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HOW TO ENABLE ENGINEERING STUDENTS TO APPLY SUSTAINABLE SOLUTIONS IN THE PRODUCT DEVELOPMENT PROCESS?

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ABSTRACT
Novice product designers are often insufficiently trained for sustainability-related challenges in engineering practice as sustainability or eco-design have not yet become standard topics in engineering curricula at German universities. The authors developed a course for engineering students to familiarise them with a sustainable way of thinking and train skills required to develop more sustainable solutions. This paper provides details on the concept's structure, content, and methods. The course is part of the Bachelor's and Master's programmes in Mechanical, Biomedical and Industrial Engineering. In order to understand the importance of the topic, students get an introduction to sustainability in general through diverse methodological approaches. Subsequently, they learn and apply relevant basic methods from the field of product development and material selection. Furthermore, special attention is paid to the synergy between university engineering education, science and industry through excursions and guest lectures. Evaluations assess students' learning outcomes, thus enabling the continuous adjustment of addressed content and applied methods.

Keywords: Engineering education, sustainable development, sustainability, materials science, materials selection, product design

1 INTRODUCTION
The world population is growing. By 2050, more than 9.7 billion people could live on this earth [1]. The global extraction of raw materials is steadily increasing and could reach over 100 billion tonnes per year by 2030 if the trend remains the same [2]. Due to the rapid pace of this resource consumption and the often missing recovery frameworks, there is a gradually increasing shortage of resources and a rapidly growing burden on global ecosystems [3].
Engineering designers play a key role in the necessary shift towards a circular economy, as technologies they develop actively use resources on a large scale and are a driving factor of social change [4]. This responsibility should be considered at the very beginning of the development of any product and process. However, prospective product designers are still insufficiently trained to consider their work's ethical and sustainable dimensions. Therefore, a comprehensive discussion of sustainability issues in product development is urgently needed for university engineering education, considering existing guidelines regarding the selection of materials and design [5, 6]. This paper presents a course at a German university intending to fill this gap.

2 COURSE CLASSIFICATION
As a response to the challenge of sustainability in engineering, there is a global shift towards student-centred learning in education for sustainable development (ESD). In global comparison Europe has the highest number of publications in this area. Particularly younger universities are demonstrating successful systemic approaches. Overall, however, the publications are still scarce, and one cannot yet speak of an implementation of ESD content in the engineering education on a large scale [7, 8].
In Germany one can find a few entire degree programmes on sustainability in the engineering sciences particularly at Universities of Applied Sciences [9]. However, corresponding approaches can also be found at a few universities, like the quite novel degree programmes "Sustainable Systems Engineering" at the University of Freiburg (since winter 2016/17) [10], "Sustainable Engineering of Products and

Processes" at the Technical University of Braunschweig [11] and "Sustainable Engineering" at the University of Hannover [12] (both since winter 2021/22). As stated in the German “National Action Plan on Education for Sustainable Development,” it is important to train "sustainability experts" in special degree programmes, as well as to integrate content on ESD into every degree programme via discipline specific and interdisciplinary courses [13]. In addition to the existing demand for corresponding competencies in engineering practice, the positive effects of interdisciplinary teaching on students and their later professional lives have already been shown [14].
The new course "Sustainable Material Selection and Product Development" presented here aims to promote relevant competencies of ESD in product design according to Bormann and de Haan [15] among engineering students through its innovative structure. It is offered at the Faculty of Mechanical Engineering and Marine Technology at the University of Rostock, Germany. The course is taught in equal parts and thus interdisciplinary by the Chairs of Product Development and the Chair of Materials Science, two disciplines that (should) go hand in hand for the design of sustainable products. It has been established and conducted for the first time during winter semester 2021/2022.

3 COURSE STRUCTURE

The number of students who can enrol in the course is limited to 24. Students from advanced Bachelor's and early Master's courses in Mechanical Engineering, Biomedical Engineering and Industrial Engineering can participate. Ideally this results in a very heterogeneous group with different professional perspectives, although we have not set a specific ratio of the number of students per degree programme. Learning and cooperating in heterogeneous groups can promote the development of design competencies (Gestaltungskompetenzen) according to Bormann and de Haan in the area of interdisciplinarity as well as social competencies [15], e.g., a multi-perspective approach, interdisciplinarity, cooperation and conflict of objectives. This distinguishes the course from standard engineering courses usually offered for a specific semester or a specific degree programme. Lectures, usually offered by one chair, run throughout the semester and tutorials facilitate the application of the lecture content through assignments. The acquired knowledge is then tested in a written or oral exam. In some courses, the students also complete laboratory work. This new course on the contrary offers a modified and varied approach to teaching. The unique elements are presented in Figure 1 and are described in more detail in the following subsections.

						week							
1	2	3	4	5	6	7	8	9	10	11	12	13	14
introduction to sustainability, semester project		problem solving in design - *theorie*		materials selection and material life cycle - *theorie*				sustainable design guidelines - *theorie*		pre-paration of final presen-tations	ex-cursion, guest lecture	students final presen-tations	
		problem solving in design - *workshops*		materials selection and material life cycle - *tutorials with GRANTA EduPack*				sustainable design guidelines - *workshops*					closure and feedback

Figure 1. Timeline of the course "Sustainable Material Selection and Product Development", including seminars, lectures, tutorials, excursion, guest lecture and student contributions

3.1 Introduction

In the first two weeks, students will be introduced to sustainability in the form of a seminar. The students engage interactively with the concept and necessity of sustainability, the Sustainable Development Goals (SDGs), their role as engineers, and product design and materials engineering. An important meta-goal is the creation of a communicative and collaborative working atmosphere as a desirable prerequisite for the entire module. In addition, the semester project topics are determined during this time (see section 3.5).

3.2 Product development topics

Divided in two parts (weeks three and four, as well as nine and ten) topics of product development are devised in lectures and exercises. The first part examines the theory and practice of solution-finding methods and problem-solving processes, which should support defining the semester topic (see section 3.5). In the second part, the topics "Design for X" and guidelines for eco-design are discussed to summarise the materials selection topics (see section 3.3). This is applied by dismantling a washing machine and using eco-design guidelines to a coffee capsule.

3.3 Materials selection topics

In weeks five to eight the lecture deals with material selection topics. Starting with an introduction to systematic material selection, the students subsequently explore corresponding aspects in the following exercises with the GRANTA EduPack[1] software. Lectures on the material life cycle with a focus on the key materials steel and aluminium as well as polymer materials succeed the aforementioned topic. Online units created in a teaching and learning platform complement the lectures. In this way, students can activate their prior knowledge and develop new content before the lectures.

3.4 Excursion, guest lecture

During its first iteration, the course includes a guest lecture on Life Cycle Analysis and a virtual excursion in week twelve. The lecture is intended to give the students an overview of the topic while highlighting the complexity of this framework. The virtual excursion is organised at a large German car manufacturer which will demonstrate how sustainability issues are gaining practical importance in the industry.

3.5 Semester project

Instead of taking a written exam, students are asked to work on a self-selected topic that connects product design or materials selection and sustainability and is of particular interest to them. For this purpose, we included an event to identify subjects during the third week of the course. After presenting an example project, the students are asked to form teams of three to five and select a subject based on the SDGs. It must be relevant to engineering with reference to product development or materials science. Until the end of the semester they prepare this topic considering the following aspects:

- **Problem**: Motivation, relation to sustainability, relevance and consequences
- **Research**: Examples of current measures, initiatives, strategies to solve the problem and connection with product development/materials science
- **Own thoughts on solutions**: Classification regarding the SDGs and conflicting goals, presentation of a (self-developed) favoured solution (specific measure or specific product)

If required, students can get in touch with tutors. Otherwise, there is one fixed meeting in the middle and at the end of the semester (week eleven). The examination performance consists of a 30-minute presentation and a 15-minute discussion. This takes place in week 13. Relevant assessment criteria are personal skills (knowledge and own initiative), course of work (accuracy, systematics), documentation/result (content, structure, elaboration), and presentation style. The contribution of the whole project group is evaluated. Therefore, all group members receive the same grade. This design of the semester project, especially in connection with the SDGs, is intended to strengthen design competencies according to Bormann and de Haan from all three areas - subject and methodological competence, social competence and self-competence [15], cf. section 2.

3.6 Closure and feedback

In the last lecture in week 14, no additional content is developed, but a detailed review and feedback are conducted. This is done with the help of an online pinboard application and a subsequent group discussion. The students also complete an evaluation via a course management system (CMS, Stud. IP). This event aims to improve the course in the following semesters and adapt it to include ideas and incorporate suggested improvements by the students.

4 OBJECTIVES

Besides aiming for a good first run of the course, we focused on the three following objectives being evaluated via our observations and detailed student feedback (see section 5).

By examining the individual aspects, we want to determine whether students are becoming aware of sustainability in product design, how successfully interdisciplinary teaching and learning is implemented and how well students receive the interactive and hands-on contents, respectively. An evaluation of these questions is discussed in the next section.

[1] Leading educational software in materials selection being used by more than 1000 universities worldwide. With its help, connections between materials, processes and energy-relevant issues can be made comprehensible (https://www.ansys.com/products/materials/granta-edupack).

4.1 Awareness of sustainability in product design

Can the students be sensitised to the issue of sustainability regarding product design? How do they cope with the diverse range of topics? Do they express their thoughts? How is the overall engagement with sustainability evaluated?

4.2 Interdisciplinary teaching and learning

Is the cooperation between the chairs of product development and materials engineering fruitful and does the content really mesh well as planned? How do the students perceive interdisciplinarity in their ranks through the mixing of study sections and courses?

4.3 Interactive and hands-on contents

Since other courses often require less student engagement, are the practical components well received? Are they evaluated positively in retrospect? How are the contributions by guest lecturers and external companies received?

5 RESULTS

Most of the course took place in the form of face-to-face teaching. Only for the last four weeks of the course we switched to the online format due to the Corona pandemic. In the last lesson, we resumed the discussion on the progress of the SDGs, only then having a closer look on the consequences of the Corona pandemic. Due to the online format, the discussion required more time than expected, resulting in little time for detailed oral feedback afterwards.
However, ten out of 16 students took part in the evaluation via the CMS, which corresponds to a share of 62.5 %. Figure 2 shows the results of different aspects, which will be discussed in more detail below.

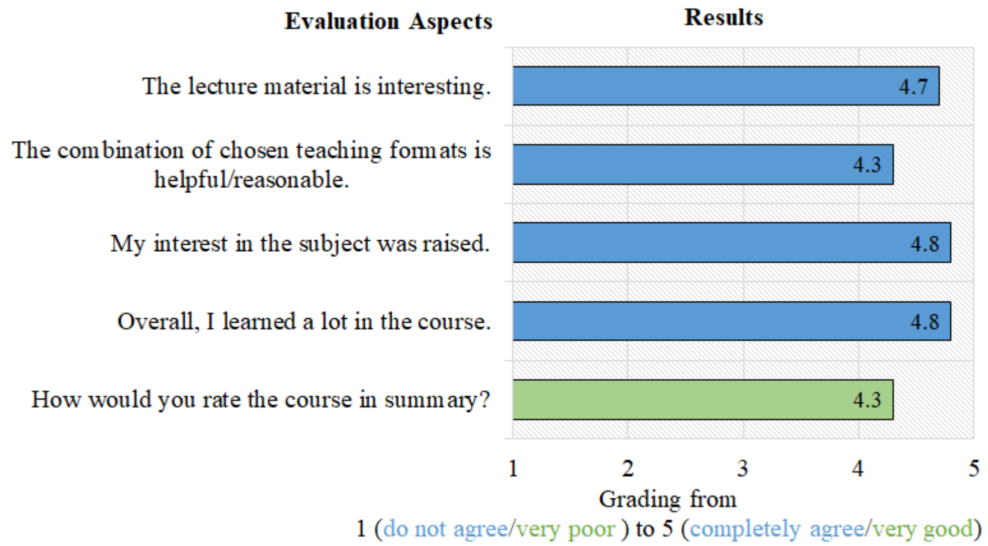

Figure 2. Evaluation aspects with results gathered via the CMS. The maximum score is 5.0

5.1 Awareness of sustainability in product design

From the authors' point of view, sensitising the students to issues of sustainability was successfully achieved, as the students repeatedly dealt with relevant content in each lecture. Throughout the course, they frequently asked in-depth questions, so that discussions could be encouraged. However, it was evident that the time available was often insufficient for a more in-depth study. In the semester projects, the students were also able to deal with content at the intersection between sustainability and engineering sciences with topics of their own choice. Out of the total number of 16 students, four groups were formed which chose the following topics for their projects:

- Sustainable materials for fused deposition modelling (FDM)
- Fibre-reinforced plastics
- Mass products in medicine
- The Great Pacific Garbage Patch

The link between sustainability, product development, and materials engineering remains vague when analysing the project titles. In the presentations, it was noticeable that despite the continuous exchange with tutors, the students found it challenging to narrow down their topics to such an extent that a more profound engagement would have been possible. Although the audience could gain further knowledge in the project presentations, the connection with materials technology or product development was not sufficiently addressed in some cases. The students' own ideas for solutions were also very brief or sometimes not mentioned at all. At the same time, the students' motivation for their topics became very apparent when establishing, i.e., creative approaches regarding the online instead of face to face presentations - caused by the Corona pandemic. For instance, one group used special presentation software, another had chosen the colours of the SDGs as virtual backgrounds. The four presentations were marked with grades A+ to A in the German system. Considering the direct feedback from the students, the form of examination was evaluated positively. The evaluation, indicated that the students' interest in the subject could be raised. Here, on a scale of 1 (do not agree) to 5 (completely agree) an average of 4.8 was awarded, which is an excellent result. The information content of the lecture material was rated on the same scale with a 4.7 (see Figure 2, respectively).

5.2 Interdisciplinary teaching and learning

All 24 offered places in the course were booked during the enrolment, and 17 students then actually took part in the first lectures, 16 of whom passed the exam at the end. Students from different degree programmes and levels took part, as Table 1 shows.

Table 1. Number of Students of different degree programmes and levels who took part in the course. 16 Students passed the oral exam

Degree Programme		Mechanical Engineering	Industrial Engineering	Biomedical Engineering
Number of Students	Bachelor	4	3	4
	Master	4	1	0

Thus, the heterogeneous composition of the overall group was successfully established, which promoted interdisciplinary learning. In addition, students from different degree programmes and levels came together in the small groups formed for the semester project, which made a level-based differentiated examination assessment dispensable. According to the authors, the topics from product development and materials selection complemented each other very well. Solely the order of lectures was not coherent: The lecture on design for X covered topics that had already been discussed in an exercise on GRANTA EduPack. In addition, the lecture on eco-design was not entirely coherent at the end, offering an overview of all topics. Conforming this only marginal inconsistency, in the CMS, students strongly agreed to the statement "Overall, I learned a lot in the event." which underlines the successful selection of course content. Despite this minor inconsistency, in the CMS the students agreed with the statement "Overall, I learned a lot in the course."(score of 4.8, see Figure 2), which underlines the successful selection of course content.

5.3 Interactive and hands-on contents

We could observe that the students appreciated the interactivity of the course and that their participation was above average compared to other courses held by the authors of this paper. Only during the guest lecture, the activity of the students in the subsequent discussions was not engaged. In contrast, the students' participation in the exercises was above average. Everyone got involved and developed good ideas. In the free-text feedback in the CMS and the online pinboard, the students rated the exercises with large practical parts positively. Figure 2 also shows the positive rating regarding the combination of chosen teaching formats (score of 4.3).

6 CONCLUSION AND OUTLOOK

In summary as you can see in Figure 2, the students evaluated the course with a 4.3 (scale from 1 (very poor) to 5 (very good)). The teachers and authors of this paper share this positive opinion. The students were sensitised to sustainability issues in product design, were very active as intended and appreciated the course's innovations - especially the high practical content. Therefore, this course efficiently supports prospective product designers to consider their work's ethical and sustainable dimensions. In the follow-up we want to further reduce the content to enable more space for discussions, hopefully resulting in a livelier discussion after the guest lectures. It would also be desirable to have a proper excursion in the follow-up if the pandemic situation allows it. Furthermore, we will state the guideline for the semester project much more precisely, facilitating and supporting a deeper engagement of the students with actual products in the context of sustainability. The topic of the semester project will be determined after the problem-solving event in order to give the students a better idea of their assignment and more time to narrow it down. We will bring forward the course on eco-design in order to use it as a starting point for introducing the following topics and the course on design for X will be used as a summary of preliminary course contents. The practical parts are to be further structured to enhance the resulting outcome in addition to a sole "fun factor." Finally, we aim for a more in-depth evaluation of the students' learning outcomes with regard to the three objectives (cf. section 4) and the design competencies for sustainable development.

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