Curriculum Development for Socially Responsible and Sustainably Acting Engineers

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Abstract **- It is the self-proclaimed ideal of university education to provide students with knowledge and skills to act responsibly and sustainably. There seems to be a university-wide consensus that ethics, sustainability, digitization, diversity, and scientific practice should be added to the subject-specific syllabi. What might be construed as a contradiction between industry demands and societal norms is in fact a response to the corporate needs of industry and business. They too require engineers to be trained to think systemically and react adequately to changing societal conditions. This also includes the on-going challenge of diversity and gender equality in industry and business, and in particular the well-established demand to attract more women to pursue a career in engineering. Based on recent experiences in the curriculum development process at the Technische Universität Berlin, the article discusses, based on first qualitative insights, how the development of the curricula can work in the given context.**

Keywords - curriculum development, ethics, sustainability, digitization, diversity, scientific practice, including all status groups

I. Introduction

Not all citizens are engineers, but all engineers are citizens. Given the key role engineers hold in shaping technological development and its impact on social development it is essential that they are empowered to shape their actions with an awareness of their overall social responsibility. Fostering the corresponding competencies is an educational mission. In that regard it is the university's mission to provide students (as representatives and multipliers within society) with knowledge and skills for responsible and sustainable action.

The argument to be developed shall be understood in the context of the canon of values of European-style liberal democracies as enshrined in the Charter of Fundamental Rights of the European Union [1]. Therefore what 'responsible and sustainable action' means is not argued based on ideas of ethical pluralism [2] or individual opinions as part of a democratic will-building process, but on well-established principles and core values that safeguard citizens' rights and their duties as part of constitutionally consolidated social contracts within the European Union [3].

Building on these principles there seems to be a consensus in higher education that research agendas and teaching curricula should be complemented by content and competence building around ethics, sustainability, digitization, diversity, and good scientific practice [4].

In the first part of this article, we illustrate the named topics that should be integrated into modules and curricula to educate socially responsible and sustainable engineers. The remainder of the paper explains why these choices were made. In addition to the requirements from industry and business, this section also addresses a targeted increase in the attractiveness of the courses, especially for women. Finally, it is discussed how, based on our experience, integration into and revision of the curricula can succeed.

II. What to Include in the Curriculum for Socially Responsible Engineers

A. Digitization and its Ethics

In 2021 the European Commission proposed a policy program "for the Digital Decade" including targets and objectives for digital skills, infrastructures, and the transformation of businesses and public services [5].

In addition, the Commission proposed a "European Declaration on Digital Rights and Principles" in which it elaborates the value-based and human-centered approach, whereas technology should serve, benefit, and empower all people through responsible and diligent action by all actors – public and private – involved in its design [6].

In that regard the importance of acquiring digital skills through training and lifelong learning is emphasized, along with the commitment to bridge the digital gender divide and support efforts to develop digital competences such as media literacy and critical thinking for active participation in society and democratic processes [6].

The idea of a declaration of digital rights and principles for the European Union continues a supranational development that is described as digital constitutionalism [7] and which aims to strengthen the digital sovereignty of European citizens in a legally binding way [8]. Consequently, the European institutions have established (or are preparing) a regulatory framework to safeguard European values in the digital sphere [9]: General Data Protection Regulation; Digital Service Act; Digital Markets Act; Data Governance Act; Draft Machinery Regulation; Revision Product Liability Directive; Draft Artificial Intelligence Act (AIA).

In the context of this paper, the risk-based approach of the draft AIA shall be highlighted as an example for digitization as a hole. The goal of this Regulation is not to ban technologies but to avoid undesirable application scenarios [10]. The prerequisites for this approach are on the one hand, that undesirable application scenarios are clearly defined, and, on the other hand, that producers, providers, users and affected persons have the skills, knowledge and understanding that guarantees an informed deployment of respective technologies as well as a sufficient level of awareness about opportunities and risks of AI, and thereby promoting its democratic control [11].

The ethical basis that defines the framework for undesirable applications scenarios in the context of establishing a trustworthy AI ecosystem has been defined by the High-Level Expert Group on Artificial Intelligence set up by the European Commission [12]. Four ethical principles – respect of human autonomy, prevention of harm, fairness, and explicability – and seven key requirements have been proposed: Human agency and oversight; technical robustness and safety; privacy and data governance; transparency; diversity, non-discrimination, and fairness; societal and environmental well-being; accountability. This normative approach will only be executed as intended if respective actors have the knowledge and skill to do so.

Considering our discussion, we follow the argument of [11, 13] that digital skills, knowledge, and competencies, that is Digital Literacy, must be promoted in all sectors of society and must not be limited to learning about tools and technologies but also to learn about the social dimension, that is the value and risk-based approach, of (digital) technologies. Engineers play a key role in that effort because they bear special responsibility as experts and potential innovators in their respective fields and are gatekeepers when it comes to the implementation of social values within technology and its development.

While digital competencies within the EU have been defined as part of a key competence framework for lifelong learning, interlinked with other competences in particular for citizens and educators [14, 15] we argue such a framework needs to be refined for engineers with a particular focus on fostering an ethical mind-set [12]. The goal must be to make engineers aware that they can and should participate in shaping the societal development. This includes all stakeholders, e.g. those involved in making the products (the designers and developers), the users (companies or individuals) and other impacted groups (for whom decisions are made during the research, development and deployment phase).

B. Ethics for Engineers

Ethics describes the theory of morality, which deals with the analysis, reasoning, justification and criticism of moral norms, principles, values and more [16].

In [17] the development, motives and possibilities to integrate Ethics across the curriculum are presented in detail. The article mainly refers to the integration of ethics in engineering. One origin of this initiative lies in the 80s in the United States, where as a reaction to some political and financial scandals and a perceived increasing decay of moral values as a result of declining religiousness, the teaching of ethical content was gaining more importance.

According to [18], teaching ethics has five main goals, these are: Stimulate the moral imagination; recognize ethical problems; create a sense of moral obligation; develop analytical skills; tolerate and reduce disagreements and ambiguities.

With regard to engineering training, we argue, that ethical content should not be taught separately from technical content but should be linked to it. The consequences of technology should be assessed and reflected on, for example, using case studies on ethical issues or dilemmas.

This is of particular importance since digital competencies for responsible engineering are – as deduced above – based to a great extent on ethical approaches. It might therefore be useful to link general reflections on ethical principles with applicable approaches currently discussed e.g., in the context of trustworthy AI. Having key principles and corresponding requirement (human oversight, transparency, accountability etc.) consolidated in a respective framework will be helpful when it comes to the implementation and translation of ethical principles into technology and its development.

C. Sustainability

Building on the EU's logic of competence profiles and the intertwined nature for ethics and digitization identified above it seems reasonable to assume that there is also a high degree of intersection regarding the topic of sustainability. According to the definition of the United Nations Sustainable Development Group, sustainability is the vision of a peaceful, just, socially inclusive, intra- and intergenerational coexistence of all people while at the same time respecting nature and the environment under the prerequisites of ecologically and socially compatible economic activity [19].

Accordingly, to "embody sustainability values, and embrace complex systems, in order to take or request action that restores and maintains ecosystem health and enhances justice, generating visions for sustainable futures", knowledge, skills and attitudes must be promoted by way of education and training [20].

Again, when it comes to sustainable development, that is "the many processes and pathways used to stimulate development, or achieve progress, in sustainable ways" Engineers play a key role because they bear special responsibility as experts and potential innovators in their respective fields and are gatekeepers when it comes to the implementation of sustainable approaches within technology and its development [20].

D. *Diversity*

The UNESCO Salamanca Declaration emphasizes that every child has a right to education, and schools should accommodate learners' individual characteristics, abilities, and learning needs [21]. Since this concept of individuality is not limited to general education in schools, this mandate must be extended to teaching in higher education as well, where the challenge lies in balancing the individual prerequisites of the students with the social and professional requirements outlined above. To achieve this, good teaching must be designed based on seven principles [22], whereas good teaching (1) promotes contact between students and lecturers, (2) cooperation between students, (3) active learning, (4) gives prompt feedback, (5) places special emphasis on study-related activities, (6) sets high standards, and (7) respects different abilities and skills.

How do these considerations relate to diversity and variety? Good teaching is inclusive teaching and therefore normal learning groups are no different from inclusive learning groups [23]. Teaching should be fundamentally designed to be diversity-sensitive, building upon students' prerequisites, while encompassing all aspects of diversity, including different talents and abilities, and enabling them to engage with the teaching content [24, 25].

Three fundamental structures that notably impact teaching quality are identified: cognitive activation, constructive support, and class management [26]. Effective class management enables efficient and goal-directed learning, while cognitive activation and constructive support provide students with opportunities to learn based on their individual prerequisites. Individual learning and processing paths should serve as the foundation of learning, which necessitates appropriately oriented teaching that considers these quality dimensions [27].

E. *Scientific Practice*

In 2017, the academic senate of the Technische Universität Berlin passed a statute to ensure good scientific practice [28]. Accordingly, all members of this institution see the safeguarding of good scientific practice in research and teaching as one of their top priorities. In addition, it is understood as a core task of the university to convey the basic principles of scientific work to the students. The basic principle here is honesty towards oneself and others, which is both an ethical norm and the basis of scientific professionalism. Specifically, it means working according to regulations in the respective discipline, storing primary data, documenting processes and results in a comprehensible and comprehensive manner, appropriately evaluating and involving contributions from others in publications, and respecting third-party intellectual property. The students should be introduced to the rules of good scientific practice from the beginning of their studies in order to prevent scientific misconduct in the long term, whether knowingly or unknowingly. During the first phase of the course, the emphasis is placed on respecting the intellectual property of others through the teaching of citation guidelines and rules.

III. Why should these topics be included in the engineering curriculum

The enrichment of engineering studies with "non-technical" components, such as social and cultural studies, ecological aspects and the debate with the consequences of technology is seen as a glimmer of hope to attract more female students [29]. This hope was confirmed, for example, at the Carnegie Mellon University, where a change in the curricula in the computer science department increased the proportion of women among first-year students from 7% to 42% within 5 years [30].

Not only women are attracted by a stronger integration of socially relevant topics, but also young men, who do not necessarily base their decision to start studying engineering on a mere interest in technology [29]. Since topics such as climate change and sustainability, social justice and the consequences of technological progress (AI) are increasingly becoming the focus of young people already at school, improved visibility of these topics in engineering studies promises to increase the attractiveness of engineering courses. Likewise does the clarification of the influence of an engineering profession in connection with the environment and society.

But the goal of creating forward-looking, comprehensive, sustainable and socially responsible engineering sciences also meets the needs of industry and business. Many companies owe their reputation in society to the consideration of social, ethical, and ecological factors and the encouragement of responsible innovations. Investments are made in the development of new technologies, products, services, and business models that are socially accepted and desirable. The consideration of gender and diversity aspects in product research and development is increasing [31]. Impacts, that an innovation will have, are already anticipated during the development and construction phase and considered accordingly in order to benefit society and the environment and to largely rule out bad business investments [32].

The 21st century post-modern, value-based engineer is a person who, in addition to technical knowledge, has also developed soft skills during their studies; who is aware of the responsibility of their own work, their own decisions and their effects, who is able to reflect on their decisions and their own actions from different points of view, who can perceive and evaluate risks and risk groups and who can react adequately to constantly changing social and technical conditions [33].

IV. How to include these topics in the engineering curriculum

Even if the content to be included in a program has been decided, curriculum development is a lengthy process, at least in Germany. Here we would like to briefly describe how the development started at the Technische Universität Berlin. Where we are now, and what was considered helpful.

In 2018, a mission statement for teaching was adopted at Technische Universität Berlin, which was developed during a year-long participatory process involving all status groups. This mission statement includes educational goals and contents. For example, teaching should be modern, innovative, digital, practice-oriented and international. Students should be enabled to face technological change and its social effects with professional qualifications and a sense of responsibility, while learning to consider the ethical consequences of their actions [34]. Based on this guiding principle, the General Study and Examination Regulations (AllgStuPO) were also changed. The new version has been in force since August 2021. Here, a clear requirement for the curricula of the study programs emerges [35, §44, 3]:

[1]In the study programs, the rules of good scientific practice are taught at the earliest possible stage and continuously trained. [2]Students learn to place knowledge and action in an overarching historical, social and cultural context and to consider ethical consequences of action in order to be able to contribute to sustainable development. [3]It is to be ensured that all students have completed relevant study content amounting to at least 12 LP by the time they graduate.

The mission statement and the new AllgStuPO, constitute binding guidelines for all faculties which have to revise their courses accordingly. These obligations primarily initiate and facilitate a process of course development; the need for revision is also likely to reduce, for example, idle, fruitless discussions with professors about the indispensability and inevitability of their original content. However, there are also some potential risks.

Specifying a number of credit points to be guaranteed in each program may tempt people to offer courses that cover exactly the required topics, detached from the technical content of engineering. Then the integration of the topics might remain too superficial and conceptual. In order to build and develop competencies such as systemic thinking, critical reflection or technology assessment, the technical context dimension of the engineering modules and the competencies dimension must be integrated in a meaningful manner, e.g. room for discussion must be established and critical questions, case studies or vignettes that do not have a clear right or wrong solution, but invite the development of own position, should be foreseen.

Furthermore, the framework does not answer how the integration of topics or the required scope of the credit points can or should be ensured. This vagueness in turn leads to uncertainties. The desired integration of the topics in each module makes it difficult to prove the credit points. It remains unclear whether the collection of partial points by a percentage e.g. of sustainability and ethics in modules of construction and mechanics, is equally recognized. A central readjustment is required here, which creates clear guidelines and instructions for this.

With regard to ensuring integration into the modules, this can be demonstrated by the teaching staff via the module descriptions, on the one hand, and on the other hand, the students' perspective can also be queried with regard to the integration achieved by means of the teaching evaluation.

Regardless of the vagueness of the new AllgStuPo, the Faculty V of Traffic and Machine Systems translated its implications by first holding a closed teaching conference to inform the faculty members about the new requirements. Building on this, a Think Tank was founded which, with the participation of all status groups and fortunately a high level of student participation, is driving the process of curriculum development forward in monthly meetings.

The low-threshold discussion rounds in the Think Tank, which took place or still takes place in hybrid form both in presence and digitally, contributed in particular to identifying the needs of students in the various study programs. These will also be incorporated into further work on the study and examination regulations.

The first step conducted within the Think Tank was a curriculum mapping. It was analyzed which existing modules already contain or address topics such as digitization, sustainability, ethics and gender and diversity. Since this analysis does not create a complete picture of the courses at Faculty V, it is planned to fill the gaps through respective questions in a bi-annual teaching evaluation that takes place at the University.

The second step was dedicated to reflections about possible means to ensure the integration of these topics into the curriculum. One possibility is the establishment of a compulsory elective area, from which modules dealing with the named topics are to be selected based on a certain number of credit points. However, as mentioned above, it must be ensured that integration and reflections take place within the specialized engineering modules. To assure this, the following possible formats were developed in the Think Tank: Accentuation, empowerment, embedding, development of an integrated required foundation course at the beginning of the Bachelor's degree program [36].

Accentuation refers to subject-specific content that is reflected through a special focus on a topic. E.g. a course on *Sustainability in Space Flight*. Content on satellite operations and manned and unmanned spaceflight is reflected against the background of sustainability and both positive aspects, such as the observation of climate-related changes on our planet through satellite images, and negative aspects, such as waste in orbit, are highlighted.

Empowerment refers to enabling teachers of a module through dedicated trainings on how to enrich their own courses with content on digitization, sustainability, ethics, gender and diversity or scientific practice and to link these together.

In the case of embedding, external experts are invited to the courses to give input in a kind of mini-building block. It is then up to the module leaders to build on this input, integrated in to the on-going course and encourage the students to reflect upon it.

Work is currently in progress on an introductory compulsory course for the bachelor's degree in mechanical engineering, in which the basics of ethics, sustainability and diversity are integrated into a subject-specific introduction. There is already an Introduction to Mechanical Engineering module with a strongly practice-oriented character. This module is specifically intended for the beginning of the degree program. It is meant to qualify the students to function as multipliers for aforementioned topics and to reduce early dropouts by enriching the quality of the studies through the integration of socially relevant topics.

In addition to these formats, certificate programs such as the Sustainability Certificate and the Berlin Ethics Certificate, which can be obtained at the Technical University of Berlin, provide students with an opportunity to explore the topics of sustainability and ethics in greater depth.

The faculty also seeks advice on curriculum development. For example, a peer-to-peer faculty advisory process is currently taking place for the mechanical engineering department under the guidance of the Higher Education Forum for Digitization (HFD). In this advisory process, the University of Bremen and the Technische Universität Berlin provide peers who support each other. In addition, they receive input and feedback from experts and the HFD on the basis of a self-report on the status of digitization at the university, the faculty, and academic degree programs.

During the HFD consultation process, facilitators from the HFD and experts from different universities who provided their expertise regarding faculty development, curriculum development and digital strategies were invited. A crucial realization was the change of perspective from a focus on subject content to competencies. The central question is: What competencies characterize our engineering graduates? The OKR (Objectives and Key Results) method [37] helped us to plan the next steps. The competence orientation confirmed the importance of integrating the above-mentioned topics into the modules, since competencies to be achieved consist of professional, methodological, social and personal competence.

The involvement of student groups and their perspective on teaching is essential for the further development of the curricula. A promising method to be implemented is the lottery method of participation, as already practiced at the Hochschule Ruhr West [38]. Here, candidates for a series of workshops were drawn at random and then personally invited by the vice president. The students involved reported that both the aspect of "winning" in the lottery and the personal approach by the president were decisive for their participation and that they probably would not have responded to a general call.

A key recommendation from the consulting process was to define achievable goals and communicate them using a step-by-step plan. Even though our original goal of the HFD consulting process was to develop a digitalization strategy, we had to rethink and define other goals and stages along the way. These are the exchange and networking of all parties involved - students, teachers, management - and the joint development of a competence profile for prospective engineers. Only then it can be determined which opportunities and methods need to be established, what framework conditions, incentive systems and support structures are required. This ultimately leads to the development of a strategy. It's important to set small goals and be bold and positive to move forward.

The next steps are the analysis and evaluation of relevant policy papers and the development of a list of requirements for prospective engineers. This will be followed by a teaching conference on the topic of graduate profiles and the development of an exemplary graduate profile. Only after this has been done and the goals have been clearly defined the curriculum process will be continued. Ultimately, we are starting a specific degree program where we are going through the entire process of redesign based on the competencies of the graduates. The extension of this redesign to all engineering programs will be implemented gradually over the next few years.

As this process of redesigning programs takes time, it must be accompanied by the sensitization and empowerment of lecturers to integrate digitization, sustainability, ethics, gender & diversity, and scientific practice into their lectures. To this end, we are planning a low-threshold, regular, subject-specific exchange between lecturers and to strengthen their networking. On the topics to be integrated, we want to implement peer-to-peer consultations, mutual shadowing, and the possibility of advice and support from experts in a timely manner. The next concrete step in this direction will be workshops at the next internal faculty conference on the topics: How can I integrate social issues into my courses? and How can I make the integration of social issues visible in the module description?

V. Conclusion

It is the self-proclaimed ideal of university education to provide students with knowledge and skills to act responsibly and sustainably. Accordingly, future engineers are to be enabled to shape their actions in awareness of their responsibility for society. To this end, the curricula must be supplemented with content and the development of competencies in the areas of ethics, sustainability, digitalization, diversity, and good scientific practice. In addition to the comprehensive qualification of engineering students for their later professions, the integration of socially relevant topics will make their studies more attractive, not least for women. On the way to developing a new curriculum, we believe that all status groups should be involved and that the needs of in particular students should be considered. Even if the integration of the topics into existing courses seems like a compromise compared to the desired fundamental paradigm shift in teaching, it is a first important step in the right direction and one that can be implemented more quickly, especially at very large universities than the complete redesign of a study program. A rapid implementation towards the integration of these topics into all academic degrees, and syllabi is of utmost importance given the rapid changes in and around our societies driven i.e. by the development of new technologies as a result of engineering activities. We argue it is time to act now, with courage, motivation, and an evidence-based willingness for necessary adaptions.

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