | 5 |
| 3 | 5 | 3 | 4 | 5 | 3 | 5 |
| 4 | 3 | 2 | 4 | 5 | 4 | 4 |
| | 5 | 3 | 6 | 6 | 5 | 5 |
| 4 | 4 | 3 | 5 | 5 | 4 | 5 |
| 7 | 3 | 1 | 2 | 4 | 2 | 5 |
| 3 | 4 | 3 | 4 | 4 | 3 | 4 |
| 5 | 4 | 4 | 3 | 5 | 4 | 6 |
| 3 | 4 | 2 | 5 | 6 | 4 | 5 |
| 3 | 4 | 5 | 4 | 5 | 4 | 4 |
| 3 | 3 | 2 | 3 | 5 | 2 | |
| 4 | 4 | 4 | 6 | 5 | 4 | 6 |
| 6 | 3 | 4 | 3 | 6 | 4 | 6 |
| 2 | 3 | 2 | 3 | 4 | 4 | 5 |
| | 4 | 3 | 5 | 6 | 4 | 5 |
| 2 | 4 | 4 | 4 | 5 | 2 | 4 |
| 3 | 4 | 3 | 3 | 4 | 3 | 5 |
| | 6 | 6 | 6 | 6 | 6 | 6 |
| 3 | 4 | 1 | 5 | 4 | 2 | 6 |
| 4 | 4 | 3 | 4 | 6 | | 5 |
| | | | | | | |
| 3.6 | 3.91666667 | 3.04166667 | 4.04166667 | 4.95833333 | 3.43478261 | 4.95652174 |
| 1.27320565 | 0.97430763 | 1.30147631 | 1.26762931 | 0.85867272 | 1.19947288 | 0.76741958 |

| | | | Demand | | | |
|---|---|---|---|---|---|---|
| The lecturer h | The lecture an | The subject m | Exercise assigr | I had sufficien | Teaching aids | The applied m |
| 5 | 3 | 4 | 4 | 5 | 5 | 4 |
| 5 | 4 | 3 | 4 | 4 | 4 | 4 |
| 5 | | 6 | 5 | 6 | 6 | 5 |
| 4 | 4 | 4 | 5 | 4 | 5 | 5 |
| 3 | 1 | 4 | 3 | 4 | 2 | 1 |
| 5 | 5 | 4 | 5 | 4 | 6 | 5 |
| 5 | 3 | 5 | 4 | 6 | 5 | 4 |
| 6 | 5 | 5 | 5 | 4 | 5 | 5 |
| 5 | 4 | 4 | 4 | 4 | 4 | 5 |
| 4 | 3 | 4 | 3 | 5 | 4 | 4 |
| 5 | 4 | 3 | 3 | 1 | 4 | 4 |
| 4 | 5 | 4 | 3 | 4 | 5 | 4 |
| 5 | 4 | 4 | 4 | 4 | 5 | 5 |
| 3 | 4 | 5 | 3 | 5 | 4 | 5 |
| 4 | 3 | 4 | 4 | 4 | 5 | 3 |
| 5 | 4 | 5 | 4 | 5 | 5 | 5 |
| | 4 | 4 | 3 | 4 | 6 | 4 |
| 4 | 5 | 5 | 5 | 4 | 5 | 5 |
| | 4 | 4 | 3 | 2 | 5 | 6 |
| 4 | 4 | 5 | 4 | 4 | 6 | 5 |
| 4 | 3 | 4 | 4 | 5 | 4 | 4 |
| 6 | 6 | 5 | 5 | 6 | 6 | 6 |
| 2 | 4 | 5 | 4 | 1 | 4 | 5 |
| 5 | 5 | 4 | 4 | 4 | 6 | 6 |
| 4.45454545 | 3.95652174 | 4.33333333 | 3.95833333 | 4.125 | 4.83333333 | 4.54166667 |
| 0.96250035 | 1.02150784 | 0.70196412 | 0.75060362 | 1.29589653 | 0.96308682 | 1.06236679 |

| Material, teaching methods | | | | | | |
|---|---|---|---|---|---|---|
| I find the lectu | The lecturer a | The lecturer o | Difficult facts ; | The lecturer u | The lecturer a | The lecturer a |
| 4 | 3 | 3 | 4 | 3 | 3 | 3 |
| 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| 4 | 5 | 5 | 5 | 4 | 5 | 5 |
| 5 | 5 | 4 | 4 | 4 | 5 | 5 |
| 1 | 1 | 3 | 1 | 1 | 4 | 3 |
| 4 | 4 | 4 | 4 | 4 | 5 | 5 |
| 4 | 2 | 3 | 4 | 4 | 6 | 6 |
| 5 | 4 | 4 | 4 | 5 | 6 | 6 |
| 5 | 3 | 4 | 4 | 5 | 5 | 5 |
| 5 | 3 | 4 | 4 | 5 | 2 | 5 |
| 4 | 2 | 4 | 3 | 4 | 5 | 4 |
| 5 | 4 | 5 | 5 | 4 | 5 | 5 |
| 4 | 5 | 5 | 5 | 4 | 5 | 5 |
| 4 | 5 | 4 | 4 | 4 | 6 | 6 |
| 3 | 3 | | | 3 | 5 | 4 |
| 4 | 4 | 3 | 5 | 4 | 6 | 6 |
| 4 | 4 | 4 | 4 | 4 | 6 | 6 |
| 3 | 4 | 3 | 4 | 3 | 6 | 4 |
| 5 | 5 | 5 | 5 | 4 | 6 | 6 |
| 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| 3 | 3 | 3 | 3 | | 4 | 5 |
| 6 | 6 | 6 | 5 | 6 | 5 | 5 |
| 5 | 4 | 5 | 4 | 5 | 5 | 4 |
| 4 | 4 | 5 | 4 | | 6 | 6 |
| 4.125 | 3.79166667 | 4 | 4.04347826 | 4 | 4.95833333 | 4.875 |
| 0.99181432 | 1.14128709 | 0.90453403 | 0.87792425 | 0.97590007 | 1.0417029 | 0.94696311 |

| | | Your knowledge | | | | | |
|---|---|---|---|---|---|---|---|
| The preparatic | I've understoo | I can apply the | I'm now able t | The course en | After the cour | The course sti |
| | | 4 | 4 | 4 | 4 | 4 |
| 4 | 4 | 3 | 3 | 4 | 5 | 4 |
| 5 | 5 | 5 | 4 | 5 | 4 | 3 |
| | 5 | 4 | 4 | 4 | 4 | 5 |
| 5 | 4 | 1 | 4 | 4 | 4 | 2 |
| 5 | 4 | 4 | 4 | 5 | 5 | 3 |
| | 4 | 4 | 4 | 4 | 4 | 3 |
| 5 | 5 | 4 | 4 | 6 | 5 | 5 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 5 | 4 | 4 | 6 | 4 | 4 |
| 4 | 4 | 3 | 3 | 3 | 4 | 4 |
| 5 | 4 | 4 | 3 | 3 | 5 | 5 |
| 5 | 5 | 4 | 5 | 5 | 5 | 4 |
| 4 | 4 | 4 | 4 | 4 | 4 | 2 |
| 4 | 4 | 2 | 3 | | 2 | 2 |
| 4 | 5 | 2 | 3 | 5 | 5 | 4 |
| 5 | 4 | 3 | 4 | 3 | 4 | 4 |
| 5 | 5 | 5 | 4 | 4 | 6 | 5 |
| 4 | 5 | 5 | 5 | 4 | 4 | 4 |
| | 4 | 4 | 4 | 6 | 6 | 5 |
| 4 | 4 | 4 | 4 | 5 | 5 | 5 |
| | | | | | 6 | 5 |
| 1 | 5 | 5 | 5 | 5 | 6 | 5 |
| | 4 | 4 | 4 | 4 | 5 | 4 |
| 4.29411765 | 4.40909091 | 3.73913043 | 3.91304348 | 4.40909091 | 4.58333333 | 3.95833333 |
| 0.98518437 | 0.50323628 | 1.00983308 | 0.59643208 | 0.90811636 | 0.92861124 | 0.99909379 |

| Interest, Communication | | | | | | |
|---|---|---|---|---|---|---|
| By attending t | By attending t | Attending this | All in all, the c | Was ist beson | Was könnte ve | What semeste |
| 4 | | 4 | 3 | [BILD] | Organisation i | 2 |
| 4 | 3 | 4 | 5 | [BILD] | [BILD] | 1 |
| 3 | 4 | 5 | 5 | [BILD] | Datenlage zur | 1 |
| 4 | 4 | 5 | 4 | [BILD] | [BILD] | |
| 1 | 1 | 1 | 1 | [BILD] | Case Study Ök | 1 |
| 3 | 3 | 5 | 4 | [BILD] | Das Mensabila | 1 |
| 3 | | 5 | 3 | [BILD] | Lösungen wer | 1 |
| 5 | 4 | 4 | 5 | Die Abwechslu | Die Mensabila | 1 |
| 4 | 4 | 4 | 4 | Interessante T | Lösungen der | 2 |
| 4 | 4 | 2 | 3 | [BILD] | [BILD] | 1 |
| 4 | 2 | 2 | 2 | [BILD] | klarere Struktu | 1 |
| 4 | 4 | 5 | 4 | [BILD] | [BILD] | 1 |
| 4 | 5 | 5 | 4 | [BILD] | [BILD] | 1 |
| 1 | 2 | 4 | 4 | Sympathische | Projekt vom U | 1 |
| 2 | 2 | | 2 | [BILD] | Projekte wie d | 1 |
| 4 | 3 | 4 | 4 | Gute Betreuur | Vielleicht auch | 1 |
| 4 | 3 | 4 | 4 | Netter Dozent | Lösungen nich | 1 |
| 5 | 4 | 4 | 4 | Die praktische | Die praktische | 1 |
| 4 | | | 4 | [BILD] | Lösungen zur Verfügung stell | |
| | | | 4 | - Skript, das be | #NAME? | 1 |
| 4 | 4 | | 3 | Geringe Distar | #NAME? | 1 |
| | | | 6 | Jonas versteht | [BILD] | 1 |
| 5 | 4 | 4 | 4 | [BILD] | [BILD] | |
| | 4 | 4 | 4 | Schnelle Antw | [BILD] | 1 |
| 3.61904762 | 3.36842105 | 3.94736842 | 3.75 | | | |
| 1.11696869 | 1.0116283 | 1.12909424 | 1.07339364 | | | |

| Degree | Sustainable M | Chemistry and | Timestamp |
|---|---|---|---|
| Master | 1 | 0 | 16.01.2020 um 10:06:53 |
| Master | 1 | 0 | 16.01.2020 um 10:07:50 |
| Master | 0 | 1 | 16.01.2020 um 10:07:58 |
| | 0 | 0 | 16.01.2020 um 10:08:49 |
| Master | 1 | 0 | 16.01.2020 um 10:09:26 |
| Master | 1 | 0 | 16.01.2020 um 10:10:46 |
| Master | 0 | 1 | 16.01.2020 um 10:11:40 |
| Master | 1 | 0 | 16.01.2020 um 10:11:59 |
| Master | 1 | 0 | 16.01.2020 um 10:13:43 |
| Master | 1 | 0 | 16.01.2020 um 10:14:03 |
| Master | 1 | 0 | 16.01.2020 um 10:14:11 |
| Master | 1 | 0 | 16.01.2020 um 10:14:14 |
| Master | 0 | 1 | 16.01.2020 um 10:14:22 |
| Master | 0 | 1 | 16.01.2020 um 10:14:57 |
| Master | 0 | 0 | 16.01.2020 um 10:14:58 |
| Master | 1 | 0 | 16.01.2020 um 10:15:21 |
| Master | 1 | 0 | 16.01.2020 um 10:16:22 |
| Master | 1 | 0 | 16.01.2020 um 10:16:48 |
| len Vorlesungs | 0 | 0 | 16.01.2020 um 10:17:20 |
| Master | 1 | 0 | 16.01.2020 um 10:17:53 |
| Master | 1 | 0 | 16.01.2020 um 10:27:00 |
| Master | 0 | 1 | 16.01.2020 um 10:29:14 |
| | 0 | 0 | 20.01.2020 um 08:25:52 |
| Master | 1 | 0 | 20.01.2020 um 09:48:48 |

| Questionaire # | Timestamp |
|---|---|
| 11792 | 11.03.2021 10:58:51 |
| 11788 | 11.03.2021 07:18:34 |
| 11809 | 15.03.2021 07:14:11 |
| 11783 | 10.03.2021 18:15:11 |
| 11789 | 11.03.2021 09:22:47 |
| 11787 | 11.03.2021 04:55:30 |
| 11782 | 10.03.2021 17:05:46 |
| 11784 | 10.03.2021 18:29:37 |
| 11790 | 11.03.2021 09:32:18 |
| 11781 | 10.03.2021 16:57:29 |
| 11780 | 10.03.2021 16:51:33 |

**Arithmetic mean:**
**Standard derivation:**

| Conducting th | If you have no | Based on the | I would like to | The cooperati | The goal of he | I would have l |
|---|---|---|---|---|---|---|
| 5 Ich habe voral | 4 | 6 | 5 | 6 | 6 | |
| 5 Noch mehr Be | 2 | 6 | 6 | 6 | 4 | |
| 5 Einkauf nach | 3 | 6 | 5 | 3 | 4 | |
| 4 Zutatenlisten | 3 | 5 | 3 | 1 | 6 | |
| 5 Überlege seit | 4 | 6 | 6 | 6 | 2 | |
| 5 | 4 | 6 | 4 | 4 | 6 | |
| 5 Ernähre mich | 3 | 6 | 6 | 3 | 4 | |
| 6 Strukturierte | 5 | 5 | 5 | 5 | 5 | |
| 4 Umweltwirku | 4 | 6 | 4 | 3 | 4 | |
| 5 mehr auf Regi | 5 | 6 | 5 | 4 | 2 | |
| 4 Hat mir geholf | 5 | 6 | 5 | 6 | 4 | |
| 4.82 | 3.82 | 5.82 | 4.91 | 4.27 | 4.27 | |
| 0.60302269 | 0.98164982 | 0.40451992 | 0.94387981 | 1.67874412 | 1.42062726 | |

| I would have l | Overall, I wou | Additional remarks |
|---|---|---|
| 4 | 2 | |
| 3 | 1 | |
| 6 | 2 | |
| 5 | 3 | Die Übung war leider sehr, sehr zeitaufwändig, was vorher nicht so an |
| 3 | 5 | Bitte unbedingt weiter so!!!! |
| 6 | 5 | |
| 2 | 4 | Schade, dass bisher keine Klausureinsicht statt finden konnte. Ein zusä |
| 4 | 5 | |
| 2 | 2 | |
| 2 | 1 | Die Übung hat mir sehr viel gebracht, z.B. konnte ich bei einem Vorstel |
| 3 | 2 | |
| | | |
| 3.64 | 2.91 | |
| 1.50151439 | 1.57826141 | |

die Studierenden kommuniziert wurde. Außerdem wäre eine Betreuung durch 2 Dozent*innen schö

tzlicher Betreuer in der Übung im PC-Pool wäre gut gewesen, um Fragen schneller zu klären. Anson

llungsgespräch zum Thema LCA glänzen, weil ich "Praxiserfahrungen" habe :)

ön gewesen. Auch die Absprache zwischen den Gruppen hätte besser gefördert werden können, da

ısten sehr tolles und praxisnahes Projekt!

ıs Moodle-Forum war da z.T. nicht ausreichend geeignet.