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A Theory-Based Teaching Concept To Embed Sustainability In The Engineering Curriculum

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A THEORY-BASED TEACHING CONCEPT TO EMBED SUSTAINABILITY IN THE ENGINEERING CURRICULUM

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ABSTRACT

The implementation of sustainable development and the responsible use of the resources available to us are among the key objectives of our time. To meet the challenges of global sustainable development, young professionals with a growing set of skills are needed. Higher education is crucial in fostering the skills graduates need to become agents of change for sustainable development. Therefore, new teaching and learning approaches are needed in engineering education that link technical and sustainability-oriented topics and integrate education for sustainable development (ESD). Studies show that there is a particular lack in the design and implementation of engineering courses that address the close connection between technical and sustainability-oriented issues and contribute to the promotion of the new required competencies. This paper addresses this gap, in which the authors present a teaching example for sustainable engineering education. The article presents the implementation process of a research-based concept. The aim of the module is to expand and strengthen students' competences in the field of sustainability. Various didactic teaching and learning methods were used. Thus, an attempt was made to

combine learning aspects from education, sustainability and engineering and thus to ensure more sustainability in engineering education. The article provides an overview of the structure and the most important components of the module. The knowledge gained will contribute to the evidence-based implementation of sustainability in the engineering sciences. The presented findings should serve as a basis for discussion for the community and contribute to the further development of teaching concepts for sustainable-technical education.

1 INTRODUCTION

The implementation of sustainable development and the responsible use of the resources available to us are among the key objectives of our time. Higher education is crucial in fostering the skills graduates need to become agents of change for sustainable development [1]. Therefore, new teaching and learning approaches are needed in engineering education that link technical and sustainability-oriented topics and integrate ESD [2]. Studies [2-6] show that there is a particular lack in the design and implementation of engineering courses that address the close connection between technical and sustainability-oriented issues and contribute to the promotion of the new required competences.

This is where this paper starts by working with two research questions:

> ***(1)*** How are sustainability issues currently represented in engineering education research (EER)?
>
> ***(2)*** How can a theory-based concept for the integration of sustainability issues in engineering look like and how can it be implemented?

In the sense of design-based work, the pursuit of these two research questions provides both a contribution to the research landscape of engineering sciences and a contribution to teaching practice. The necessary methodological procedure is described in sec. 2. In order to implement sustainability in study program across the board, concepts must be developed. The level of engineering education research (EER) is relevant for this. Methods and theory-based concepts must be developed to integrate sustainability into the engineering degree program, and these in turn must be integrated into teaching practice. Due to the increasing urgency of the problem, concept development and implementation must proceed in parallel, cf. [7,8].

For research question ***(1)***, an introduction and overview of the integration of sustainability in engineering is given. In section 3, a literature analyse shows to what extent the topic of sustainability is currently addressed in the research landscape of EER and which specific concepts exist that integrate sustainability aspects in engineering education. In this context, an analysis looks at the research landscape in EER to find out to what extent sustainability has been addressed between the years 2014-2018 and 2021. For this purpose, the mention of sustainability in 3,570 conference articles was evaluated. As a result of that survey, it becomes clear that there is a research gap especially in the development of theory-based teaching concepts for linking sustainability and engineering.

To answer question ***(2)***, this research gap will be addressed. In section 4, an exemplary teaching-learning concept is developed and transferred into practice. The aim is to develop an interdisciplinary concept that enables the integration of sustainability topics into the engineering sciences in order to promote sustainable development. The elective module was carried out in the Master's degree program " Management & Engineering" in the winter semester 2022/2023 at Leuphana University. Section 4 describes the learning objectives as well as the developed concept, first student feedback is evaluated. The concept is intended to serve as a guideline that enables other engineering program or universities to implement a similar module and simplifies the integration of sustainability topics into the engineering sciences.

2 METHODOLOGY

“Methodology can be seen as the strategy, the plan of action, process or design lying behind the choice and use of particular methods and linking a choice and the use of methods to the desired outcomes” [9]. For a successful completion of the research question it is necessary to clarify the connection between the research goals and the selected methodology. The research objectives in this article are standing for both, theoretical understanding and educational practice. In order to design and to study within the same research process (see [10]) we´ve chosen design based research. Design based research is a multi-faceted approach that "...can yield valuable results for both theoretical understanding and educational practice" [10]. The generic model for educational design research is shown in fig.1. This methodology has also been used because the main stages of the research interact with the educational practice. In this way we were able to achieve our research objective by dual outputs of innovative approaches and theoretical findings. Fig.1 presents the three stages of the process model for the design based research: Analysis, Design and Evaluation. All three stages are implemented in the research process and are explained below.

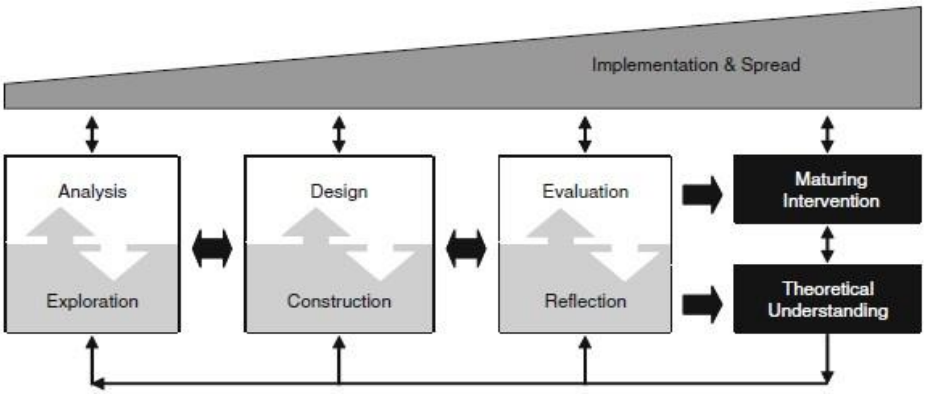

Fig.1. Generic model for conducting educational design research [11]

Within the ***analysis phase*** we surveyed the EER landscape. The result is a research-guided category system consisting of ten main categories and 78 subcategories that

encompasses the essential aspects of the research field, their specification, and the relationships and delimitations of the individual categories to one another (exemplified by the example of sustainability in Section 3). General statements of the overall analysis are given in [3], the results with a focus on linking sustainability and engineering are presented in section 3. For the purpose of gaining knowledge at the interface of engineering and sustainability, two leading IEEE conferences of the international EER research landscape, the FIE and EDUCON, were selected as the basis for the systematisation, whose publications appear annually in a two-stage blind review process. With the aim of an international and up-to-date analysis, contributions to EDUCON and FIE from the years 2014 to 2018 and 2021 (EDUCON only) were systematically analysed and categorised using a catalogue of categories developed in advance. In doing so, EDUCON, like SEFI Annual conferences, focuses more on the European research landscape, while FIE expands the research work to include a more international (especially american) view. This approach addresses the critiques of [12-14], who point to existing disciplinary and geographical divisions in the research landscape. Although the research presented does not provide a complete overview, basic statements and research trends on sustainable engineering education can be derived. The number of articles from the respective years that were used to categorise the scientific articles is presented in Tab. 1.

Table 1. Number of published and categorised papers of the international EER conferences Global Engineering Education Conference (EDUCON) and Frontiers in Education Conference (FIE) in the years 2014 - 2021, own data.

Year	EDUCON	FIE	Total
2014	196	519	715
2015	154	403	557
2016	191	410	601
2017	289	306	595
2018	300	537	837
2021	265	-	265
Total number of categorised paper			**3,570**

Based on the findings we next turned our attention to the development and the implementation of a theory-based concept to embed sustainability in the engineering curriculum, worked out in section 4.1 and 4.2. This ***design stage*** of the design-based research process was followed by evaluation process. To register statements about students understanding and feedback to the module an ***evaluation*** was undertaken, that results of which are presented in section 4.3..

3 ANALYSIS OF THE EER-LANDSCAPE REGARDING SUSTAINABILITY

The total of 3,570 FIE and EDUCON conference articles from 2014-18 and 2021 (EDUCON only) were each assigned a minimum of one and a maximum of two main and sub-categories. A total of 6,627 categories were assigned. What is noticeable in

the overview of the results of the category allocation is the lower number of allocations in the contributions to EDUCON, which can be attributed to the different absolute number of contributions to the respective conference (see Tab. 1). In both conferences, topics in the context of teaching and learning processes were addressed most frequently by far. For limited reasons, a more comprehensive overall evaluation is not included in this paper, as the focus is on the evaluation of the topic area of sustainability. The category "Topics related to Engineering" as one of the 10 main categories categorises publications that place the thematic focus on topics that are not subject-specific but are related to engineering content [3]. One of the subcategories belonging to this main category is “Sustainability”. In the following, the number of contributions dealing with the topic of sustainability is quantitatively highlighted. The results are analysed qualitatively.

Fig.2 gives an overview of the categorisations of the articles of the FIE and EDUCON to the sub-category sustainability over the years. Out of a total of 6,627 categorisations, 48 (0.72%) were made in the sub-category "Sustainability". By way of explanation, it should be added that a category is only awarded if the *majority of the contribution* deals with the theme. Most articles were sighted in 2017. In general, the proportion of articles that address the topic of sustainability is extremely low at 0.72%, which illustrates and supports the situation described in the introduction. Contrary to expectations, there is no trend to be noted in the results.

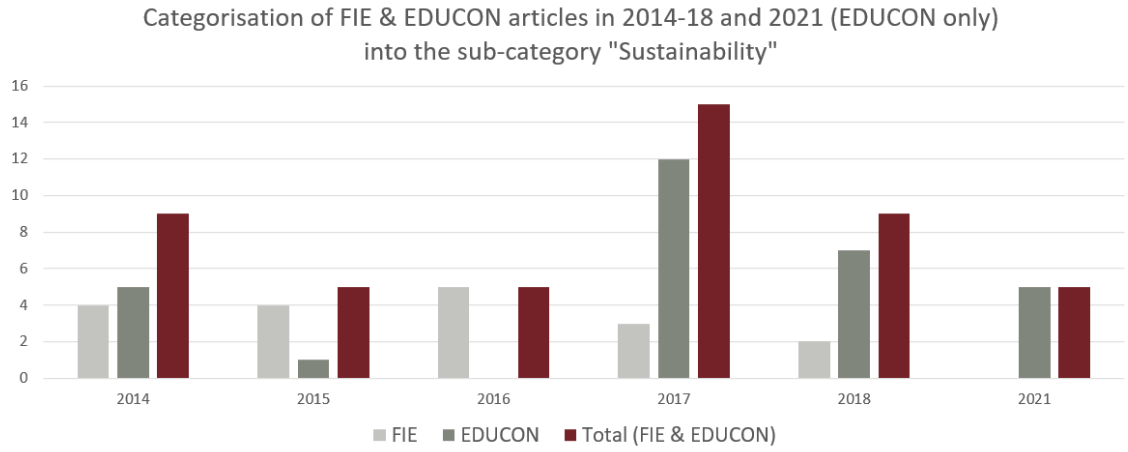

Fig.2. Categorisation of FIE & EDUCON conference articles in 2014-18 and 2021 (EDUCON only) into the sub-category “Sustainability”, own data

In order to find out whether the topic of sustainability nevertheless plays a role in the categorised articles, a "COUNT IF" query was carried out in Excel. It was analysed how often the word "sustainability" was written in the title (9 times), in the keywords (20 times) and in the abstract (39 times). In addition, the words "sustainable" and "climate change" were filtered. The word "sustainable" appeared in a total of 18 out of 3,570 titles, in 17 keywords and 55 abstracts. "Climate Change", on the other hand, was only mentioned once in the title and keywords and three times in the abstract. The occurrence of the word "sustainable" should be interpreted with caution, as it refers not only to sustainability aspects, but also, for example, to long-lasting projects that do

not directly include sustainability issues. With a total of only five mentions, the occurrence of the word "climate change" can be neglected. Fig.3 shows the frequency of the word "sustainability" in the title, abstract and keywords depending on the year.

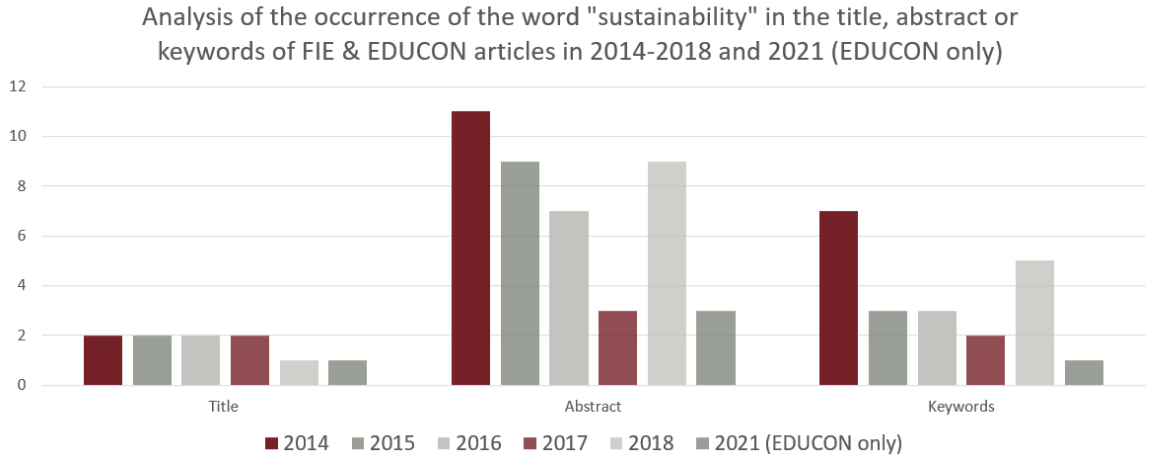

Fig.3. Analysis of the occurrence of the word "sustainability" in the title, abstract or keywords on FIE & EDUCON conference articles in 2014-18 and 2021 (EDUCON only), own data

The latter analysis confirms the results of the categorisation, as the frequency of the keywords is in similar dimensions to the allocation of the articles. Basically, however, it becomes apparent that very little relevance is attributed to the topic of sustainability in engineering education research and practice, which urgently needs to be changed. An approach for integrating sustainability aspects in engineering education is therefore presented in the following chapter.

4 THEORY-BASED THEACHING CONCEPT FOR SUSTAINABLE ENGINEERING EDUCATION

In order to anchor sustainability aspects in the teaching of engineering and to strengthen the students' awareness, especially in the area of social and ecological sustainability, a teaching-learning concept was developed based on the theoretical findings of the analysis and constructivist learning approaches, e.g. [15].

4.1 Teaching concept for sustainable competences in engineering

The developed concept for sustainable competences in engineering is shown in Fig. 4. It consists of a triad of a content level, a methodological-didactic concept and an individual process level. With the concept, a structured program development is designed that promotes the teaching of sustainability aspects in an engineering context, can be flexibly adapted to the interest of the students and involves the participants in the design of the module through the flipped classroom approach. On the ***content level***, the technical basics in the areas of sustainability science and didactics are first taught. The Blue Engineering Concept [16] is included in this. By participating in the first thematic teaching-learning modules, students should begin to understand the interactions. Through the selection and implementation of an existing

Blue Engineering module as well as the subsequent deepening of the content of a self-selected topic, the participants should acquire professional basics.

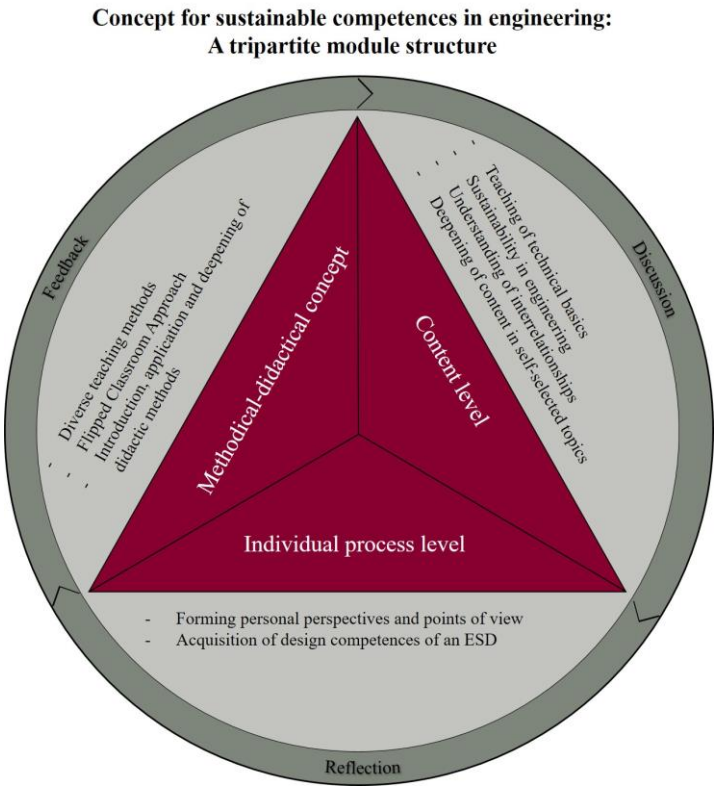

Fig.4. Teaching concept for sustainable competences in engineering

For a successful ***methodological-didactic concept***, a variety of learning methods are to be used. Personal perspectives and points of view should be developed and enable participants to act. The acquisition of factual and methodological competence, social competence and self-competence on an ***individual level*** should take place.

4.2 Implementation

The 5 CP module "Sustainable (Blue) Engineering" was designed for 15 participants and offered in winter semester 2022/2023. The learning group consists of students of the Master's program "Management & Engineering" at Leuphana University. The biweekly 3.5-hour course was structured as follows, so that a step-by-step approach and deepening of the interplay between technology and sustainability was possible:

- **Teaching the basics in the subject area of sustainability in the engineering sciences (**Introduction to didactic methods and feedback rules, Introduction to Sustainability Science, Participation in initial teaching-learning modules)
- **Application of the basics in the subject area of sustainability in the engineering sciences (**Application of didactic methods and feedback rules, Teaching content on the topic of engineering and sustainability, Preparation and implementation of existing Blue Engineering teaching-learning modules)

- **Exemplary deepening through the development of own teaching-learning modules (**Choice of didactic methods for teaching the chosen topic, Examination of the content of self-selected topics, Implementation of the self-developed teaching-learning modules)

4.3 First findings and feedback

At this point, the first findings of the evaluation are presented, in particular the participants' feedback on the course. It should be noted that the evaluation is not to be understood in the sense of a complex effectiveness analysis, but rather aims to provide insights into initial implementation experiences and student feedback on the implementation of the program. A selection of the student feedback is shown in Fig. 5. The results show that the students are very satisfied with the course and their knowledge gain and that the module motivates them to engage with and reflect on the topic. In general, these statements can be considered as implementation success. Further findings can be presented at the SEFI 2023 conference.

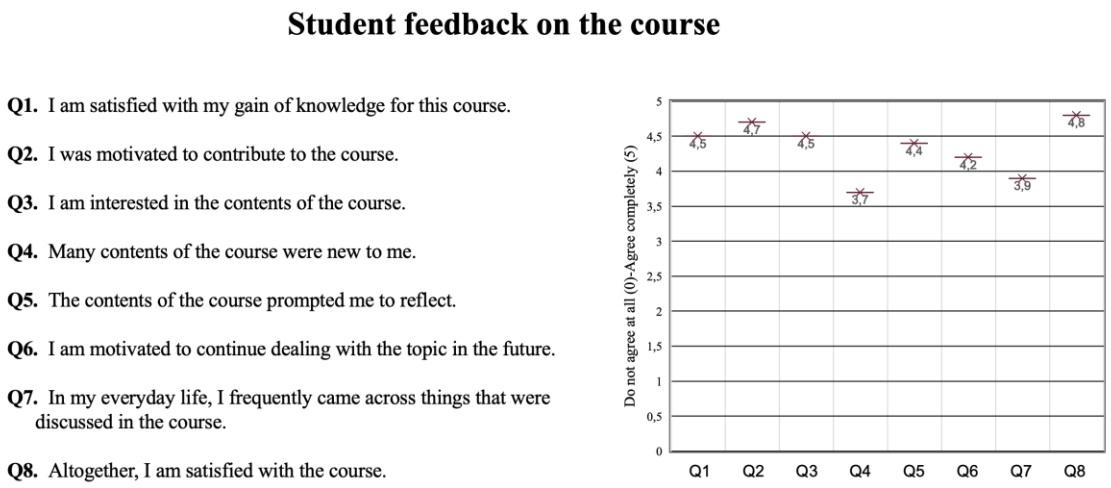

Fig.5. Student Feedback on the Course (own data)

5 SUMMARY

The paper provides research-based evidence that the topic of sustainability has so far been underrepresented in engineering, which is why evidence-based interdisciplinary implementation procedures, as presented in Section 4, are highly relevant. An interdisciplinary approach has been developed and implemented in educational practice. The course received positive feedback from participants and allowed for knowledge growth. Further module runs are planned in the coming semesters in order to continuously evaluate, adapt and optimize the developed concept.

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