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TEACHING SUSTAINABLE LOGISTICS AS A PROJECT-BASED LEARNING COURSE

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ABSTRACT

Sustainable logistics combines the task of the 6R of logistics (right product, right place, right time, right condition, right cost) with social and environmental sustainability, especially low emissions and low resource consumption. This means that a problem that is already challenging, namely planning, executing, and controlling logistical processes, gets even more complex and requires aspects of systems thinking to incorporate environmental and social impacts. Classical approaches of teaching, e.g. lectures with presentations and short exercises on closed problems, do not do justice to the complexity and intricacies of the topic sustainability. In such a context, project-based learning (PBL) where students do group work on open-ended problems with real-world complexity seems to be a more adequate means to teach the subject. The paper describes a PBL course in which students worked on projects to conceptualize

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micro-depots for parcel delivery in different areas of Düsseldorf. A micro-depot is a temporary storage location in a city from which parcels can be delivered by cargo bikes. The aim was to locate the micro-depot, design the delivery routes, check the feasibility, and calculate the reduction of greenhouse gases and other emissions. The course was taught in cooperation with a partner from the courier, express, and parcel delivery industry. The paper describes the experiences with the course and gives recommendations for a successful implementation of PBL in courses on sustainability.

1 INTRODUCTION

1.1 Research motivation

Students in industrial engineering learn the basics of logistics in diverse courses such as production management, supply chain management, or operations management. Logistics typically includes the functions of transportation, warehousing, and packaging as well as the processes of purchasing, production, distribution, and reverse logistics, i.e. return and disposal logistics (Deckert 2017, 58-59). The planning, execution, and controlling of logistical processes is usually challenging and complex enough for students and in a classical context does not include considerations of sustainability.

Sustainability adds another layer of complexity to logistics and also forces students to include aspects of systems thinking to incorporate environmental and social impacts. Classical approaches of teaching, e.g. lectures with presentations and short exercises on closed problems, do not seem to do justice to the complexity and intricacies of the topic sustainability. For an elective course on sustainable logistics it was decided to use project-based learning (PBL) where students do group work on open-ended problems with real-world complexity since this approach seems to be a more adequate means to teach the subject. The project task was to conceptualize micro-depots for parcel delivery in different areas of Düsseldorf. This article reports the experiences with PBL in teaching sustainable logistics and gives tentative recommendations for further courses.

1.2 Theory of project-based learning (PBL)

Project-based learning (PBL or PjBL) can be understood as “an inquiry-based instructional method that engages learners in knowledge construction by having them accomplish meaningful projects and develop real-world products” (Guo et al. 2020, 2). Typical characteristics of project-based learning are a driving question, autonomous inquiry and active investigations, collaboration in a team, realism of the problem, and development of a functional solution, usually an artefact such as a prototype or a report with recommendations for action (Kokotsaki, Menzies, and Wiggins 2016, 268; Krajcik and Blumenfeld 2005, 320-328). These characteristics are mainly derived from the fact that students work in teams on a concrete real-world project with different tasks.
According to the PMBOK Guide by the Project Management Institute (PMI) a project is a “temporary endeavour undertaken to create a unique product or service” (Project Management Institute 2021, 4). This means that projects typically have a start and an end, different distinct phases, and a clear and novel goal. Typical features of a project, thus, are time limitation, complexity, uniqueness / novelty, and a distinct set of goals. Such a challenging problem typically leads to a high level of student engagement and motivation (Kokotsaki, Menzies, and Wiggins 2016, 268).

Project-based learning is sometimes grouped together with and in some cases even misunderstood as the concept of problem-based learning, especially since they both share the same acronym. It's true, that both are concepts of learning-by-doing based on autonomy, collaboration, and curiosity. However, there is a distinction between project-based and problem based learning: In project-based learning a well-defined project task is assigned to the team, while problem-based learning evolves around an ill-defined problem without many restrictions. Thus, project-based learning is usually experienced as being more authentic (de Graaf and Kolmos 2007, 5-6). This makes project-based learning especially suitable for learning in mechanical and industrial engineering.

1.3 Sustainable logistics and micro-depots

Sustainable logistics can be defined as the "application of principles from sustainability to logistics, i.e., the functions of transportation, warehousing, and packaging" (Deckert 2020, 1) and includes concepts of both Green Logistics and City Logistics. The task of logistics is the fulfilment of the 6R, i.e. to make the right quantity of the right product available at the right place and the right time in the right condition for the right cost. Green Logistics complements this set of goals with a low resource consumption and low emissions (or two furthers R if you want: right resource efficiency and right emissions). City Logistics focusses especially on the supply of cities and urban areas with goods. Main targets are a low stress on transport infrastructure (e.g. less traffic jams and accidents) and low direct emissions (e.g. noise or particulate matter) (Deckert 2017, 58-64; Deckert 2021, 24-37).

A micro-depot is a temporary storage location in the city – usually a container or a swap body which is dropped off by a truck. From this temporary location parcels can be delivered by cargo bike to the final customers. The micro-depot is typically located at the center of gravity of the deliveries. The logic behind this concept is that it subdivides the last mile into a second last mile (transport of container full of parcels by truck from the depot of the company into the city) and a very last mile (transport of parcels by cargo bike to final destination) (see fig. 1). The transport to the final destination is called a loop which includes several end customer deliveries (Deckert, Stodick, and Hertz-Eichenrode 2021a, 272-273, Deckert, Stodick, and Hertz-Eichenrode 2021b, 550-552, Stodick and Deckert 2019, 237-238).

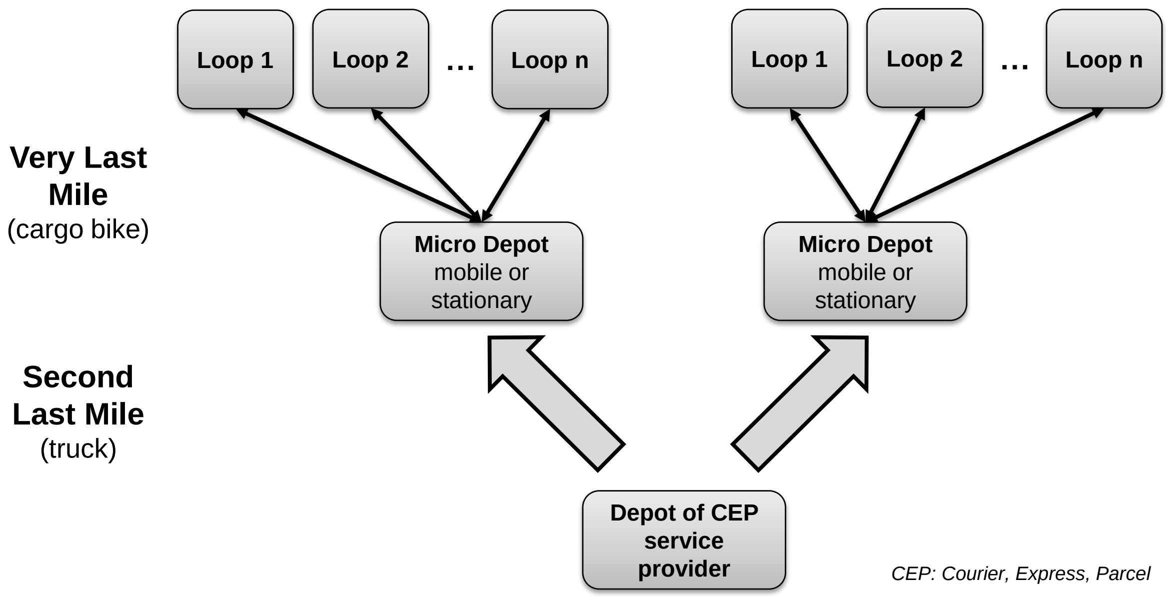

Fig. 1: Concept of micro-depots (Stodick and Deckert 2019, 237)

In this way, the micro-depot combines the advantages of transport bundling with the advantages of environment-friendly transportation and creates necessary conditions for the use of cargo bikes (e-bikes as well as conventional bikes), i.e. delivery of low volumes of goods over short distances. Current research on micro-depots shows that the concept has a high potential to reduce greenhouse gas emissions as well as exhaust fumes and to reduce the strain on the traffic infrastructure in urban areas (Deckert, Stodick, and Hertz-Eichenrode 2021a, 277-279, Deckert, Stodick, and Hertz-Eichenrode 2021b, 553-558).

The challenge to teach sustainable logistics is twofold. First, sustainable logistics is, up to now, not well integrated with classical logistics which focusses mainly on the classic goals of logistical performance (e.g. delivery time) and logistical costs already constituting a trade-off. To this, the dimension of sustainability is added which mainly deals with the externalities of a business and demands a systems thinking approach. Second, sustainable logistics also includes trade-offs between the functions of transportation, warehousing, and packaging, as decisions on the sustainability of one function influences the sustainability of the others (Deckert 2021, 38).

2 COURSE DESIGN

2.1 Target and tasks

As part of the course "Sustainable Logistics" at Hochschule Düsseldorf University of Applied Sciences, students had to work in groups on a project to design micro-depots for parcel delivery in different areas of Düsseldorf. The course was held three years in a row, each summer term from 2018 to 2020. A total of eight groups of three to five participants took part in the course, resulting in a total of 33 participants over the three years. The goal of the course was to locate the micro-depot, plan the supply to and from the depot, verify feasibility, and evaluate the reduction of greenhouse gases and other emissions (see fig. 2).

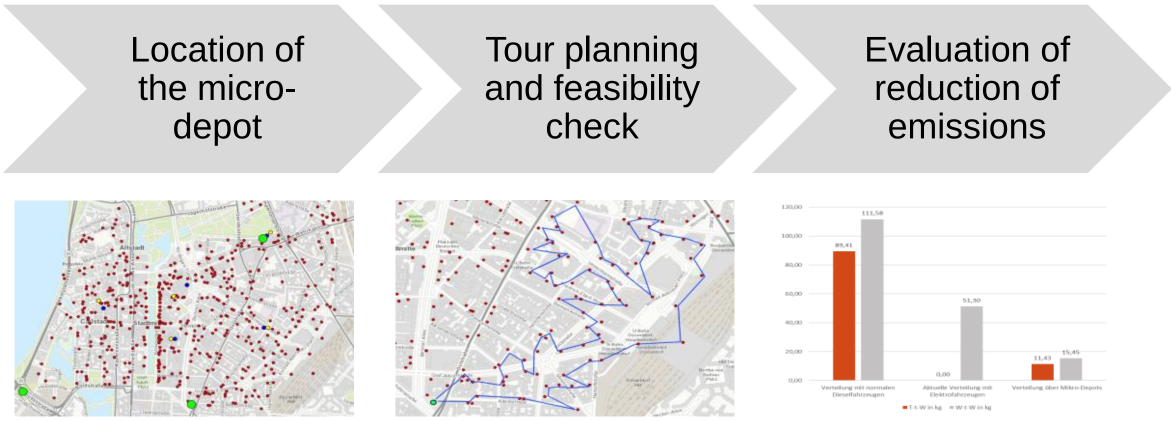

Fig. 2: Project tasks and sequence

In order to be able to evaluate the results obtained, a comparison was made between the emission output of the micro-depot delivery and the output of the currently implemented variant with delivery by diesel and electric vehicles. The course was conducted in cooperation with a partner from the courier, express, and parcel delivery industry who provided the real-world data to the students. A total of three delivery districts, or "loops" within the company, were defined as locations. The loop "Altstadt" is limited to Düsseldorf's old part of town, the loop "West" to the districts located west of the Rhine, and the loop "Hafen" to the southern part of the city center and the port region. The result of the course was a report with recommendations for action.

The research method of this paper is based on a mixed-method approach where qualitative as well as quantitative data are analysed. The qualitative data are based on the lecturer's perceptions and on an analysis of the final reports of the students. The quantitative analysis is comprised of the comparison of the grades and the course evaluations of the PBL course (2018-2020) with those of the same course with a written exam in 2022.

2.2 Outcomes

Locate the micro-depot

The first aim of the task was to find a suitable location for the micro-depot. The location was found by means of a theoretical and practical location determination. For theoretical determination, the parcel data provided to the students by the logistic partner were converted into individual coordinates using different geocode programs. These coordinates were then transferred to a location map. Next, seven of the eight groups determined the optimal location using the center-of-gravity method. One group determined the optimal location using the Steiner-Weber approach.

Following the theoretical determination, it had to be checked whether it is possible to set up a micro-depot at that location in practice. For this purpose, all groups visited the location to get an idea of the conditions on site. In doing so, they all found that due to various constraints such as pedestrian zones, unfavorable road layout, already developed land, etc., they had to choose a different location nearby in order to determine the practical location of the micro-depot. The geographical difference between the theoretically calculated optimal locations and the possible practical locations for the micro-depos identified during the site visits ranged from 0 to a maximum of 500 meters.

Plan the supply to and from the depot and verify feasibility

The delivery of parcels from the micro-depot to the customers is carried out by e-bikes equipped with an exchangeable box. The box has a capacity of max. 50 packages. Depending on the loop, a different number of e-bikes is required. To calculate the number of e-bikes needed, several factors were taken into account including the maximum working time per employee, the capacity of the box, the maximum range of an e-bike, the calculated distance to the customer, and the time per drop off. To calculate the possible trips per driver, the groups used various route planning methods. Mainly, the groups used the Sweep Algorithm, where clusters are formed first and then the route is determined. Two of the eight groups used the Nearest Neighbor approach for route planning, where the closest customer is served at a time until capacity is exhausted. Based on this planning, the number of e-bikes needed is four to eight e-bikes.

For the supply of the micro-depot, all groups decided to use trucks. The truck delivers the micro-depot in the form of a container. This container already contains the exchangeable boxes, in which the packages are pre-sorted for each tour. This means that the driver at the micro-depot only has to exchange the box as a whole and does not have to load each package individually. For certain deliveries that are impossible or difficult to handle by e-bike, for example, due to unsurfaced roads on which an e-bike can only travel to a limited extent, or when express or large deliveries are involved that require a quick turnaround or a large vehicle, five of the eight groups have designated electric vans for the tours in addition to the e-bikes.

Evaluate the reduction of greenhouse gases and other emissions

After completing the route planning, the students had the task of finding out whether energy consumption and emissions could be reduced by using the micro-depot. For the calculation of energy consumption and greenhouse gas emissions, DIN EN 16258 was used. In the first step, the transport performance was divided into individual legs. Then the energy consumption and emissions were calculated for each leg. In the final step, the results of all legs were summed up. For the evaluation of the carbon footprint, calculations were performed in the different variants of (1) standard delivery with diesel delivery vehicles, (2) standard delivery with electric delivery vehicles, and (3) delivery with the use of micro-depots and e-bikes. The result for all groups shows that when using the micro-depots, both greenhouse gas emissions and other emissions (e.g. exhaust fumes) are the highest for transportation with diesel delivery vehicles followed by delivery with electric vehicles. The highest savings can be achieved using the micro-depots.

All in all, the analysis of the outcomes from 33 students in the summer terms 2018-2020 shows that there was a high student engagement – as indicated by the self-reported motivation in the course evaluation and the attendance quota during lectures. No student failed the course, the average grade was 91% with a span of 77%-100% which is above average.

3 EXPERIENCES & RECOMMENDATIONS

3.1 Experiences

The experiences of teaching the course three years in a row show some advantages and disadvantages of project-based learning (PBL) which are mainly in line with what can be expected from the theoretical concept. The main advantages are as follows:

- PBL offers the opportunity to combine the theory of a subject with a practical part, e.g. the theoretical calculation of a center of gravity for a location and the practical search for an appropriate space for the micro-depot in the real world. This offers a deeper learning experience for the students, as they are forced to translate their findings into reality with all the related decisions necessary to accommodate for real-world restrictions. The combination of theory and practice in PBL also shows students the need for compromises in real-world situations. A theoretical calculation is never a perfect solution, as it is based on certain assumptions and cannot take all real-world restrictions into consideration. So students experience that there is no cure-all or silver bullet, but that theory gives good approximate solutions which can serve as a starting point for the practical solution. They also learn that there is no one-size-fits-all solution, again requiring compromises, e.g. some deliveries, especially big ones, still have to be made with a classical delivery vehicle, as they are not feasible with a cargo bike.
- In a PBL course on sustainability, students not only learn new methods (e.g. calculation of greenhouse gas emissions), but they also learn that standard methods of logistics (e.g. methods for vehicle routing) make a valuable contribution to sustainable logistics. It is the integration that matters.
- A project with interlinking tasks can only be solved through collaboration which means it requires a good deal of social interaction and a functioning team. Thus,

besides functional competence in logistics and sustainability, students gain social competence in a PBL course.

The main disadvantages of a PBL course in sustainable logistics are as follows:

- As PBL focusses on one specific project, students do not get a good overview over the topic (e.g. sustainable warehousing and packaging were not part of the course which focussed on micro-depots), and not all necessary methods and trade-offs can be included. So the breadth of knowledge which students acquire is rather limited. This contrast became clear when the course was taught to a larger group of students using a written exam as the method of examination in 2022: Students gained more breadth of knowledge but sometimes lacked in depth of understanding.
- A PBL course means more effort for the lecturer than a standard course. Main efforts occur in the design of the project, the preparation of the excursion to the industry partner, and the coaching of the teams. As the solutions to open-ended problems might vary, the grading also demands more instinctive feel than e.g. grading exercises or exams with closed problems. Furthermore, the success of a PBL course depends to a large part on the industry contacts of the lecturer.
- An important prerequisite for the students who want to participate in a PBL course about sustainable logistics is that they need to be well acquainted with the concepts and methods of classical logistics. The course only teaches sustainability aspects of logistics content-wise.

Student behaviour and feedback mirrored these advantages and disadvantages (as expected from the theory on PBL):

- In the three years when the course was taught in the PBL format there was a high student engagement and motivation. No student failed the course and the average grade was relatively high. Engagement and grades were distinctly lower when the course was taught with a written exam as method of examination in 2022.
- The students reported that they gained a deeper understanding through the course, but some criticized the lack of an overview over the subject or specific topics of interest.
- The course demanded social competence through team work due to the interlinking steps or tasks. The groups with the weakest team spirit – visible through bickering in the team or incoherence in presentation style – usually delivered the worst results and got the lowest grades.

3.2 Recommendations

From our experiences we generated three recommendations for problem design suitable for a PBL course. In accordance with the 6R of logistics we called them the 3R of PBL:

- Right topic: To get a driving question which motivates the students, the problem needs to be based on real-world data about an interesting topic and divided into interlinking tasks that force students to collaborate.
- Right partner: A realistic problem for a PBL course requires an industry partner who is willing to share data, talk openly about business intricacies, and give feedback on the students' solutions.
- Right limits: In the design of the problem there is a trade-off between realism and effort: The problem needs to be realistic enough to be motivating, but needs to respect the time and capacity limits of a semester course. Furthermore it

needs to be neither too specific for students to get lost in details nor too broad for students to lose focus. If the solution is implemented by the company, the damage potential of the solution needs to be kept low.

4 SUMMARY AND ACKNOWLEDGEMENTS

In summary it can be said that project-based learning (PBL) offers the opportunity for a deep learning experience of the students in sustainable logistics and significantly improves engagement and outcomes of the course. However, there are three caveats to be taken into consideration. First, there is a tension between breadth and depth of learning. PBL lacks in conveying the breadth of a subject. A combination of traditional courses with PBL courses would be an optimum solution, but often fails because of time restrictions. Second and related to the first point, when teaching sustainability there is the challenge of more and more additional contents which requires lecturers to re-examine their contents and set a new focus to keep within the time restrictions of a course. Third, up to now there is no real integration of classic and sustainable logistics which are usually taught in separate courses. This shows that sustainability – important as it is – is still often perceived as an add-on to classical logistics. Time will tell if such an integration will be possible in the future.

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