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Development In Students' Perceptions Of Sustainability And Responsibility As Relevant Aspects Of The Role Of Engineers

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ABSTRACT

Engineering and technology-based solutions can address the global challenges associated with sustainable development. In this context, engineers have a substantial responsibility in achieving the Sustainable Development Goals (SDGs). Meeting the challenges of all SDGs influences economic, political and social aspects of human life. However, engineering students' understanding of sustainability is often limited to its ecological and economic dimension, not taking into account or even neglecting social issues. Therefore, teaching approaches in engineering education should address the different dimensions of sustainability and the responsibility of technological development concerning society.

This paper provides a case study on successfully addressing competencies related to sustainability and responsibility in the context of a mandatory lecture called "Engineering and Society" for undergraduate environmental and civil engineering students. With this work, we aim to discuss how engineering students can become aware of the relevance of social responsibility and sustainability through an introductory mandatory lecture. For this purpose, students' competency development and their knowledge acquisition related to social aspects of sustainable development are analyzed. It is investigated how far the lecture contributes to students' perception of sustainability and responsibility as relevant aspects of the engineering profession. To do so, on a quantitative level the self-assessment of competency development is analyzed, and on a qualitative level we analyzed the students´ self-perception of the role of engineers and their statements on learning gains and knowledge gaps after the lecture.

1 INTRODUCTION

To address the challenges of the Sustainable Development Goals (SDG), technology and engineering contribute significant solutions (UNESCO 2021). Engineers are for example jointly responsible for functional infrastructure in areas such as housing, transportation or water supply (UNESCO 2021). Systems they construct tend to be both expensive and long-term investments that get shaped by and do shape the people living within. Accordingly, responsible and sustainable engineering designs characterize an important challenge for future engineering professionals. This includes not only technological, economic and ecological, but also social aspects (Tabas, Beagon, and Kövesi 2019; Steuer-Dankert et al. 2019).
Engineering students are motivated to deal with social impacts of technology and to learn how to use technology for the benefit of all. There is also an interest in dealing with social issues in their education (Niles et al. 2020). However, research has shown that engineering students' understanding of sustainability is often limited to its ecological and economic dimension, neglecting social issues (Haase 2014; Segalàs, Ferrer-Balas, and Mulder 2010; Drake et al. 2023; Björnberg, Skogh, and Strömberg 2015). Using the framework of the SDGs in engineering education allows to enhance the necessary competencies of future engineers (Beagon et al. 2022). As identified by Beagon et al. (Beagon et al. 2022), social responsibility and sustainability awareness are relevant competencies of engineers. To sensitize students for these issues and to enable them to assess the effects of their decisions on society, teaching approaches for sustainable development in engineering education should address different dimensions of sustainability and also focus on the impact of technological development on society (Drake et al. 2023; Børsen et al. 2021). Moreover, students have different perceptions of engineers and their social responsibilities, which are influenced by family, media or practical experiences (Rulifson and Bielefeldt 2019). For this reason, courses within engineering programs have to offer opportunities to improve students´ understanding of social responsibility and its relevance for engineers (Rulifson and Bielefeldt 2019). In this paper, we present a case study on a flipped classroom concept, that has been developed for a mandatory course which many participants. For this purpose, we analyze the students´ competency acquisition in the context of this course, which focuses on social aspects of sustainability. It will be discussed which competencies are particularly strengthened by the implementation of a flipped classroom approach. In addition, the change in students´ perception of the role of engineers based on participation in the lecture will be examined.

2 STUDY CONTEXT AND METHODOLOGY

2.1 Lecture Concept

The context for this study is a bachelor´s course on "Engineering and Society" which is mandatory for all Bachelor students of civil and environmental engineering, and technical communication in their first year of study at RWTH Aachen University. The lecture takes place every summer semester and on average 400 students take part. "Engineering and Society" serves as an introduction to the interdependencies between gender, diversity, sustainability and engineering and teaches the significance of sustainability, ethics and social structures.The course is framed by the UN Sustainable Develoment Goals (SDGs) (Decker, Winkens, and Leicht-Scholten 2022). After an introduction of fundamental theoretical concepts, such as sustainability or responsibility, current and global challenges of selected SDGs are considered to discuss the role of engineers in achieving them.

To structure the learning content, the lecture consists of three thematic blocks with eight learning units: (1) Fundamentals of a social and sustainable technology design, (2) Introduction to social structures, and (3) Tools for a sustainable habitat design. The first block provides the fundamentals for the following learning units and gives an insight into basic concepts and ideas of sustainability, responsibility, as well as ethics and technology assessment. After this, the second block deals with social issues, such as diversity, gender, discrimination or international cooperation (SDGs 5, 10, 16 and 17). In the third block, the previous theoretical foundations are connected to practical implications, such as urban planning, mobility and water supply (SDGs 6, 9, and 11).

The framing by the SDGs embeds the content of the lecture in a global context as well as illustrates the interface between engineering and the social dimension of sustainability. After completing the couse students should not only be able to analyze the connection between sustainability and responsibility and their relevance as well as the implications of the intersection between technology and society, but also discuss current issues with their fellow students and reflect on their responsibility as engineers.

Fig. 1 shows the structure of the one-semester course, where the learning units of each block and the related SDGs are shown. Because the course is offered in German, we translated all material into English.

Thematic Block	Learning Units	Related SDGs
Block I: Fundamentals of a Social and Sustainable Technology Design	Sustainability & Responsibility	
	Technology Ethics & Assessment	
Block II: Introduction to Social Structures	International Cooperation	10 Reduced Inequalities; 5 Gender Equality; 16 Peace, Justice and Strong Institutions; 17 Partnerships for the Goals
	Gender & Feminism	
	Gender Equality Strategies & Diversity	
Block III: Tools for a Sustainable Habitat Design	Urban Planning	9 Industry, Innovation and Infrastructure; 11 Sustainable Cities and Communities; 6 Clean Water and Sanitation
	Mobility	
	Water Supply	

Fig. 1. Thematic structure of the lecture “Engineering and Society”

The teaching and learning concept of the lecture is based on flipped classroom principles, which have been iteratively developed over several years (for more information see Decker, Winkens, and Leicht-Scholten 2021, 2022). Self-directed learning, self-reflection and plenary discussion and reflection are the didactic focus of the lecture. The students work out the learning content independently with the support of various materials (self-directed learning). In addition, various offers are available for reflection on the content and to deepen the understanding of the learning content (self-reflection). For this purpose, students have the opportunity to reflect on their understanding of the lecture content in form of reflection papers on given questions. Discussion and reflection sessions for plenary sharing are offered during the semester.

2.2 Data Collection and Analysis

In the following, students´ competency development in the context of a flipped classroom course and their knowledge acquisition related to social aspects of sustainable development are analyzed, where both quantitative and qualitative data are evaluated. To do so, the self-assessment of competency development and the self-perception of the role of engineers of the students are analyzed.
Students performed a pre-post self-assessment of their competency development using pre-determined items on a five-point Likert scale: 1 – disagree, 2 – rather disagree, 3 – neither, 4 – rather agree, 5 – agree. The students answered 20 items, divided into five areas: knowledge and understanding (K1 – K7), methodological (M1 – M5), social (S1 – S2), personal (P1 – P3) and media (ME1 – ME3) competencies (see Table 1). In accordance with the competency model of the German Higher Education Qualification Framework (HQR) (HRK, KMK, and BMBF 2017), we understand the specific competency areas as follows: Knowledge and understanding are defined as knowledge processing, comprehension and deepening. Further methodological competencies include the use, application and generation of knowledge. Social competencies refer to communication and cooperation. Personal competence includes students' scientific self-image and professionalism. In this assessment, media competencies deal with the organization of the digital learning units. In addition, the survey contained items on motivational factors for participation and attitudes towards the lecture topics as well as on experiences with blended learning.

Table 1: Items of the self-assessment of competency development

K1	I know the different dimensions and aspects of the concept of sustainability.	M1	It is easy for me to recognize critical discourses as such and to deal with them reflectively.
K2	I know the Sustainable Development Goals in the context of sustainability.	M2	I am able to integrate sociological knowledge into engineering problems.
K3	I know the German ethical principles for engineers.	M3	I am able to independently develop learning content and acquire knowledge.
K4	I understand the relevance of the Sustainable Development Goals for my work as an engineer.	M4	I am able to assess my learning progress and check it independently.
K5	I am able to explain the relevance of ethical principles in engineering in my own words.	M5	I am able to write an argumentatively logical assessment of a given issue.
K6	I am able to explain the connection between social responsibility and sustainable development in my own words.	S1	It is easy for me to exchange ideas with my fellow students, to communicate and to discuss current issues.
K7	I understand my responsibility as a future engineer for society.	S2	It is easy for me to discuss my views in front of a large and unknown group.
P1	I am open to new things and can acquire new knowledge in a reasonable period of time.	ME1	I feel confident in using RWTHmoodle and can easily use the provided tools.
P2	I am able to assess the consequences of my decisions, so I act prudently and take responsibility for them.	ME2	I feel confident organizing learning materials provided online and keeping track of current assignments.
P3	I am able to adapt my usual thinking and actions to changed structures.	ME3	I feel safe participating in a discussion.

On a qualitative level, we analyzed students´ written thoughts on their self-perception of the role of an engineer as well as their learning growth and knowledge gaps at the end of the course. For this purpose, the free-text item "What role do engineers have in society" of the self-assessment was analyzed. The analysis was conducted by inductively categorizing students´ self-perceptions.

3 RESULTS

3.1 Competency Development

Of 426 students who participated in the course in 2022, 387 completed the pre- and 77 completed the post-self-assessment. The use of personal IDs preserved students' anonymity while allowing the analysis of matched pre- and post-data for n=44 participants in sample test.
A Wilcoxon signed-rank test for dependent samples was used to analyze the matched pre- and post-data of the students competency development. The test shows only for the competency area knowledge and understanding a significant higher self-assessment at the end of the course ($p<0.01$). Therefore, we examine the cumulative percentages of agreement and disagreement for the items of the four competency areas. Fig. 2 and 3 illustrate the competency development for knowledge and understanding as well as methodological competencies. The competency development during the course is shown by the cumulation of the percentages of the answers on the Likert scale of (rather) agree and (rather) disagree. The data indicates a positive development in many of the self-reported competencies. Except for the social competencies (S1 and S2) and the first item of the methodological competencies (M1) descriptive statistics show also the reported increase in competencies.

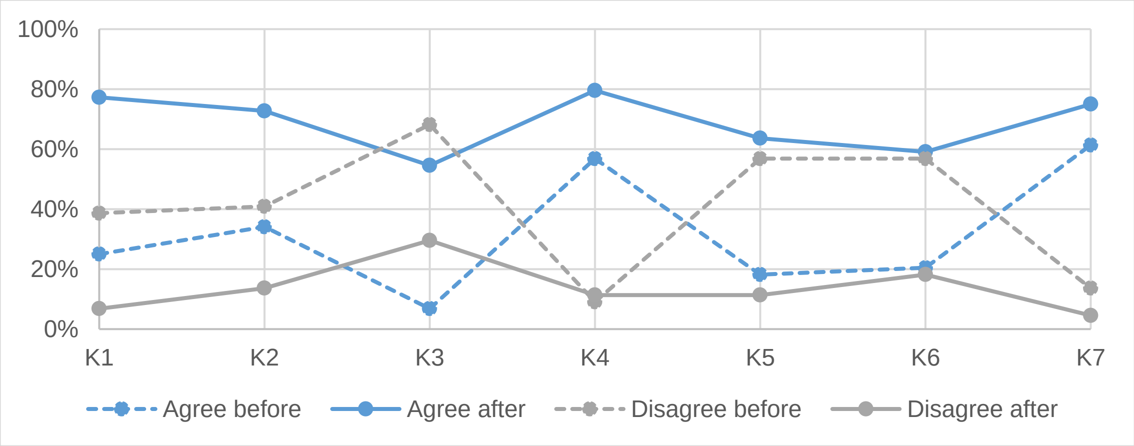


Fig. 2. Competency Development Knowledge and Understanding

Fig. *2* illustrates the competency development for the area knowledge and understanding. At the beginning of the lecture, only a quarter of the students were able to explain the concept of sustainability, one third knew the SDGs and only about seven percent had come into contact with the German ethical principles for engineers (see Fig. *2*). At the end of the course, about three quarters of the students know the concept of sustainability as well as the SDGs. In addition, more than three quarter of the students agreed with the items "I understand my responsibility as a future engineer for society" and "I understand the relevance of the SDGs for my work as an engineer". Answers suggest that participation in the lecture results in an increase of knowledge and understanding with regard to the learning content. Notably, especially the competencies related to knowledge acquisition are significantly higher after participation in the course (Wilcoxon test for dependent samples at $\alpha = 0.01$).
Fig. 3 shows the competency development for the competencies. After the course, one-fith more of the students report that they are able to assess and evaluate their learning process by themselves (M4). Positive competency development can also be

seen for the independent development of knowledge (M2). Half of the students, up twelve percent from beginning, are according to their self-asssessment able to integrate socological knowledge into engineering problems. Furthermore, after the course, more students (nine percent) agree with the statement that they are able to write a argumentative logical assessment (M5).

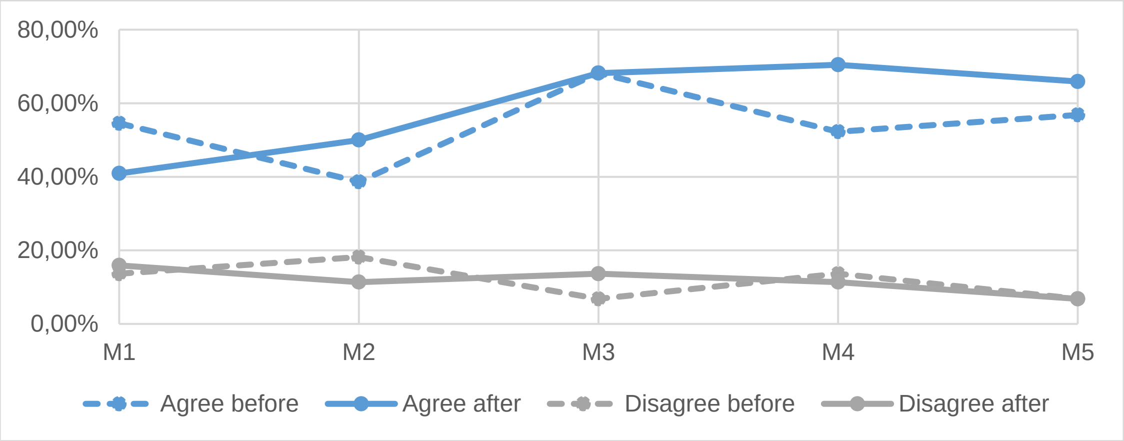


Fig. 3. Competency Development Methodological competencies

For the social competencies exchange of ideas with fellow students (S1) and discussion in front of a large group (S2), no positive development can be identified. Students´ agreement with these items remains unchanged between pre- and post-asessment with 32 percents (S1), and25 percents (S2), respectively.

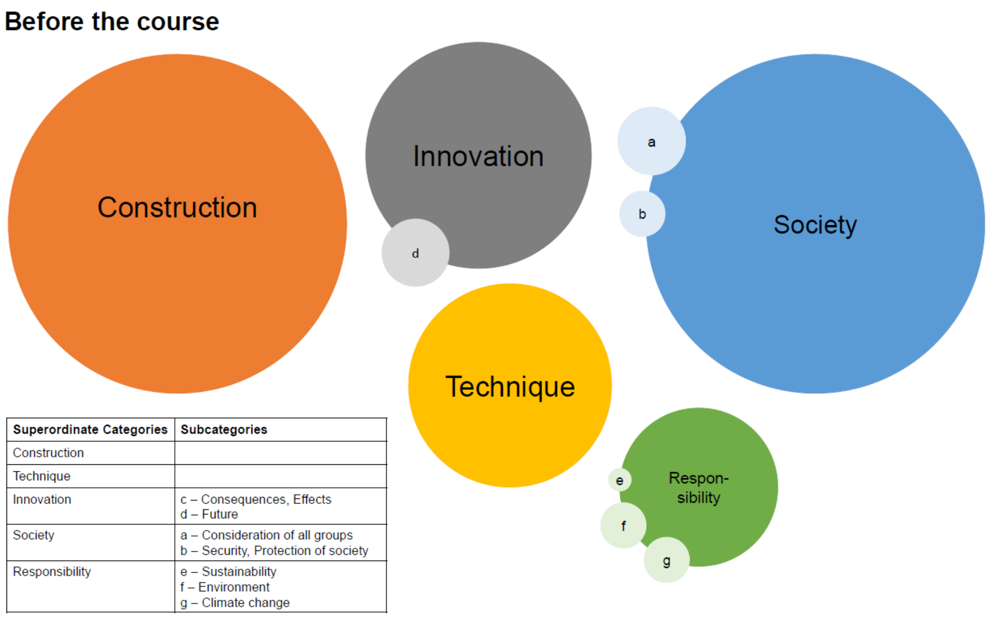
For the personal competencies (P1-P3), a change between the two assessments is only discernible for the adaption of habitual thinking and action to change structures (P3). Around three quarters of the students agreed with this statement after the lecture, a quarter more than before.

3.2 Students´ perceptions of their role as engineers

The high agreement of the students in the self-assessment on the ability to adapt their thinking and acting to change structures (P3) is also shown in relation to the perception of the role of engineers. The analysis of the free-text item shows a change in the perception after having attended the lecture “Engineering and Society”.

To analyze the free-text item “What role do engineers have in society”, we inductively formed categories from the available material to cluster the students´ statements and compare the pre- and post-data. The following superordinate categories emerge from the analysis*: construction, technique, science, innovation, society,* and *responsibility*. Fig. 4 and 5 show the assignments of the students´ statements to the superordinate categories and the subcategories (a–g). The size of the circles represents the frequency of assignment to the categories.

It is identifiable that students see construction aspects as an important element of the role of an engineer before and after the course. As the majority of students in this course study at the faculty of civil engineering, a focus on construction is to be expected. The pre-data analysis shows that students particularly associate the role of engineers with infrastructure construction, technology, and development, e.g., *“Planning and implementation of construction projects”* (ST16) or *“Developing and improving processes in their respective areas”* (ST17). Furthermore, some students describe the connections between building infrastructure and society, e.g., “*network* *social togetherness by creating housing structures, sports facilities, shopping facilities”* (ST19) or *“we engineers seek to improve and facilitate the lives of ourselves and those around us with new technologies” (*ST30). Few students are aware of the connection between technology and society.



Superordinate Categories	Subcategories
Construction	
Technique	
Innovation	c – Consequences, Effects d – Future
Society	a – Consideration of all groups b – Security, Protection of society
Responsibility	e – Sustainability f – Environment g – Climate change

Fig. 4. Assignments of the students´ statements to the superordinate categories and the subcategories (a–g) before the course

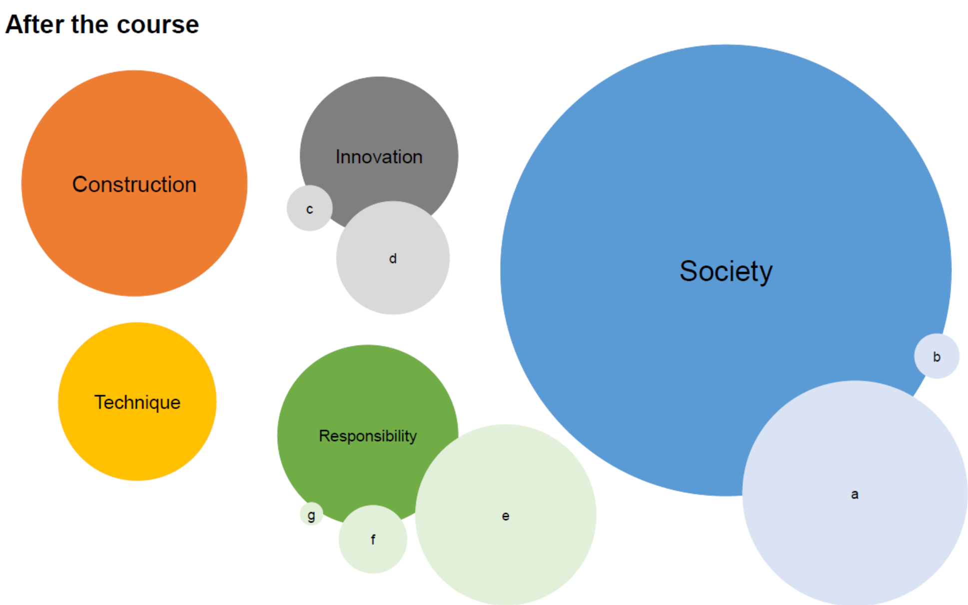


Fig. 5. Assignments of the students´ statements to the superordinate categories and the subcategories (a–g) after the course

The students' statements after the lecture are more frequently assigned to the categories *society* and *responsibility*. Thus, for the superordinate category *society*, the subcategory *consideration of all social groups* can be added after the analysis of the post-data. Students emphasize that "*all groups of society and their needs must be taken into account in the planning of any constructional undertaking*" (ST11). The results after the lecture show that in addition to incorporating societal needs into the planning of infrastructure, students also address the responsibility of engineers for sustainability and society as part of the role of engineers. According to the students' statements, engineers are "*shapers of a society*" (ST30) as much as "*solving future problems*" (ST41). In addition, they must "*take responsibility in areas that are relevant to all fellow human beings, but not everyone is equally knowledgeable and able to participate*" (ST36). The results of the free text analysis are in line with the positive competency development for the items K4 as well as K7 – both referring to social responsibility. In line with the observed changes in the self-perception of the role of engineers, students perceive the largest learning to have taken place in the area of social responsibility of engineers. In addition, in accordance with the quantitatively determined positive self-reported competency development (K1 and K2), students name sustainability and the SDGs as newly learned content. At the same time, students recognize knowledge gaps in these areas at the end of the lecture. In this context, they also formulate topics such as social responsibility, equality, diversity, and sustainability as knowledge gaps. When we asked about key questions that arise for the students at the end of the course, the students often answered with aspects regarding professional practice, e.g., "*How can I incorporate the knowledge I have learned into my professional life later on?*" (ST21) and the engineers´ awareness of social responsibility, e.g., "*How can we make it so that ALL engineers are aware of their responsibilities and live up to them?*" (ST38). This is also reflected in the quantitative data: Half of the students indicate that they are not better able to integrate sociological knowledge into engineering problems after the lecture (M2).

4 DISCUSSION

This study shows how a flipped classroom concept can promote different areas of competencies even in a mandatory bachelor course with many participants. The selection of the learning content addressing different dimensions of sustainability, focusing on the impact of technological development on society and referencing the SDGs, changes the students' perception of the role of engineers – a result that has also been illustrated by Drake et al. (2023) and Børsen et al. (2021).
About three-quarters of the respondents were interested in sustainability and social responsibility issues before the course but only a few of them were familiar with the concept of sustainability or social responsibility. Lectures on these topics in the first year of study can contribute to an acquisition of knowledge and understanding as well as changes in the perception of the role of engineers. After the course, the majority of students are motivated to engage with sustainability and social responsibility and to consider the issues in light of their engineering careers. This is also shown by the qualitative analysis: On the one hand, sustainability aspects and social responsibility play a larger part for students' perception role of engineers after the lectures. On the other hand, students still feel a lack of skills to integrate this knowledge into their work.
In term of methodological competencies, the strongest change is seen for the students´ability to assess and evaluate their learning process by themselves (M4). To implement the flipped classroom concept, a moodle learning platform is used. Through this students receive e-tests, glossaries and checklists to check and evaluate their learning progress. The positive development of the ability to write an

argumentatively logical assessment (M5) is probably related to the various offerings for reflection on the content and to deepen the understanding of the learning content. The implementation of a flipped classroom concept, the division of the learning content into learning units, the various reflection and discussion options as well as the offers for monitoring the learning progress can also be useful for other mandatory courses with many participants, regardless of the topic of the course. The lecture “Engineering and Society” introduces topics related to social aspects of sustainability and social responsibility, but is not a teaching approach that promotes student learning in a particular way (R. Lozano et al. 2017). Lectures can promote the competency area knowledge and understanding as well as methodological competencies, while social competencies, as the results show, are not explicitly promoted.

After the course, more students (12 percent) than before perceive being able to integrate sociological knowledge into engineering problems. The selected basic sociological concepts and theories, i.e. diversity dimensions, development cooperation or social responsibility support this, as they are explained on the basis of the SDGs using concrete enginnering examples related to them.

The intended increase in knowledge in the areas of sustainability and social responsibility is not only evident in the quantitative analysis, but also in students’ perception of engineers’ role. Half of the students mention aspects which are covered in the two learning blocks “Fundamentals of a Social and Sustainable Technology Design” and “Introduction to Social Structures” (see Fig. 1) as relevant for their role perception. As Rulifson and Bielefeldt (2019) recommend, “Engineering an Society” offers a opportunity to understand the relevance of sustainability and social responsibility for engineers and to develop students' perceptions of them as engineers.

The data of this study are limited with regard to generalizability, because matched pre- and post-data are only available for 44 students. The data collection for competency development and the perception of the role of engineers is based on a self-assessment. Strengths and weaknesses of self-assessments for measuring competency development are discussed frequently (Redman, Wiek, and Barth 2021). Participation in the post-survey was voluntary, and only twenty percent of the students took part. Probably, interest in the lecture content and participation in the survey are related. Moreover, the participating students primarily study at the faculty of civil engineering, which is why the perspective with regard to the role of engineers here might differ from that of engineering students from other disciplines.

An introductory lecture, as the results show, can raise awareness about sustainability and social responsibility in engineering. However, based on this, follow-up courses are needed to systematically address the aspects formulated by students as knowledge gaps and to emphasize the linkage of social responsibility and sustainability with engineering and technical aspects, such as mobility, urban planning or clean energy. For example, the development of real case studies can be one further step to enable the students to apply their lecture-based gained knowledge into real-world experiences in the context of their education.

However, our qualitative results show that the discussion of sustainability and responsibility in the first year of studies can provide a change in students´ perception of the role of engineers and that students recognize the relevance of this for the engineering profession.

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