AFFECTIVE LEARNING GOALS – KEY FOR TEACHING SUSTAINABLE PRODUCT DEVELOPMENT

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ABSTRACT

Sustainability in engineering sciences is of rapidly growing importance. However, its integration into engineering education is still in its infancy. This paper is based on the finding that, in addition to conventional cognitive learning outcomes, affective outcomes like mindset and attitude play a major role in teaching sustainability effectively. We present the didactical theory behind this and the evaluation of two university courses which serve as practical examples and research objects. These course puts high importance on affective learning outcomes, teaching not only design and assessment methods but also encourages students to reflect sustainability goals in broader contexts. We describe the theoretical course design following the principle of constructive alignment and conducted a quantitative and qualitative evaluation of the learning outcomes. The evaluation results confirm the importance of affective learning goals but also point out the need for further improvements to the course, which were implemented and re-evaluated.

Keywords: Sustainability, Design education, Social responsibility

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1 INTRODUCTION

Sustainability in engineering sciences is of rapidly growing importance. The EU Commission recently presented a proposal for an enhanced ecodesign regulation for sustainable products (European Commission, 2022). Since technical products through their entire life cycle significantly impact many aspects of sustainability, product developers have a particular responsibility when designing these products. The United Nations Sustainable Development Goals (SDGs) (United Nations, 2015) formulate respective requirements. Furthermore, the German National Academy of Science and Engineering demands that circular economy should become part of all engineering degree programs (acatech, 2021). Therefore, aspects of sustainable product development should be integrated in the education of aspiring (design) engineers as soon as possible.

Our investigation on the representation of sustainability in national and international university programs found many different aspects of sustainability, such as lightweight design or supply chain analyses, already represented in the curricula (Kattwinkel et al., 2018). Even though the importance of a comprehensive integration of sustainability goals into existing engineering processes is increasingly recognized, holistic approaches comprising all relevant perspectives on a product from an engineering point of view were hard to find. Therefore, an extensive summary and comparison of design methods suitable for teaching on sustainable products was compiled by Kattwinkel (2022). In this dissertation different approaches were evaluated regarding criteria such as the approaches' practical relevance, supporting methods and tools, available application to product examples, or the integration of users' behavior. The approach of McAloone and Bey (2009) met these criteria particularly well. Besides a set of suitable engineering methods, we postulate that the ability to design sustainable products requires an internalization of the enhanced life cycle view and a change in mindset. The present study supports this hypothesis.

An important aspect when teaching sustainable design engineering is the formulation of corresponding learning outcomes and their appropriate representation in exam formats. Taking into account the importance of the mindset, it becomes clear that relevant learning outcomes for sustainable design comprise not only cognitive learning outcomes (facts, methods) but also affective learning outcomes (attitudes). While Shephard (2008) already noted the necessity of including affective outcomes in sustainability courses, cognitive learning outcomes and corresponding examination formats still dominate in engineering degree programs. Therefore, we focus in this paper on how both affective and cognitive learning outcomes can be integrated and evaluated.

We have derived and applied this new set of learning outcomes in the context of two recently developed courses at two German universities: firstly, the course "Entwicklungsmethoden für nachhaltige Produkte" (Development Methods for Sustainable Products) at Technische Universität Berlin (TUB) and secondly, the course "Umweltgerechte Produktentwicklung" (Environmentally compatible product development) at Ruhr-University Bochum (RUB) (Kattwinkel et al., 2021). Here, we present the analysis of the learning outcomes for the first course based on the approach from (Kattwinkel, 2022). The analysis for the second course is described in (Kattwinkel, 2022).

2 LEARNING OUTCOMES, ACTIVITIES AND COMPETENCE ORIENTED EXAMINATION

In the theory of "constructive alignment", intended learning outcomes, learning activities and assessments must complement each other (Biggs, 2003). This section gives an overview on the scientific literature for each of these topics. Subsequently, we discuss the implementation in our courses.

2.1 Learning outcomes

Learning outcomes describe a hierarchical structure of competencies, knowledge, and skills students should have acquired in their studies. Classically, indicative or guiding learning objectives for a whole course of study or a module, rough learning objectives for lectures or series of courses and detailed learning objectives for individual course dates or smaller sections of a seminar series are distinguished. One of the most widely used approaches to structure and phrase learning objectives is Bloom's taxonomy (Bloom et al., 1956), providing a reference systems for classifying learning objectives. Cognitive learning outcomes can be structured from the lowest to highest level: remember, understand, apply, analyze, evaluate, create. The upper levels require a higher complexity of understanding, going from pure remembering of facts through the understanding of causes and effects to the ability to create new

Table 1. Key learning outcomes of the course based on Kattwinkel (2022). In the first column, 'C' refers to "cognitive" and 'A' to "affective" goals of Bloom's taxonomy.

No.	Learning Goal After the course, students will be able to	Level	Competencies Subject	 Method	 Social	 Self
C 1	describe central concepts of sustainable product development.	2. Understand	x			
C 2	identify the relevant stakeholders and processes along the life cycle of and systematically assess the resulting impacts.	5. Evaluate	x	x	x	
C 3	create sustainability targets for exemplary products and the development processes	6. Create	x	x	x	
A 1	organize and weigh the increased complexity of the decision-making process in the development of sustainable products	4. Organizing	x	x		x
A 2	display and judge the key concepts in the context of the philosophy of technology and the ethical principles of the engineering profession and reflect their own mindset and responsibility	4. Organizing	x	x		x
A 3	value sustainable topics and issues in their private and future professional environment and to assess them as important.	3. Valuing	x			x
A 4	internalize a sustainability-sensitive attitude and be convinced that they want to apply their knowledge, skills, and competencies in sustainable product development in want to apply in their later professional life.	5. Characterizing	x	x	x	x

knowledge. The hierarchical representation as a pyramid illustrates that each level requires the skills of the level below (Anderson and Krathwohl, 2000).

In addition to the degree of complexity, learning objectives can also be distinguished by their type: cognitive, affective and (psycho-) motor learning objectives (Krathwohl et al., 1964). In higher education, cognitive learning objectives are mostly targeted (Ritter-Mamczek, 2016). These primarily describe technical and methodological competencies. However, to achieve comprehensive competencies, enable so-called deep learning, and avoid inert knowledge, affective learning objectives must also be considered (Paschel et al., 2021). For affective learning objectives the lowest to highest level of the pyramid are: receiving, responding, valuing, organizing, characterizing and therefore describe social, personal or self-competencies.

For the TUB course "Development Methods for Sustainable Products", we derived the learning objectives in context of sustainable product development following the taxonomy for affective and cognitive learning objectives. The key learning outcomes are given in Table 1.

2.2 Learning activities

The second step in constructive alignment is choosing teaching and learning activities that correspond to the intended learning outcomes. The instructors cannot make students learn, but by properly designing activities matching the subject matter and the student body, they create an environment in which learning happens.

The course understands the design of sustainable products as a superset of engineering design. It requires added skills and reflection abilities. For this reason, the learning activities extend the lecture-exercise-discussion format typical of engineering education. In addition to classical teaching methods such as giving presentations (in which we mainly restrict ourselves to short keynote speeches kicking off other more active formats) and (group) exercises we enhance the course with activities that are relatively new to engineering education. These activities include structured formats for extracting the meaning of texts from the philosophy of technology, reflecting the group processes during solution finding, and debating personal values, for example with differing utopias for sustainable technology.

2.3 Examination

Constructive Alignment and the definition of competencies as learning outcomes require the design of examinations to be considered jointly with the learning outcomes (Jungmann, 2011). Besides new

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knowledge, the learners' gain in competency should also be assessed in examinations. Examinations are only adequately designed if they are clearly aligned with the learning and competence objectives (Paschel et al., 2021).

The model of the German Higher Education Qualifications Framework (HQR) is composed of four competence dimensions, professional competence (knowledge, understanding), methodological competence (use, application and generation of knowledge), self-competence (scientific self-conception/professionalism) and social competence (communication and cooperation) (Baumgartner, Alexander et al., 2016).

Problem- and action-oriented examination formats and tasks which require complex, cognitive performances to be processed in correspondence to the competence requirements of the defined learning objectives are particularly suitable for competence-oriented testing. To meet this requirement, realistic tasks from the discipline or professional field should be posed in the learning process itself and in the examinations (Ertel, 2008). To validly assess interdisciplinary competencies, such as problem-solving competencies, it may be useful to give examinees a greater degree of freedom in the design of the examination situation (Schaper et al., 2013).

Table 2. Examination components in the course and relationship with competencies based on Kattwinkel (2022).

Format	Description	Competencies				Degrees of Freedom
		Subject	Method	Social	Self	
Group Presentation	Presentation on a topic, supported by slides if necessary, with submission of written documents if necessary.	x	x	x	x	Medium
Group Project Work with written report	Working on practice-related questions in small groups and processing a complex written assignment	x	x	x	x	High
Individual Journal	Subjective summary and evaluation of the event content, reflection on own learning process, if necessary, support by guiding questions	x	x		x	Medium

For the examination formats of the course "Development Methods for Sustainable Products", the competence assignments and degrees of freedom according to (Schaper et al., 2013, p. 33) are summarized in Table 2. All competences are demanded in the group project and presentation, however its collaborative nature makes it difficult to assess individual contributions. The individual examination component is a "learning journal", in which students are tasked to reflect on the course's contents and develop their own opinion, being encouraged to freely explore creative forms of discussion and voice disagreement with the course's contents where applicable.

3 EVALUATION OF THE LEARNING OUTCOMES

To check whether the students have met the previously defined affective learning objectives we conducted quantitative pre-post self assessments and qualitative analyses of the reports and journals described above. This study was conducted at TUB in summer semester 2021, parallel to the evaluation of the course at the RUB, of which the results can be found in Kattwinkel (2022).

3.1 Quantitative pre-post self assessment

At the beginning and end of the course, all 50 students attending the course were asked to participate in an online survey asking how the students perceive the importance of sustainability and how they judge their competencies to deal with various sustainability-related product development problems. 30 students successfully completed both surveys, with their demographic composition closely matching the university's averages. The answers from the "before" and "after" surveys were then correlated for each student[1]. The students were asked to rate their perceived importance or competence on a scale from zero ('disagree' or 'I cannot make an impact at all', depending on question) to four ('agree completely',

[1] Anonymity was preserved using a student-selected "secret" entered into the "before" and "after" survey.

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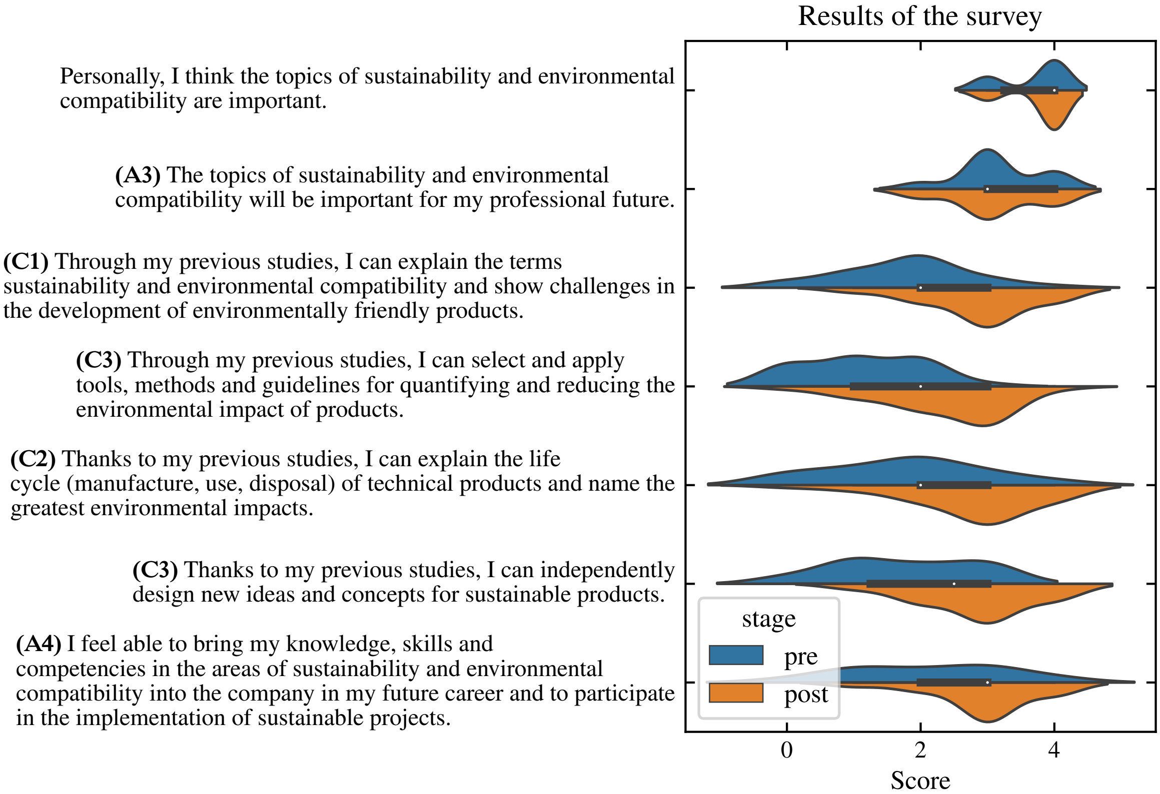

Figure 1. Results of the quantitative assessment. The associated Learning objectives from Table 1 are shown in bold.

'I can have a very large impact'). Additionally we checked the demographic parameters of our student sample and found it closely matching the university's average values.

Figure 1 shows an excerpt of typical results. The first two answers underline that the topics of sustainability and environmental compatibility in product design are important to the students personally ($\mu = 3.7$), but they are less confident about them being important in their professional life ($\mu = 3.2$). Both of those values only changed slightly (± 0.1 mean change) throughout the course.

Questions three to seven refer to the students' self-assessed skills regarding:

- Explaining the terms sustainability and environmental compatibility and showing challenges in the development of environmentally friendly products ($\mu = 1.8 \rightarrow 2.9$)
- Selection and application of tools, methods and guidelines for quantifying and reducing the environmental impact of products ($\mu = 1.1 \rightarrow 2.4$)
- Explaining the life cycle (manufacture, use, disposal) of technical products and naming the greatest environmental impacts ($\mu = 1.8 \rightarrow 2.8$)
- Independently designing new ideas and concepts for sustainable products ($\mu = 1.8 \rightarrow 2.8$)
- Bringing their knowledge, skills and competencies in the areas of sustainability and environmental compatibility into the company in their future career and participating in the implementation of sustainable projects ($\mu = 2.1 \rightarrow 2.9$)

The values in parentheses show that the mean shifted to higher values in the post-assessment, indicating that the students feel confident in achieving the key learning goals of the course.

Additional questions in the survey (excluded from figure 1) concerned the perceived ability to influence sustainability aspects *in the students' subsequent professional career*. Here, the rated ability was between 2 (medium influence) and 3 (rather strong influence), with only small changes in both directions over the duration of the course.

3.2 Qualitative assessment

To gain further insights into the effectiveness of the course, we conducted a qualitative analysis of the reports and journals described above from an examiner's perspective. Five questions shown in Table 3

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were derived to determine to what extent the students can apply what they have learned in a practical situation. Questions one to four (Q1 - Q4) refer to the project report (Section 3.2.1) and question five (Q5) refers to the journal (Section 3.2.2). Based on these questions, two instructors of the course analyzed and evaluated all reports and journals.

Table 3. Questions for the qualitative review of examination materials.

No.	Question	Corresponding Learning objectives
Q1	Is the identified sustainability problem real, relevant, solvable using technology and within the scope of action of a product developer?	C2, A2
Q2	Has a solution been developed using appropriate design approaches that can actually reduce the effect of the problem described?	C3
Q3	Have the impacts of the problem at hand been quantified and the expected improvements compared to the status quo been identified and discussed in a conscientious and methodologically correct manner?	C2, C3, A1
Q4	Has there been an assessment of whether there are new implications in other impact categories as a result of the improvement, and if so, have these been discussed and the merits of the improvement evaluated?	A3
Q5	Are the students able to reflect on their own experiences from the course and with the issue of sustainability and to express this in a comprehensible form?	A3

3.2.1 Assessment of project reports

An important part of the learning and assessment concept of the described course is a group project which is carried out during the semester. The task is to identify a sustainability-related problem, describe and quantify it and find a technical solution by optimizing an existing product or outlining a new one using the methods and concepts taught in class. The results of this project are presented in class and the methodological approach is described in detail in a technical report.

To verify the accomplishment of the learning outcomes, a qualitative assessment was carried out using the reports from the summer semester 2021. In this semester nine groups participated in the course.

Applying questions Q1-Q4 to the reports revealed an acceptable level of achieving cognitive learning outcomes such as competence in applying the methods taught. In this sense, all but two groups were able to use methods correctly and achieve satisfactory results. However, significant room for improvement can be identified when it comes to the achievement of the affective learning outcomes. This particularly includes the selection of relevant problems and the verification of real improvement while excluding (or at least discussing) new problems, which not a single group was able to fully achieve.

Answering question one (Q1), only one of the nine groups identified, well described and derived a relevant problem. For three groups, it remained completely unclear which exact problem they wanted to address, or it appears that the problem does not exist or is far beyond the scope of product developers.

Question 2 (Q2) revealed that the design improvement of the products is entirely sufficient for only two groups. Most of the groups at least applied the methods correctly, but tended to design products that could be described as interesting but not necessarily more sustainable. One group described a product that already exists in this exact form, another group developed a product that can no longer guarantee the original functionality.

When considering question 3 and 4 (Q3 & Q4), it was apparent that a basic methodological competence was achieved, but the affective learning outcomes that allow the meaningful use of these methods are developed insufficiently. Two groups were able to use methods for measuring the impact of a product in a correct way and thus were able to quantify the impact of the products they aimed to improve. Most groups were able to perform the task with some limitations. However, the students had great difficulties in describing and quantifying the improvements made by their redesign and in critically questioning

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whether new problems might have arisen as a result of the redesign. Although some groups at least had good approaches in this regard, not a single group was able to achieve a satisfactory result.

3.2.2 Assessment of learning journals

The students create a journal in which they subjectively outline and evaluate the content of the course and reflect the content and their own learning process.

Initially, the task description was kept brief to promote self-analyzing and introspection of the goal to be achieved from the examination element. The goal of the examination task was explained: to reflect on, evaluate and interpret taught content. There were no extensive formal requirements as a creative or scientific approach was accepted. The journal should contain one to two pages per topic. Additionally, we briefly summarized the focus of the evaluation: explanation, structure, presentation, transfer and reflection, citation, and design and format.

The assessment of the journals revealed that although a great part of the students created profound and reflective journals, for some of the students the term "reflection" was unclear. They rather summarized the content than dealt in depth with their own thoughts regarding the contents and their attitudes. Furthermore, some students misunderstood the proportions of reproduction and reflection, leading to large proportions of pure content repetition and reduced independent engagement. Another issue was that some students referred to sources but did not clearly identify them.

A smaller issue for this batch of students but a greater issue for us was the unclear definition of "one to two pages per topic". This was accompanied by many filler words and empty, repetitive text passages resulting in journals containing up to 70 pages. This caused a significant additional effort in the assessment of this examination component.

Answering Q5: A great part of the students is able to reflect on their own experiences from the course and with the issue of sustainability and can express this in a comprehensible form. Nonetheless, some of these engineering students were overwhelmed by such a "non-engineering" task.

3.3 Interpretation of the evaluation

From the quantitative survey, three main findings can be drawn[2]:

1. *Our students already care about sustainability.* This is supported by the first two questions. The audience of our course matches the intended audience we designed this course for. As an advanced course building upon the undergraduate-level sustainability courses at TU Berlin, we are correctly focusing on in-depth discussions on how to design better products rather than explaining the sustainability problems facing society. Conversely, we are not introducing students to sustainability and environmental aspects who do not already care about these topics.
2. *The self-reports indicate a competency increase.* This is supported by questions three to seven. Our students believe their competencies relating to our learning goals have improved, consistently showing a gain from "moderately capable" to "quite capable".
3. *We are not achieving empowerment.* The highest-level learning goal of the course is to empower the students to actually apply the skills in their subsequent professional career, believing that they are able to effect change towards a more sustainable future. The results regarding their self-assessed capability do not show a significant change over the course.

The qualitative investigations support the results of the survey, but allow even more profound conclusions to be drawn. The analysis of the reports shows that a certain level of methodological competence is achieved. This supports the students' self-assessment and suggests that the mapping of cognitive learning objectives in the course is successful to a certain degree. The fundamental interest of the students in the topic of sustainability is clear from the journals, which also supports the self-assessment here. The survey shows that after the course, students do not improve in seeing themselves as being able to make a positive contribution to sustainability in product development. This is supported by two results of the qualitative survey. First, the journals show that some students have difficulty engaging in a self-reflection process and thus seeing what they have learned from their own perspective and applying it to fields outside of what they have been taught. The analysis of the reports suggests that the students

[2] It should be noted that as our assessment does not include a control group, the causal relationship between participating in the course and the observed changes cannot be established from the quantitative assessment alone. However, our interviews with the students do not show them attributing their skill increase to other causes.

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have great problems with independently finding relevant problems, analyzing them precisely and also naming the targeted improvements and making them measurable. It seems that the students after attending the course are able to work on clearly defined tasks using their methodological skills, but it has not yet been possible to provide students with the skills they need to independently weigh up the options to achieve a holistic increase in sustainability. Our findings suggest in accordance with Kattwinkel (2022) that affective learning goals play a much more important role in sustainability teaching than previously thought. It seems to be of great importance to broaden the engineering mindset by a perspective that enables students to weigh and decide in the complex environment of sustainability and to bear in mind that all decisions can have new effects in other categories. Teaching this must become a goal of higher education courses like the one at hand.

4 CONTINUOUS IMPROVEMENT PROCESS

The quantitative and qualitative evaluation discussed in section 3 suggests a need to improve the achievement of the affective learning outcomes for this course. The results from the qualitative analysis underline our hypothesis that affective capabilities are of crucial importance for the effective integration of a sustainability mindset into the skill set of product developers and thus into product development. In order to better achieve the key learning outcomes, some improvements were incorporated into the course and re-evaluated. These improvements relate first to the course content as well as to the semester assignments.

4.1 Learning/Teaching activities

To integrate affective learning outcomes into the curriculum, various adjustments were made. The classical "three pillars" model of sustainability was replaced by motivating sustainability through the SDGs. While the "three pillars" model is simpler to understand, the SDGs allow the students to grasp the inherent complexities and conflicts between different areas of sustainability more easily. The SDGs are also used as an example to practice identifying and describing problems in one's own environment. The clear focus on one's own physical environment and one's own personal or professional scope for action ensured that no unrealistic problems were selected. Another adaptation concerns an additional teaching unit dealing with roles and impact. In other words, the roles of the students as an individual, as a consumer, as a participant in political processes and as a professional in their later jobs. Discussion formats are used to try to raise students' awareness of where they have influence and what impact they can make. In this way, it is attempted to promote the activation of students as future engineers.

4.2 Report

The task for the semester assignment was adapted to shift the focus away from pure design methodology towards the correct definition of the problem to be solved and the verification of the effectiveness of the found solution. This was achieved by also implementing the SDGs as guideline for the problem definition. Also a new section was required in the report where the students should describe in detail the process of identifying and selecting the problem they want to solve. To give the students more time and energy to focus in depth on quantifying the impact of the selected problem and verifying the effectiveness of their solution, it was decided to step away from having the students use all presented methods for measuring impact but rather have them select the method they think is able to describe the implications of their problem best. This way a more precise and elaborated application of that method can be achieved. Finally, the task description was simplified and the expected outcomes were described in more detail to avoid misunderstandings. The grading process was made transparent to the students by publishing detailed grading tables.

4.3 Journal

We reworked the task description of the journal. The proportions of reproduction (10-25%) and reflection (75-90%) were explicitly specified and the term reflection defined: "reflection means thinking about contexts that are not immediately given". To avoid excessively long journals, the definition of "one to two pages per topic" was clarified, and conciseness encouraged in the task description.

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Furthermore, we created a best-practice document in which we provide examples, comments and explanations on how the journal is graded. It is composed of excerpts from different submissions from the previous semesters highlighting the diversity of possible approaches and how they were graded.

4.4 Re-evaluation

A second evaluation was conducted to verify the impact of the course and exam format adjustments. In this case, the evaluation was limited to the project reports, as these allowed the greatest depth of information with regard to the affective learning objectives. The second evaluation was conducted in the summer semester of 2022. In this semester, 6 groups submitted a project report. It became apparent that all groups had defined the problem in a much more reflective way as a result of the new task and the adapted teaching approach. It was clear that a deeper process of engagement with the actual problem had taken place. The solution finding also proved to be better but the improvements were not as strong. Three groups found very good solutions to their problem, one group was acceptable, and two solutions did not provide an acceptable improvement to the problem. The evaluation of the problem and the verification of the effect of the solution was again significantly better. Only one group was not able to provide acceptable results. The identification and discussion of new problems caused by the product proved to be appropriate in half of the groups, but there is still room for improvement. Three of the groups remained very much on the surface and were unable to identify obvious problems. In summary, the adjustments had a clear effect on the quality of the work and the students' skills were further developed in a desirable direction. Further potential for improvement will be addressed in the next cycle of the course.

5 DISCUSSION

In response to the increasing importance of sustainability in higher engineering education, two courses for sustainable engineering design were developed at TU Berlin and Ruhr-University Bochum. In line with didactic concepts, learning outcomes were defined and allocated according to type, cognitive or affective. While cognitive skills such as knowing how to correctly apply existing methods of sustainable product development are common in higher engineering education already, affective learning outcomes are not commonly represented in engineering degree programs. This could be observed in the work results of the students participating in our courses. They had difficulties in reflecting their own activities and – probably as a reason for that – did not feel empowered to solve sustainability problems autonomously. Still, a significant improvement of the ability of the students in terms of adequately finding and solving sustainability related design problems can be seen when affective learning outcomes are taught. However, learning and examination formats need to be adapted to correctly teach and measure the achievement of affective learning outcomes. This can be achieved by regular short-cyclic student evaluations that allow for adaptations in the course concept during the semester. We will continue to apply this approach to our courses and encourage colleagues to adopt affective learning outcomes for their sustainability-related engineering education.
The ever-increasing impact and pace of new technological developments necessitates an increase in the ability of engineers to take a holistic view on the implications of their work. The evaluation of the course underlines that the implementation of affective leaning goals in engineering education plays a crucial role in enabling this holistic view.

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