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Teaching Topics of Responsibility and Sustainability in Large Engineering Classes*

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Introducing engineering students to topics of social responsibility and sustainability in the field of science and technology studies is internationally discussed, but there is little common consensus on best practices. Especially in large and mandatory engineering courses, initiating reflection processes among the students imposes difficulties on lecturers. The lecture "Engineering and Society" is attended each year by about 500 engineering students at RWTH Aachen University in Germany. Intended to familiarize engineering students with central theories and topics in the field of science and technology studies as well as sustainability and responsibility, the lecture creates a contrast to the highly technical engineering contents in these study programs. To increase the accessibility of these topics for students, a detailed teaching concept was developed by the authors which is reviewed in this paper. The paper proposes this approach for teaching sustainability and responsibility to engineering students in a large mandatory bachelor's course as well as raising awareness for their own responsibility while maintaining focus on the academic content of the lecture. The paper aims to answer the following research questions: How to teach sustainability and responsibility to engineering students in a large mandatory bachelor's course? How to raise awareness for personal responsibility as engineering students? Challenges and possible solutions related to the academic content of sustainability and responsibility are discussed based on evaluation outcomes and lecturers' experiences.

Keywords: engineering education; blended learning; teaching large classes; sustainability; RRI

1. Introduction

Engineers are creating technical solutions and thus, through their work, shaping social realities and trends, as visible in many aspects of society and industry [1]. As builders for the future and transformers of the world, they increasingly need to cope with the social changes that come along with responsibility for societies and the environment [1, 2].

These challenges call for engineers to reflect upon the interactions of engineering outcomes with society and the environment and to integrate the perspective of sustainability in their daily work. As stated in the ASEE-SEFI joint statement [2], "engineers have not consistently made informed judgments that consider equitably the far-reaching societal impacts of engineering solutions" and that some of the "unintended consequences partially result from an engineering profession with a limited diversity of lived experiences". Homogeneous and purely technical study programs, which set the standard for future engineers, perpetuate unexamined norms and values through common scientific engineering methods [2, 3]. In order to break from this, a change in engineering education is necessary. This change does take place. The updated CDIO Syllabus from 2011, which formulates goals for engineering education and serves as the basis for many international engineering curricula, names, for example, "Ethics, Equity and other Responsibilities" as well as environmental issues as important aspects of engineering education [4, 5].

Implementing aspects of social responsibility and sustainability in higher education is commonly subsumed under *Education for Sustainable Development* (ESD). ESD is explicitly addressed in the 2030 Agenda for Sustainable Development and its related Sustainable Development Goals (SDGs) [6]. In these, Goal 4.7 specifically calls for ESD.

In the framework of higher education for sustainable development, the bachelor's lecture *Engineering and Society* for engineering students at RWTH Aachen University in Germany intends to not only make the students familiar with central topics and theories of social responsibility and sustainability but also to initiate critical thinking and an understanding of the consequences of their actions to approach future challenges of engineers. The lecture is framed by the SDGs [6] and mandatory for Civil and Environmental Engineering students and is therefore attended by a large number of students each year. Focusing on socio-technical content and integrating theories of gender and science and technology studies, the lecture creates a contrast to the highly technical engineering content in these study programs. Over the last years, the authors developed a detailed methodology based on evaluation outcomes and their teaching experiences to now provide a well-structured teaching concept so

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that the topics become easily accessible for students and sustainable learning takes place. The development of the lecture is explained in detail in [7].

The paper proposes this approach for teaching sustainability and responsibility to engineering students in a large mandatory bachelor's course as well as raising awareness amongst the student body for personal responsibility, while maintaining focus on the academic content of the lecture. The paper aims to answer the following research questions: How to teach sustainability and responsibility to engineering students in a large mandatory bachelor's course? How to raise awareness for personal responsibility as engineering students? Challenges and possible solutions related to the academic content of sustainability and responsibility are discussed based on evaluation outcomes and lecturers' experiences.

The next section provides theoretical background on the relevance of ESD as well as on common practices and state of the art teaching methods for sustainability and responsibility in higher education. Section 3 presents in detail the design of the lecture. Section 4 explains the methods of course evaluation, experiences, and insights on teaching results from summer semester 2021. Section 6 discusses the limitations of the teaching concept and resulting implications for research and education practice. A conclusion is provided in section 6.

2. Theoretical Background

The global challenges of the 21st century include, among other things, more heterogeneous societies and an even greater rate of change in trends, digitalization, and globalization. Engineers, working to assess the challenges of today's society [8–10], need now, more than ever, to develop a socially responsible technical understanding [11] and integrate socio-technical perspectives in their work. Moreover, social responsibility is strongly related to sustainable action. As Engineers try to solve problems for or of society, they have a significant impact on society and the environment. Yet, studies with students show that there is only little knowledge and understanding about these topics and their implications for engineers [12, 13].

The following section highlights the relevance of ESD in engineering, followed by a section sketching current examples of teaching topics of social responsibility and sustainability in higher education.

2.1 Education for Sustainable Development in Engineering

Education must enable competence gain for sustainable development [1, 4]. Goal 4.7 of the SDGs demands "all learners acquire knowledge and skills needed to promote sustainable development, including, but not limited to, education for sustainable development and sustainable lifestyles, human rights, (and) gender equality" [6], thus specifically calling for ESD. ESD is a concept first proposed by UNESCO [4] and aims to empower learners to make informed decisions and responsible actions for the environment, economy, and society – for the present as well as future generations – and to respect cultural diversity. The concept of ESD was recognized by the United Nations Economic Commission for Europe (UNECE) and is now a main activity of UNECE [14].

Since then, the idea of integrating ESD in engineering curricula developed in many contexts. The Accreditation Board for Engineering and Technology (ABET) stated in 2000 explicitly the need for their students to gain "an understanding of professional and ethical responsibility" which has subsequently further improved [15]. Having accepted that education is a key issue in transformation for a sustainable society, the Decade of Education for ESD in 2005–2014 led to the fact that ESD is now on the agenda of many universities [4], but still far from the integration in all university curricula [16–19].

In Germany, the idea of the interaction of humankind and technology emerged after WWII to develop "technologies to benefit human society with a minimum of negative effects" [11, 20]. Therefore, a long-time commitment to social responsibility has begun [11]. Around the world, there are few opportunities for engineering students to learn about diverse structures, as study programs mainly focus on technical problems [8, 15, 21]. In particular, German engineering study programs are known for their highly technical focus. However, diversifying engineering education increasingly represents a status of excellence, ever since its identification as a driving factor [13, 22].

The Association of German Engineers (VDI) released the Fundamentals of Engineering guideline in 2002 to highlight the engineer's responsibilities in technology assessment (a process of "analyzing a technology and its developmental possibilities" and "judging these impacts" as well as "deriving possibilities for action" [23]) and the responsibilities in judging the implementations of new technologies. The guidelines were accepted by the engineering society as a whole, and may thus serve as a basis for judging engineers' actions.

2.2 Teaching of Sustainability and (Social) Responsibility in Higher Education

As teaching sustainability and responsibility in conjunction with an engineer's impact on society becomes increasingly relevant in higher education, several approaches have been proposed to integrate these topics either in existing courses or to add new courses to curricula in higher education [3, 24–26]. The Social Ecological Responsibility in Science and Engineering Education (SERSEE) Network defines social responsibility as an inclusion of ethics perspectives, peace studies, sustainability, and law [27]. Other case-studies particularly highlighted the need of considering ethics while teaching sustainability, and the topic of ethics is commonly addressed together with topics of responsibility [28–32]. The presented lecture is an introductory course, which delves into sustainability and (social) responsibility through the context of a wide range of current issues and engineering-related topics. Ethical aspects and some aspects of law and peace studies are included in the lecture content, but without forming an integral part.

The SERSEE Network provides in [27] a detailed review of current pedagogical methods and central concepts for teaching social and ecological responsibility to engineering students, resulting from a wealth of experience, discussed and shared during 14 years' worth of meetings and conferences. Current outstanding initiatives in innovative teaching concepts concerning responsibility (reviewed in [26]) are, for example, Science Outside the Lab, InnovENT-E, Sustainable Development Activities, Blue Engineering, Ethical Case Studies in Chemistry, and Introduction to German Engineering [27].

The presented lecture has been particularly inspired by the Blue Engineering concept. Blue Engineering has been implemented by Baier in various contexts [33, 34] with the aim to develop a seminar in which social and ecological responsibility are taught and awareness for the responsibility of future engineers is fostered. Furthermore, engineering students are encouraged to reflect their own values and the values of their peers, and be capable of ethical action on an individual and collective level. So-called "building blocks" cover different topics and didactic methods, ensuring that theoretical knowledge is practically transferred to the participants. In other words, participants should not only gain an understanding of their social and ethical responsibility but should also be impowered to apply the knowledge gained in practical settings. Inspired by these building blocks, the presented lecture was divided in blocks to transfer knowledge in cohesive units and enriched with different didactic methods to deepen the students' understanding. In the Blue Engineering course as well as in the presented lecture, discussion sessions encourage reflection about the learned content.

In 2010, the SERSEE Network identified barriers and key elements in teaching social responsibility, which were most recently updated in 2021 [27]. The barriers they identified stem primarily from the fact that scientific communities often assume technology to be isolated from society, and as such, have a low acceptance of societal concerns in technical areas. Furthermore, aspects of social responsibility, particularly ethics, are not "right or wrong" and therefore more complex to teach. Another aspect they mention is that interdisciplinarity is difficult to realize and often does not fit into conventional programs [27]. These barriers partly coincide with the primary problems for teaching sustainability identified in [35], as well as the lack of knowledge regarding sustainability among the lecturers and lack of acceptance of the importance of sustainability among lecturers and students [35]. Another aspect mentioned in [35] is the fact that teaching sustainable topics in engineering programs requires a special skillset, as a capacity for understanding complex and nuanced systems is imperative, when teaching and discussing sustainability within the environment and society [35]. This capability particularly only emerges at an advanced level of studies [35]. These barriers mainly coincide with the teaching experiences of the authors over the last years, particularly the acceptance of the taught content among the students was a driving factor for developing a teaching concept tailored for the students' needs.

The challenges of integrating the teaching of social and sustainable topics into otherwise technical-oriented programs also arise from the fact that teaching these topics requires a more holistic and student-oriented approach [36, 37]. Facing today's societal challenges, engineers need a focussed awareness of their responsibility and require special competencies to transfer their knowledge into practice [38]. This responsibility involves the personal engagement of the students not only as engineers and in their professional careers, but also in their identity development as private persons. For personal growth to take place, the authors believe that involvement at an emotional and personal level at an early stage is essential (see also [37]). As a result, gaps in engineering curricula concerning courses related to sustainability and social responsibility still exist [27] and there is little consensus on how best to integrate these concepts into engineering education, especially in undergraduate classes [39].

The SERSEE Network identified three areas of teaching responsibility which require specific attention, namely the content, active learning forms, and a change of science and engineering education [27].

The *content* should include elements to teach responsible interaction, should contribute to sustainable development, and impose normative input such as values or global issues so that the students learn to reflect on ambiguous questions. The content should focus on both an individual and a collective level and involve the learning elements knowledge, judgement, and action. Interdisciplinarity is identified to be important in this area and should be the key element of engineering programs, not just supplementary. The course presented in this paper aims to fulfill these requirements through its unique format and the integrated didactic methods.

The goal of this teaching approach is not to uncritically adopt the content, but rather to reflect upon it. Therefore, the SERSEE Network suggests two approaches concerning *active learning forms*: to integrate case studies and activating teaching methods, such as active discussions. Furthermore, the network suggests problem-based learning and to combine the teaching methods asking for a "what?" (content) with a "how?" (solve problems) [27]. In the presented course, this is achieved through the involvement of real-life examples through student initiatives.

Other research also shows that implementing a more holistic approach leads to a greater benefit in student learning [37, 40]. Rote learning of facts and concepts especially in the context of sustainability does not impact students' attitudes and behaviour in a significant way [41], although a lasting behavioural change is exactly the desired result in the context of education for sustainable development [14]. Therefore, learning should go beyond rote memorization of facts and concepts, rather encouraging students to be creative, make choices, act, and reflect upon consequences in an active, participatory method [42]. The updated version of the CDIO Syllabus [5] highlights the importance of active learning and reflection for the students, and the importance of providing time to evaluate their approaches. The present course adapted this point of view by integrating a more holistic teaching approach, explained in detail in the following chapters.

Active learning for a sustainable learning is in line with the OECD learning compass [43] which identifies the three phases "Anticipation – Application – Reflection" as essential for a sustainable learning process.

The last aspect identified by the network is to *change science and engineering education*. The SERSEE Network highlights the need for implementing ethics and social responsibility in engineering education, proposing an approach of bottom-up and top-down structures equally [27]. Wals [44] proposed to integrate sustainability in higher education either through a bolt-on or build-in approach, therefore distinguishing between the incorporation of sustainability in additional modules (bolt-on) or integrating it in the existing modules (build-in). The here presented course, however, takes the bolt-on approach, the realization of which with small groups of up to 30 people, as in electives, most master's courses, and seminars, allows for access to reflective topics using common tools such as group discussions, small group work, or other interactive work. Conveying social, ethical and sustainable topics in large classes, however, imposes more restrictions and challenges. In German engineering programs, particularly bachelor's lectures are often visited by a large number of students, due to the fact that most universities are state universities and are without study fees. Large classes arise from the necessity to enable the attendance of many students and to simultaneously cut costs. Often, lectures for large classes result in 90 minutes of frontal teaching due to a lack of alternatives.

3. Design of the Lecture

Building on the results and findings of the previous section, while being engaged in ESD, the educators leading the RWTH course *Engineering and Society* aim to raise awareness of their responsibility and foster debates among the students within a large, mandatory engineering class. The students shall be confronted with other opinions, debate, formulate their own opinions, and their position towards social topics. This section gives a detailed description of the goals and implementation details of the course.

The lecture *Engineering and Society* is a compulsory module in the bachelor programs Civil Engineering, Environmental Engineering and Technology Communication at RWTH Aachen University. As such, it is attended by approximately 500 engineering students each year in the summer semester. Moreover, around 40–50 students from different study programs attend the lecture voluntarily, leading to a very heterogeneous student representation.

3.1 Intended Learning Outcomes and Goals of the Lecture

The course aims to support students to develop a broad and differentiated understanding of the interfaces between engineering and society. Following a competence-oriented approach, as suggested by the Bologna Process, the intended learning outcomes of the course are structured in five competence areas, listed in Table 1.

At the professional competence level, the course intends to enable the students to reflect on technologies and innovations within cultural interdependencies. The students should get an insight into the associated relevance of technologies and innovations as well as understand the relevance of social responsibility. Furthermore, the students shall be enabled to gain competencies to transfer their knowledge into their respective professional fields. Methodologically, the students shall be enabled to assimilate learning content independently and to write and evaluate critical reflections about the learned topics. On a social basis, the students are encouraged to exchange their critical reflections with fellow students as well as to represent their position in front of a plenum. After having completed the course, the students are furthermore enabled to assess the consequences of their actions and decisions concerning their professions as engineers towards a sustainable and ethical perspective. The use of diverse media tools leads to safety in dealing with online platforms, organizing online learning content as well as keeping track of the own learning status.

3.2 Content of the Lecture

The lecture introduces fundamental aspects and issues in the context of engineering and society. The topics are framed by the SDGs and focus on the interdependencies between the SDGs, a current trend in teaching that has been identified already by Wack, Roussel et al. [45]. After a basic introduction to sustainability and central topics and theories of technology ethics and social responsibility, the SDGs are discussed based on the current local and global challenges engineers must face. Furthermore, the necessity of handling gender and diversity issues in an intersectional perspective is particularly acute in science and technology studies, in order to provide a complete concept of social responsibility.

For this purpose, and oriented on the building blocks in the Blue Engineering course mentioned above [33], the content of the lecture was divided into three different learning blocks, serving as a structuring element of the lecture. In the individual blocks, topic packages (called *learning units*) are dealt with in a bundled manner, whereby each block is defined by thematic guiding questions. The content blocks as well as the thematic guiding questions are given in Fig. 1.

The first content block *Fundamentals of a Social and Sustainable Technology Design* lays the substantial foundation of the lecture as it builds the basis for the following individual topics. In particular, the content block contains the learning units *Sustainability & Responsibility* as well as *Technology Ethics & Technology Assessment*. The learning units provide a general introduction into the concepts of sustainability and sustainable development, different assessments to those topics, as well as theories of technology ethics and technology assessment. The latter is particularly important for engineers due to their actions influencing society as discussed in section 1.

The second content block *Introduction to Social Structures* introduces knowledge about general social phenomena. The learning units in this block are *Development Cooperation* containing aspects of

Table 1. Intended Learning Outcomes of the Course

Competence Area	**Intended Learning Outcomes** The students. . .
Professional Competence	Know different dimensions and aspects of the concept of sustainability. Know the Sustainable Development Goals in the context of sustainability. Explain the relationship between social responsibility and sustainable development. Understand the relevance of the Sustainable Development Goals for the work of engineers. Explain the relevance of ethical principles in the engineering profession. Understand their responsibility to society as future engineers.
Methodological Competence	Recognize critical discourses as such and deal with them reflectively. Consider social science knowledge in engineering science questions. Independently develop learning content and acquire knowledge. Assess their learning progress and check it independently. Write an argumentative and logical assessment of a given question.
Social Competence	Exchange ideas with their fellow students, communicate and discuss specific issues. Discuss their point of views in front of a large and mostly unknown group.
Personal Competence	Are open to new things and can acquire new knowledge within a reasonable time period (willingness to learn). Assess the consequences of their decisions, therefore act prudently and thoughtfully, and take Responsibility for the consequences (responsibility). Adapt their usual thinking and actions to changing structures (flexibility).
Media Competence	Feel confident in using the RWTH-intern online platform and can use the tools provided without any problems. Feel confident in organizing online learning materials and keeping track of current assignments.

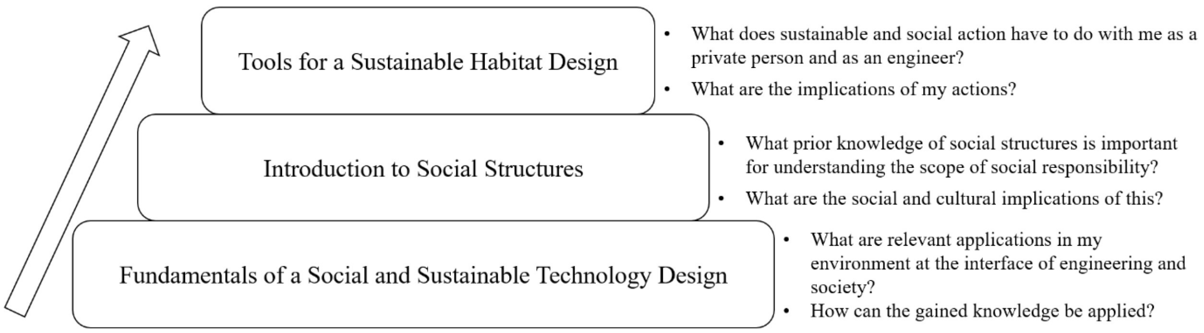

Fig. 1. Content Pyramid.

international cooperation and global relations, *Gender & Feminism* as well as *Equality Policy Strategies & Diversity*, thematizing topics of inclusion, diversity categories and modes of discrimination. To deal with societal topics and to actively treat societal problems, principal knowledge of these socio-technical therefore is indispensable.

The third content block *Tools for a Sustainable Habitat Design* serves as a point of transfer for the gained knowledge into practice, with a focus on designing sustainable habitats, particularly relevant for the target group of the lecture. However, the learning units of this block could be customized to any other target group. It comprises the learning units *Urban Planning*, *Mobility* and *Water Supply*, the latter also containing aspects of energy-related topics. The learning units in this block focus on real-life examples and current challenges in the respective areas. Modelling the practical transfer of theoretical knowledge is indispensable for engineers, due to their responsibility of designing habitat spaces.

Table 2 provides an overview of the learning units in the corresponding block and their assignment to the SDGs.

The chosen content can only provide an overview of the topics handled in the framework of the lecture. The target is to provide a basis for further engagement and understanding of information in the field of sustainability and ethical development and to initiate the first reflection processes. The goals are to give a rough introduction to the fields and to impress the importance of those topics in practical applications so that engineers are enabled to act accordingly.

3.3 Learner-Centered Teaching Methods

As indicated in the introduction, education for sustainability and thus, motivating reflection and questioning, calls for a transformative pedagogy for learning instead of transferring knowledge from one person to another [46]. Therefore, the methodology presented in this paper aims to be learner-centered, allowing and encouraging the students to construct their own understanding of information and personal reflection [47].

To meet the intended learning outcomes and to obtain higher competency levels while teaching the mentioned topics, a tailor-made flipped-classroom concept has been developed that aims to address all learning types by Felder and Silverman [48] in a satisfactory manner. The development of the teaching methods is described in detail in [7].

Flipped classroom describes the approach of students working through learning material on their own pace and afterwards working on practical

Table 2. Learning Units and Corresponding SDGs

Content Block	Learning Unit	Corresponding SDG
Fundamentals of a Social and Sustainable Technology Design	Sustainability & Responsibility	All
	Technology Ethics & Technology Assessment	All
Introduction to Social Structures	Development Cooperation	SDG 16: Peace, Justice and Strong Institutions
		SDG 17: Partnership for the Goals
	Gender & Feminism	SDG 5: Gender Equality
	Equality Policy Strategies & Diversity	SDG 10: Reducing Inequalities
Tools for a Sustainable Habitat Design	Urban Planning	SDG 9: Industry, Innovation and Infrastructure
		SDG 11: Sustainable Cities and Communities
	Mobility	SDG 9: Industry, Innovation and Infrastructure
		SDG 11: Sustainable Cities and Communities
	Water Supply	SDG 6: Clean Water and Sanitation

applications in class. Flipped classroom has been shown to be an effective method to teach sustainability in university curricula [49, 50] and is often realized in the context of teaching social responsibility and sustainability [27]. In the context of this lecture, the self-learning period is implemented via an e-learning platform. E-learning has been known to provide new aspects in traditional education as well as to increase the motivation, especially concerning sustainability topics as well as to increase the development of students' competencies, attitudes, and behaviors [51–57].

The digital teaching and learning concept which has been developed subsequently, but was fully applied for the first time in summer semester 2020, is divided into the four essential aspects *Independent Learning*, *Independent Reflection*, *Practical Transfer* and *Discussion and Reflection in the Plenum*, see Fig. 2. The students work through the theoretical parts of the lecture independently but are guided by tutors. The learning process is supported by digital reflection units and practical transfer through the involvement of student initiatives with great interest in, or a strong connection to the SDGs, such as Engineers without Borders. Discussion and reflection sessions provide a supportive framework.

The first aspect of the lecture's methodology is *Independent Learning*. Using the RWTH internal learning platform RWTHmoodle, the students attending the course can work through extensive lecture material at their own pace, supporting a highly individual learning process. The provided material is optimized to address all learning types satisfactorily, containing not only lecture slides and scripts but also short videos, podcasts, introductory and background texts, as well as newspaper articles, or links to practical examples and current issues. The latter highlights the current necessity of the topics discussed and their relevance in the working practice of engineers. As students work through the material at their own pace and to their own desired extent and interest, supporting discussion questions steer the focus to the relevant aspects and initiate the first reflection processes. Particularly the provided texts are suitable for debates in the plenum. Experience has shown that providing discussion questions in advance increased participation in the following group discussions. After having completed the learning units of a content block, the students can test their acquired knowledge in a voluntary e-test. This independent learning process enables the acquisition of both technical and methodological skills, as well as personal competencies.

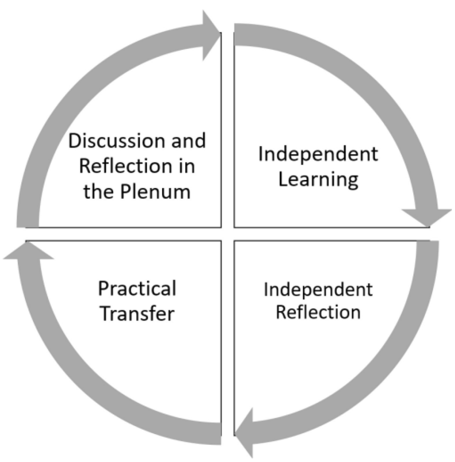

Fig. 2. Methodology Circle.

Wals and Jickling [58] highlight the importance of socio-scientific disputes and the need of theory for contextualization and reflection while teaching sustainability. Therefore, the second aspect *Independent Reflection* takes place parallel to, or shortly after, independent learning. The aim is that the learned content is processed individually, the understanding deepened, and individual reflection processes initiated. The independent reflection also takes place via RWTHmoodle so that the students can work through the process individually and at their own pace. The completion of the reflection activities is voluntary, but incentives are created in the form of obtaining bonus points for the final course exam as experience showed that completely voluntary activities are only accepted by a small number of students. More specifically, the students are encouraged to complete learning activities in which they work on a question related to the respective learning unit independently, with stringent content and argumentative logic, but otherwise freely. Through peer-to-peer assessment, students benefit from both the submission and the assessment process by being able to engage in cooperative scientific exchanges with fellow students [59, 60]. After reflecting on the content of the course, students are encouraged to evaluate their acquisition of competencies and identify any gaps that may still exist. For this purpose, a competence query is made available in RWTHmoodle after each learning block, in which students can enter the competencies they have acquired so far and provide anonymous feedback on the event. Furthermore, it is ensured that students are guided at their own learning pace and keep in touch with the lecture by allowing them to submit questions they are particularly interested in or would like to deepen further.

As described above, an important element of teaching sustainability and responsibility is the transfer into practice [61]. Being hardly realizable in large mandatory courses, the here presented course aims to provide practical transfer wherever possible. Therefore, the third aspect of the course is *Practical Transfer*. The CDIO Syllabus [5] highlights the importance of outside world examples to which students can relate their ideas. Furthermore, to increase the understanding of topics of sustainability and responsibility, concrete visualizations and examples are shown. Besides current issues provided in newspaper articles, external online links etc. as discussed above, the practical transfer was implemented with help of local student initiatives. In earlier versions of the lecture, student initiatives were involved by holding a guest lecture, but evaluations showed that students could not connect to a long frontal presentation of projects without personal relevance. Therefore, a firmer structural anchoring of student initiatives was pursued. Initiatives are allowed to present themselves via digital material (posters, presentations, videos), which is then provided in RWTHmoodle. Alternatively, or additionally, the initiatives get the opportunity to present themselves and current challenges in the plenum discussion events. In each case, the projects of the student-led self-initiatives with reference to the SDGs are presented and the challenges of the initiatives are discussed in the plenum instead of only being presented.

The presented three aspects take place in each of the previously discussed content blocks and learning units. At the beginning of the lecture, in the end as well as in between the content blocks, anchor events provide the necessary structure for supporting the individual learning and reflection process of the students. These anchor events take place in the form of *Discussion and Reflection in the Plenum*. These are attendance sessions, either in person or in a digital conference room. In these sessions where all students are invited to take part and contribute, previous content is summarized, the learning content is illustrated using selected examples, and further and current issues are discussed together using selected impulse questions and questions from the students. The learning activities completed by the students are also taken up here and the results are discussed. The anchor events support students in maintaining their focus, repeating what they have learned and reaching meaningful conclusions. Furthermore, the exchange with students serves the common learning process, cooperative learning, and the development of social skills, especially with regard to communication.

The whole semester structure is summarized in Fig. 3.

4. Course Evaluation

This section presents insights in evaluation of the course.

4.1 Methods of Evaluation

The success of the lecture depends on the students' ability to independently reflect on what they have learned and to apply it in new situations. Therefore, the entire concept is fundamentally based on self-initiative and active participation on the part of the students.

To evaluate and continuously improve the suc-

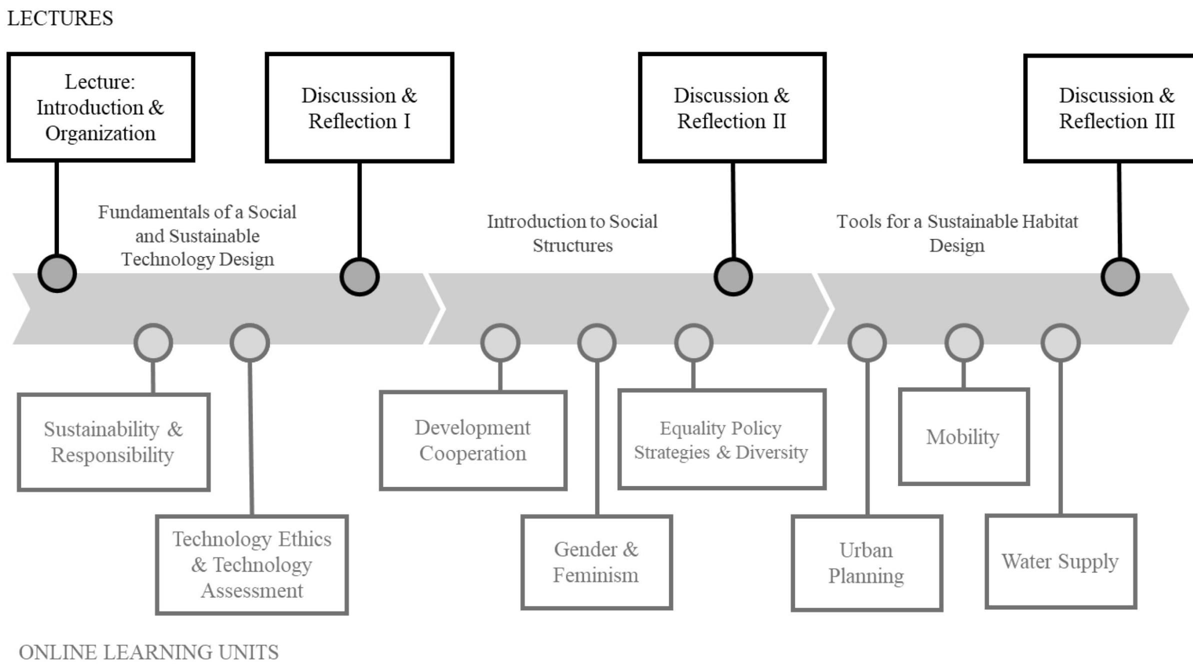

Fig. 3. Complete Semester Structure.

cess of the methods and procedures presented, feedback from the students is essential. This results implicitly from participation in the peer-to-peer processes or the willingness to discuss in classroom events. Other explicit measures, such as the regular surveys on competence acquisition, the feedback function at the end of each block, explicit surveys on learning success in the face-to-face courses, and the institutionalized evaluation survey on the part of the university, enable ongoing evaluation and improvement of the success factors. A sociological evaluation of the submissions and assessments of the learning activities in the peer-to-peer process is also conceivable.

To evaluate the motivation and learning outcomes, two surveys were first conducted in summer semester 2021 with the students: one at the beginning and one at the end of the semester. The surveys contain aspects of the student's motivation, their prior knowledge as well as their self-estimation of their competence-gain during the semester.

4.2 Results

The redesigned course was initially introduced and successfully completed in the summer semester of 2020 so that a discussion of the first implementation of the course, arisen challenges, and possible limitations and solutions is possible. The results of the rigorous evaluation of summer semester 2021 are not yet applicable. First insights are provided in the next section.

The results here presented are based on the combined teaching experiences of the course instructors, the acceptance of the provided learning tools and the course evaluation. However, teaching evaluations are not known to change significantly when using Blended Learning concepts as the satisfaction of the students is highly dependent on their learning types [62, 63].

The relevance of the course was reflected in most of the students' expectations, some of them (paraphrased and translated by the authors) formulated at the beginning of the course the following expectations:

- I would like to be sensitized with regard to the topic of sustainability.
- I would like to consider the consequences of my actions as an engineer, especially regarding diversity.
- I want to take responsibility for my fellow human beings.
- I would like to learn how engineers can act in business to achieve sustainability goals.
- I would like to (be able to) live up to my own responsibility.
- I would like to know which public structures are important for engineers.

However, there was a great discrepancy among the students concerning their motivation and acceptance of the course's topics which often represents a challenge, as discussed in section 2. The success of individual learning in the course is highly determined by the attitude of the students towards non-technical topics. Therefore, the practical transfer is crucial to motivate the students for reflecting on the topics discussed. Experience showed that there is a great variation in whether the students are very or not at all interested, an informal observation that coincides with results from [37].

The following comments (partly paraphrased and translated by the authors) on the interest and motivation after having completed the course were given in the evaluation outcomes. "The course is a useful complement to my other lectures, and I look forward week after week to new material to work on.", "Interesting content, inspiring reading" but on the other hand also "I just don't understand why I, as a civil engineering student, have to learn a useless subject. It is simply a waste of time."

On the lecture concept, students commented for example that "the concept, as a whole, seems well rounded and self-contained", they liked the "good discussions", the "strong interaction", the "very good learning materials and interesting articles". Furthermore, "I really liked the fact that there were only a few events and that we were encouraged to learn the material on our own." On the other hand, students criticized that the material was too complex, and summaries were missed.

In terms of effort spent on the preparation and assessment of the course, most of the students perceived the needed time as too high which is in alignment with the general point of view that Blended Learning concepts require more effort in terms of time spent [64]. At the same time, the students specified their average time spent as one to three hours per week which matches exactly the required two semester hours per week that are estimated for this module.

4.3 Outlook

In summer semester 2021, the course was offered for the second time with the possibility to gain first insights on the result of the pre- and post-course evaluation. There were 529 students who participated in the first survey, in contrast to the 89 students participating in the second survey at the end of the course. Considering the fact that possibly the more motivated students participated (voluntarily) in the second survey, the results may be biased. However, first insights are presented in the following. The whole survey will be subject to detailed investigation in following research.

Only 19.7% of the students participated previously in a course on teaching sustainability and social responsibility, in contrast to 67.2% who had not. This underlines the relevance for providing this course.

The authors evaluated the degree of understanding in the contexts of sustainability, ethics, and responsibility using a 5-level Likert scale. The statement (translated) "I understand the relevance of the Sustainable Development Goals to the activities of engineers" was strongly agreed by 43.5% before the course and 69.7% after completing the course. The statement "I can explain the relevance of ethical principles in the engineering profession in my own words" was agreed by 22.5% and strongly agreed by 11.3% before the course which increased to 41.6% who agreed and to 42.7% who strongly agreed. The statement "I understand my relevance to society as a future engineer" was strongly agreed by 43.9% before the course and by 61.8% after completion of the course.

Concerning these three aspects, an increase in the students' understanding of those topics did take place. However, only evaluating these answers cannot ensure that the learning success can be traced back to the innovative teaching concept presented here. This will be subject to further investigation.

5. Implications

Introducing topics regarding sustainability and responsibility to a large number of engineering students and enabling engineers to reflect on their impact on society in the future requires scalable and flexible concepts. Among the most striking advantages of the present course concept in terms of transferability are its flexibility and scalability.

A *transfer of topics* is achievable as the presented methodology is largely independent of the content discussed. The distinction of content blocks is crucial to the structure of the lecture.

Furthermore, a *transfer of structure* is achievable by adjusting the presented aspects of the methodology to the individual needs and resources. Implementation of the course is not dependent upon the instructors, as the teaching material is provided online and once prepared, can be used again in further lectures under up-to-date adjustments. The methods used at one point in time can be adapted to later semester-specific dates. Implementation of events during the semester requires online moderation, as well as accompaniment of the students, and hosting of live discussion and reflection events. Discussion and reflection sessions can be conducted digitally or in presence, making the format is very flexible. In the future, a hybrid format is also conceivable, in which the discussion sessions could take place as in-person events. The course concept is not dependant on course size, as the material is provided online, and the tools can be applied regardless of the number of participants.

The success of the voluntary learning activities is highly dependent on the student's participation. To counteract the low participation rates in the peer-to-peer process during the first run of the course in the summer semester and the resulting limited learning opportunities for fellow students, incentive systems were first implemented in summer semester 2021. The acquisition of bonus points to improve exam grades rewarded the participation in the peer-to-peer process. The first implementation of the aforementioned strategy was conducted in the summer semester of 2021, with 57 students completing the requirements for achieving the bonus. However, it remains crucial that each student can voluntarily choose the offers that are suitable for them individually.

The run of the course in the summer semester 2021 already included the contributions of student initiatives as part of the independent learning and independent reflection aspects. The feedback from the student initiatives has been overwhelmingly grateful for the opportunity to get in contact with students in an official curriculum module.

6. Conclusion

The purpose of this paper was to share experiences regarding teaching of responsibility and sustainability in large engineering classes. A teaching methodology was proposed that enables both students and lecturers to reflect on socio-technical topics within their engineering study programs, leading to the acquirement of knowledge on sustainability and responsibility as well as resulting in an increased awareness of the own's personal responsibility as engineering students and future engineers in or of society. Based on the idea of Education for Sustainable Development and the Sustainable Development Goals, knowledge and understanding about these in regard to engineering work and the resulting implications are pursued. It was concluded that scalable and flexible concepts are needed, so that the topics as well as the course structure can be transferred to courses with a large number of students.

Crucial for success is, however, a common understanding that modules dealing with social responsibility and sustainability in and of society are indispensable subjects within engineering curricula.

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