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Educating Future Engineers to be Responsible Citizens

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In a time of rapid technological and societal transformation, universities are called upon to prepare future engineers not only for professional success, but also for their societal responsibilities. In addition to technical expertise, engineers need ethical awareness, sustainability competencies, and the ability to reflect critically on the consequences of their actions. Topics such as digitalization, artificial intelligence, and data literacy are becoming increasingly essential. Engineering education must therefore integrate socially relevant skills alongside scientific and methodological foundations. This article presents the ongoing transformation of engineering curricula at TU Berlin, beginning with the adoption of a mission statement on teaching in 2018. It outlines key developments over the past six years, including structural measures and teaching formats designed to foster ethics, sustainability, and interdisciplinary thinking. Practical examples demonstrate how these topics can be embedded into existing programs through interdisciplinary collaboration and curriculum development. The article also reflects on obstacles encountered and lessons learned along the way. By sharing these insights, it aims to contribute to the international dialogue on engineering education and invites readers to discuss strategies, methods, and structures that support the development of responsible and socially engaged engineers.

Keywords: *Sustainability, ethics, data literacy, responsible citizens, curriculum development*

Introduction

Not everyone is an engineer, but every engineer is a member of society – and as such, carries a responsibility that extends beyond the technical sphere. Engineers play a pivotal role in shaping the tools, systems, and infrastructures that influence how people live, work, and interact. Because their decisions can have far-reaching consequences – socially, economically, and ecologically – it is essential that they are not only technically proficient but also aware of the societal implications of their work.

Fostering this awareness is a key educational responsibility. Higher education institutions are therefore called upon to do more than just impart technical knowledge: they must also promote the development of ethical reasoning, critical reflection, and a sense of responsibility. Universities serve as spaces where students – as both future professionals and active members of society – learn to think systemically, weigh consequences, and act in ways that contribute to a sustainable and socially just

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future.

The Faculty V - Transportation and Mechanical Systems at the Technische Universität Berlin (TU Berlin) has reaffirmed its mission statement for teaching and learning at its latest faculty retreat in February 2025. This mission statement reads: *"We educate engineers who are aware of their social responsibility, act sustainably and reflectively, and develop motivated competencies that enable them to successfully enter the professional world."*

This requires, in addition to the development of professional, personal, and methodological competencies, also digital competencies, a reflective handling of AI, technology impact assessment, and consideration of the 17 Sustainable Development Goals of the United Nations (SDGs 2015). To achieve this, inter- and transdisciplinary, practice- and research-oriented teaching, encouragement of self-regulated learning, as a prerequisite for academic and professional success, and the continuous alignment and development of course content and curricula to meet the needs of the future labour market and society are necessary.

The argument presented here is situated within the value framework of liberal democracies shaped by European traditions, as outlined in the Charter of Fundamental Rights of the European Union (EU 2012). Accordingly, the meaning of "responsible and sustainable action" is not derived from ethical pluralism (Roberts et al. 2021) or individual viewpoints within democratic discourse, but from fundamental principles and core values that uphold citizens' rights and responsibilities under constitutionally anchored social contracts in the EU (Bundesverfassungsgericht 1986). Based on these foundations, there is growing consensus in higher education that both research and teaching should systematically address ethics, sustainability, digital transformation, diversity, and the principles of good scientific practice (EUA 2021).

The TU Berlin is also working to redesign its study programs and give due place to the promotion of socially relevant competencies in the curricula. This article aims to present the steps taken so far in curriculum development and invite discussion on the necessary steps and methods to develop a curriculum that educates students not only with technical competencies but also as responsible members of our society. The analysis presented in this paper is based on a practice-based expert perspective. The author was directly involved in the strategic development and implementation of the initiatives described in her role as Vice Dean for Studies and Teaching as well as Equal Opportunities at TU Berlin, and as a founding member of the Think Tank, which developed the presented framework. Consequently, the contribution draws primarily on participatory observation and experiential knowledge from ongoing curriculum development processes. Additionally, relevant policy documents, internal reports and higher education regulations were consulted throughout to contextualize and substantiate the described developments. Thus, the paper contributes an insider's perspective on institutional change processes against the backdrop of common European ethical and legal frameworks and policy initiatives, focusing on the articulation and structuring of practices that can subsequently be subjected to empirical evaluation.

In the course of this paper, we first clarify the crucial role of engineering education in and for society and explain the core competencies that responsible engineers should possess. Next, we discuss the special perspective of TU Berlin due to its founding mandate and the implementation steps taken by the university as a whole to integrate socially relevant competencies into teaching and curricula, as well as at the Faculty of Transportation and Mechanical Systems in particular. We also address concepts and implementations, such as possible formats for integrating socially relevant themes into study programs. Building on this, we present our future plans and also address previous obstacles and insights gained.

The Role of Engineers in and for Society

The role of engineers in and for society has undergone a fundamental transformation in the 21st century. Engineering sciences are now intricately linked with societal development. From infrastructure and mobility systems to digital technologies and energy solutions, the work of engineers fundamentally shapes the functioning and development of societies. Consequently, the expectations of future engineers extend far beyond the solution of technical problems. As highlighted in the Position Paper of the European Society for Engineering Education (SEFI 2025), engineers are increasingly seen as agents of change who must steer complex socio-technical systems and proactively contribute to addressing global challenges such as climate change, digitalization, and social justice.

This expanded societal mandate requires a redefinition of the engineering profession. This involves not only the ability to design and implement technical solutions but also the competence to critically reflect on their broader consequences. Engineers are expected to act responsibly, integrate sustainability and ethics into their practice, and engage constructively with the perspectives of various interest groups. Their role entails both freedom and responsibility – the freedom to shape the world through innovation and the responsibility to consider the long-term implications of their decisions.

In summary, the following expectations of society are placed on future engineers:

- Designing sustainable and responsible technologies: Engineers should actively contribute to addressing global challenges such as climate change, resource scarcity, and social justice. They are seen as designers of a sustainable and inclusive future (Pacher 2024).
- Reflecting on societal impacts: Society expects engineers to critically reflect on the social, ecological, and economic consequences of their work and to incorporate these into decision-making processes (Engineers Without Borders UK 2022).
- Innovation and adaptability: Engineers must be able to respond flexibly to new challenges and drive innovation, particularly in the context of digitalization, AI, and green transformation (CESAER 2024).
- Responsibility: Society demands that engineers recognize their special responsibility for the safety, health, and well-being of the general public and align their actions accordingly (Engineers Without Borders UK 2022).

The education of engineers thus stands at the intersection of technological innovation and societal responsibility. To meet the demands of society, future engineers must not only be excellent professionals but also responsible, reflective, and engaged designers of a sustainable future.

The evolving role of engineers as societal stewards aligns closely with central pillars of recent EU policy: e.g. the ecosystem of trust and excellence outlined in the European Commission's White Paper on Artificial Intelligence (European Commission 2020), the Ethics Guidelines for Trustworthy AI developed by the High-Level Expert Group on AI (High-Level Expert Group on Artificial Intelligence 2019); the subsequent legislative framework established within the EU Artificial Intelligence Act (European Union 2024); or the Union of Skills Communication (European Commission2025). Across these frameworks, the EU places citizens – not only in their roles as individuals but also as professionals and economic actors such as engineers and technologists – at the heart of Europe's ambition to shape a digital and sustainable future grounded in European values. Engineers are no longer seen merely as technical implementers but as critical agents of ethical, social, and environmental foresight. As articulated in the AI White Paper, the European approach to AI must be "grounded in fundamental rights such as human dignity and privacy protection" and should contribute to the Sustainable Development Goals, the ethical use of data, and democratic accountability (European Commission 2020). This vision resonates with the societal expectations placed on engineers to reflect on the broader impacts of their work and to act with responsibility toward public well-being and long-term inclusion.

Complementing this, the Union of Skills sets forth a transformative agenda for education and training, stressing the development of critical thinking, civic engagement, digital ethics, and interdisciplinary knowledge as foundational 21st-century skills (European Commission 2020). In particular, the forthcoming AI in Education initiative and the updated Digital Competence Framework promote AI literacy, responsible technology usage, and awareness of misinformation – competencies essential for engineers expected to navigate and co-create trustworthy AI systems. Moreover, the Union of Skills explicitly supports STEAM-based approaches, international cooperation in higher education, and the recognition of non-formal learning (e.g., ethical engagement, sustainability initiatives), all of which resonate with modern engineering roles that require collaboration across disciplines and societal sectors.

The Union of Skills Communication (European Commission 2020) outlines a series of concrete initiatives to be delivered over the coming years, forming the operational backbone of the EU's strategy for skills development. These include:

- an Action Plan on Basic Skills (by Q1 2025), providing a strategic framework to raise foundational competences in literacy, numeracy and digital skills;
- a Basic Skills Support Scheme (pilot) (by 2026), targeting adults with low skills, particularly in disadvantaged regions;
- a 2030 Roadmap on the Future of Digital Education and Skills (by Q4 2025), which will guide inclusive and effective digital learning strategies;
- an AI in Education Initiative (by 2026), including an EU AI literacy framework, teacher training, and ethical guidance on the use of AI in learning environments;
- a STEM Education Strategic Plan (by Q1 2025), designed to increase

participation-especially among girls and underrepresented groups-in science, technology, engineering and mathematics;
- an EU Teachers and Trainers Agenda (by 2026), supporting the development of teaching professionals across all sectors;
- a European Competence Framework for Academic Staff (by 2026), strengthening the pedagogical and interdisciplinary competences of university educators;
- measures for increasing accessibility of higher education (by 2027), aimed at reducing dropout and expanding access for disadvantaged learners (by 2027);
- a European Strategy for Vocational Education and Training (VET) (by 2026), modernizing VET systems and improving their quality, attractiveness and mobility options;
- and an Intergenerational Fairness Strategy (by Q1 2026), promoting social cohesion and addressing age-based skill divides.

Core Competencies for Responsible Engineers

In one of our previous contributions (Derda et al. 2023b) we stated that the postmodern, value-oriented engineer of the 21st century is a person who, in addition to technical knowledge, has also developed social skills during their studies; who is aware of the responsibility of their own work, their own decisions and their impacts, who is able to reflect on their decisions and their own actions from different perspectives, who can perceive and evaluate risks and risk groups and who can respond appropriately to constantly changing social and technical conditions.

In the same article, we also discussed what content should therefore be integrated into engineering courses and curricula. In the current article, we mainly refer to the latest SEFI position paper (SEFI 2025) and the latest findings on dealing with AI.

The European Society for Engineering Education (SEFI), headquartered in Brussels, is Europe's largest network dedicated to the advancement of engineering education. Its primary mission is to promote the development and continuous improvement of engineering education across Europe. SEFI brings together a diverse community of stakeholders, including universities, academics, educators, students, companies, and associated organisations from 47 countries.

In response to global uncertainty and complexity, the SEFI position paper (SEFI 2025) calls for a renewed focus on engineering competencies that goes beyond technical expertise. SEFI identifies three core dimensions of competence – the so-called 3Ts:

- *"Technical: Range from the foundation and application of science to the applied mathematical and computational skills necessary to develop technical solutions in the sense of innovation and current demands."*
- *"Transferable: The cognitive, social and emotional skills needed to thrive in various life contexts which people can potentially transfer from one social, cultural, or work setting to another. They include the ability to work creatively, effectively, and transversely with AI; planning, organizing, and executing projects successfully; as well as motivating and inspiring team*

members to achieve common goals, active listening, persuasive writing, and the ability to work collaboratively in diverse teams. Working on self-development and continuously improving oneself as a lifelong learner is also part of this category."

- *"Transdisciplinary: Afford an outward facing, broader appreciation and active engagement with traditional and nontraditional sources of knowledge from both academic and non-academic domains. These encompass skills related to ethical decision-making, sustainability and social responsibility. These might include the full spectrum of engineering and science, humanities and social science, crafts and other practices from earlier civilisations as well as the business context of engineering solutions, beyond the project-level."*

SEFI further stresses that these competencies are context-specific and always emerge through the interplay of knowledge, skills, and attitudes. Engineering education must therefore offer challenge-based learning formats, support personalization of learning, and foster reflection, curiosity, and error literacy.

In addition to suitable learning formats that promote the development of the required competences, there is also a need, as already indicated in the section on transdisciplinary, for content that should enrich the engineering curriculum in addition to specialist content, such as ethics and sustainability as well as a critical approach to AI, which has recently been increasingly in demand. According to Thies Johannsen (Cooke & Wint 2024) teaching transdisciplinary skills further means 'that we leave the framework of disciplinary knowledge production and work on social challenges together with stakeholders from science, practice and the public.'

It becomes clear, according to the cited sources and the intentions reflected by the various stakeholders, that the role of engineers in the 21st century is expected to extend beyond technical expertise alone. Engineers are not only creators of innovative technologies but also responsible actors who shall integrate social, ethical, and ecological considerations into their work. The demands placed on engineering education reflect this expanded societal expectation: technical competence alone is no longer sufficient. Instead, critical reflection, sustainability awareness, and interdisciplinary thinking have become essential components of modern curricula. Recent European initiatives – embodied notably in the Union of Skills strategy – affirm and support this paradigm shift. They position engineers as key agents in shaping the digital and sustainable transformation of our societies. Engineering education thus plays a crucial role in ensuring that technological innovations are not only technically excellent but also ethically grounded and socially embedded – an indispensable foundation for addressing the complex challenges of our time.

These curricular goals resonate with empirical findings from engineering ethics education, which highlight that students benefit most when ethical issues are addressed repeatedly across different courses, using active and problem-based pedagogies rather than purely normative instruction (Lim 2021). Multi-level reviews also show that sustainable reform requires alignment between course-level learning activities, assessment practices and the broader institutional mission of engineering programmes (Martin et al. 2021). In parallel, the literature on responsible research and innovation underscores a shift of moral responsibility towards engineers and innovators themselves, calling for anticipatory, reflective and inclusive practices throughout the innovation process (Van de Poel & Robaey 2019).

Embedding AI & Data Literacy in the Curriculum

Because the topic of AI in teaching is highly controversial (which could i.a. be observed at our faculty's retreat), we would like to dedicate a short section to this topic.

Recent studies indicate a rapid increase in the use of AI tools such as ChatGPT in higher education. According to a longitudinal survey with over 5,000 students, the proportion of learners who frequently use AI tools for academic purposes rose from 31.8% in 2023 to 50.5% in 2025 (von Garrel & Mayer 2025). The most common applications include clarifying subject-specific concepts (73.2%), text-related tasks such as analysis and generation (56.8%), translation (53.8%), and support in research and literature review (50.8%). These findings highlight that AI is becoming a habitual part of students' learning routines. ChatGPT, alongside DeepL, remains the most widely used tool.

However, the use of artificial intelligence (AI) has a multifaceted impact on students' learning performance – with both positive and negative effects, depending on the application and usage behavior, as a compilation of several publications on the use of AI in higher education in Germany shows.

Positive Effects

- Adaptive learning systems: AI-supported learning platforms analyse individual strengths and weaknesses and adapt learning content and pace to the needs of students. This enables targeted learning and promotes motivation and learning success, especially in heterogeneous learning groups (Rommel n.d., de Witt 2020).
- Increased efficiency: AI can automate repetitive tasks such as literature research, summarizing, citing, or correcting assignments. This leaves more time for deepening specialist knowledge and self-directed learning ((PHWT 2023, de Witt 2020).
- Fast feedback and support: Virtual AI tutors offer 24/7 assistance, answering questions, and providing individual feedback, supporting continuous learning (Rommel n.d., de Witt 2020).
- Early detection of learning problems: AI-supported analyses can identify students at increased risk of performance decline or dropout early on, allowing targeted support measures to be initiated (de Witt et al. 2020.

Negative Effects and Risks

- Superficial learning: Studies show that unreflective or excessive use of AI tools can lead to a decrease in critical thinking, lower self-efficacy, and less in-depth engagement with learning content. Especially when students use

AI to solve tasks automatically without engaging with the material, sustained learning performance declines (Campus Schulmanagement 2023).
- Reduced exam performance: Studies show that students who use AI unsupervised as a "solution aid" achieve better results in the short term, but perform significantly worse in exams without AI support than control groups. A deeper understanding is lacking (Campus Schulmanagement 2023).
- Less self-efficacy and sustainable learning: The use of AI can lead to students being less immersed in the learning process ("flow") and developing less confidence in their own abilities, which negatively impacts motivation and long-term learning (Campus Schulmanagement 2023).
- Risk of dependency and plagiarism: A heavy dependence on AI tools can inhibit the development of problem-solving and analytical skills and increase the risk of plagiarism (Campus Schulmanagement 2023, Hochschule Harz, 2024).

An international study by Wang & Fan (Wang & Fan 2025) a meta-analysis of 51 studies and more than 10,000 participants, also comes to similar results. It shows that AI can improve learning, but only under certain conditions. What is crucial is systematic, planned use with didactic integration and the promotion of responsible, reflective use of AI in studies.

This increased integration as well as the results on the impact of the use of AI on learning underscores the need for higher education institutions to engage critically and constructively with AI-supported learning processes—both in terms of didactic integration and academic integrity.

An example of the didactic embedding of the use of AI in an engineering module was presented at our faculty teaching conference by Prof Kraft (2025) from the Department of Medical Engineering.

In a two-part module series on Medical Engineering, artificial intelligence tools such as ChatGPT were purposefully embedded into course design to foster critical reflection and responsible use. In the first course, Medical Engineering I, students worked in small groups to address a predefined question using ChatGPT–once with and once without a character limit. The generated responses were then evaluated in terms of scientific accuracy, depth, and relevance. Students compared the short and long versions, identified factual errors, redundancies, and missing content, and formulated suggestions for improving the associated lecture. They also reflected on the usefulness and limitations of ChatGPT for academic study and exam preparation.

In Medical Engineering II, students selected a topic from the course and prepared a group presentation that combined core lecture content with recent developments based on their own research. The use of AI tools was explicitly permitted but had to be documented transparently. The oral presentation was followed by a critical discussion to assess subject understanding and evaluate the quality of AI-assisted content creation.

This integrated approach illustrates how AI tools can be used not only to support learning but also to strengthen evaluative judgment, academic integrity, and digital literacy in engineering education.

The TU Berlin Approach: From Mission to Implementation

Democracy and market economy are not natural allies; rather, they often exist in a tense and complex relationship. Likewise, recent developments – particularly in the United States – demonstrate that the relationship between the state and science is far from inherently harmonious. Political agendas, economic interests, and ideological pressures can challenge or even undermine the independence of scientific inquiry. Against this backdrop, the integration of ethical reflection and social responsibility into the education of engineers gains particular importance. The Technische Universität Berlin has embraced this responsibility since its reestablishment after World War II and continues to see it as a core mission to educate future engineers not only with technical expertise but also with a grounded moral and societal awareness.

Due to its history and its founding mission, Technische Universität Berlin has a special perspective on the integration of ethics and social responsibility into the education of future engineers. When the university, formerly Technische Hochschule Charlottenburg, was re-established after the Second World War, the Allies decided that scientific education had to be inextricably linked with ethical reflection and social responsibility. This was to be emphasized by the aim of introducing the humanities, social sciences and education as an integral part of the curriculum. In his inaugural address on 9 April 1946, Major General Eric P. Nares emphasized that the institution should be "*a home of true education and not mere technology"* (Nares 1946) and underlined the importance of integrating ethical and social responsibility into technical education. He emphasised the university's new mission to serve humanity and to distance itself from its previous role of supporting the German war effort. All education, whether technical or humanistic, must be based on the ideal of a responsible attitude towards society (Hark 2023).

The Technische Universität Berlin remains committed to this founding mission and the associated responsibility to this day and will continue to do so in the future. Nevertheless, as outlined above, the demands on future engineers have changed in recent decades and curricula must therefore be constantly adapted to the needs of the world of work and society. We would like to summarize the main developments in this regard at the Technische Universität Berlin in recent years.

In 2018, after a year-long participatory development process involving all status groups, a mission statement for teaching was adopted, which is binding for all members of the university. The mission statement is understood as a constitution for teaching and formulates educational goals and content, some of which are relevant to society. Teaching should be modern, innovative, digital, practice-orientated and international. Students should be enabled to face technological change and its social impact with professional qualifications and a sense of responsibility and to consider the ethical consequences of their actions (Technische Universität Berlin n.d.).

In line with this mission statement for teaching, the General Study and Examination Regulations (AllgStuPO) were revised, with the new version entering into force in August 2021 and expanded in September 2023. This revision establishes a clear mandate for integrating these principles into the curricula of all study programs (Technische Universität Berlin 2024):

(3) In the degree programmes, the rules of good scientific practice are taught at the earliest possible stage in accordance with the applicable principles for safeguarding good scientific practice at the TU Berlin and trained on an ongoing basis.
(4)[1]Students learn to place their own and general knowledge and actions in an overarching historical, social and cultural context and to consider the ethical consequences of their actions in order to be able to contribute to sustainable development in the sense of the United Nations Sustainable Development Goals. [2]To this end, it must be ensured that all students have completed at least 12 CP of relevant course content by the time they complete the degree programme.

Although these regulations apply to all degree programs at TU Berlin across all faculties, the development of socially relevant competencies such as ethical reflection, sustainability, and social responsibility cannot be assumed to occur automatically within any disciplinary context. Depending on disciplinary traditions, curricular structures, and teaching cultures, these competencies may be addressed to varying extents or remain implicit. The present contribution therefore deliberately focuses on engineering education, as the transformation processes described here were initiated, piloted, and institutionally anchored at the Faculty of Transport and Mechanical Engineering.

In response to the mission statement for teaching and the new version of the AllgStuPO, which established centrally binding requirements for all faculties to revise their degree programmes, the Faculty of Transport and Mechanical Engineering held a teaching retreat in 2022. The aim was to inform faculty members about these new requirements. Building on this, a Think Tank Technology Reflection was founded at the same event, tasked with driving the curriculum development process forward through monthly meetings. This think tank involved participation from all status groups and, fortunately, a high level of student involvement.

The Think Tank Technology Reflection's first step was to analyse the existing modules at the faculty and in the module catalogues that cover topics such as ethics, sustainability, digitalization and technology assessment. This was done in order to establish the current state of affairs as a basis for further curriculum development.

Concepts and Formats from TU Berlin

In a second step, options were identified and developed as to how these topics could continue to be integrated into the curricula. The most easily realisable option is the establishment of a compulsory elective area from which modules on the above-mentioned topics can be selected for a certain number of credit points. Interestingly, this option was already implemented in the Physical Engineering degree programme at the insistence of the students before the AllgStuPO was amended. Here there is a compulsory elective area on the topics of *'ecological and social competences'*, in this respect this degree programme was ahead of its time. Nevertheless, this solution for integrating the topics is not the last choice, as it harbours the risk that students may learn about socially relevant topics, but that these remain unreflected and detached from the subject-specific content. It must therefore be ensured that integration and reflection also take place in the engineering modules.

To this end, the Think Tank Technology Reflection developed a concept and various formats that are summarised in the ENG+ Framework, which has already been presented at various conferences (Ammon et al. 2023, Derda et al. 2023a). The ENG+ Framework is designed as a transferable model that can be adapted to other disciplines, provided appropriate subject-specific connections are developed systematically. It offers a systematic approach to anchoring ethics, reflection on science and technology and sustainability in the curriculum and strengthening core values such as diversity and good scientific practice and is based on the fundamental strategies of *advancing* and *complementing*, which should go hand in hand. It is important to emphasize that the ENG+ Framework does not primarily rely on the introduction of additional, isolated courses. Instead, its central objective is the discipline-integrated embedding of ethical, societal, and sustainability-related reflection into existing engineering modules (*advancing*), complemented by selected interdisciplinary formats where appropriate (*complementing*).

The *Advancing* strategy focuses on further developing existing engineering courses to highlight the relevance of ethics and reflection in engineering and their connection to sustainability. Central to this approach is providing targeted support and training for engineering educators. It comprises three core measures:

- *Emphasize* refers to the enhancement of courses that already incorporate ethical, scientific, or technological reflection by making these aspects more visible and explicitly linking them to questions of sustainable development.
- *Empower* describes the process of equipping educators – particularly those teaching courses that have not yet addressed such dimensions – with the knowledge and tools needed to integrate ethical and reflective content into their disciplinary frameworks.
- *Embed* involves the inclusion of external expertise from the humanities, ethics, or social sciences. In this model, short teaching units (2-6 hours) are incorporated into engineering courses to address ethical and reflective questions directly within the course topic.

The *Complementary* strategy, *Complementing*, focuses on the development of new courses dedicated specifically to ethics, science reflection, and technology reflection. These courses are tailored to the thematic contexts of the respective engineering disciplines and are typically co-taught in interdisciplinary formats. Three types of courses are observed:

- *Enable* courses provide foundational knowledge in ethics and introduce basic reflection practices, typically by contextualizing engineering topics within broader societal and ethical frameworks.
- *Enrich* courses offer more in-depth engagement with ethical or reflective content and may lead to formal recognition through certificates, such as the Berlin Ethics Certificate or the Sustainability Certificate (Ammon et al. 2022).
- *Encounter* formats create interdisciplinary learning environments where instructors and students from engineering fields and the humanities or social sciences work together. These settings allow participants to experience

different disciplinary perspectives and underscore the value of cooperation across academic cultures.

While the ENG+ framework offers a coherent and modular approach to integrating ethics, sustainability and technology reflection into engineering curricula, it also exhibits characteristic strengths and weaknesses. A key strength lies in its hybrid design which combines the advancement of existing disciplinary modules with complementary, stand-alone learning opportunities. This aligns with empirical findings that ethics and societal issues are most effective when taught both in dedicated courses and embedded across the curriculum, rather than in isolated "add-on" formats (Martin et al. 2021, Martin et al. 2020).

At the same time, the approach is vulnerable to several bottlenecks. First, successful implementation relies heavily on motivated individual instructors who are willing and able to redesign their courses, a challenge widely documented in engineering ethics education where faculty often report lack of time, pedagogical training and institutional incentives. Second, the framework presupposes sufficient institutional resources for coordination, staff development and inter-faculty collaboration, which are not always available. Third, the complementary courses and certificates risk attracting primarily already interested students, thereby reproducing a "preaching to the converted" effect instead of reaching the full student body (Martin 2024, Telsang & Kulkarni 2014).

When contrasted with similar initiatives at other universities, ENG+ shares important features but also follows a distinct trajectory. Case-based and project-based ethics integration, as reported for instance in North American and European engineering programs, similarly emphasises contextualised ethical reasoning within technical design courses. However, the TU Berlin model places comparatively stronger emphasis on institutional anchoring through faculty-level governance structures and on linking ethics and sustainability to broader university-wide missions and certificates, thereby combining bottom-up experimentation with top-down curriculum regulation. This dual anchoring increases robustness but also makes the process slower and more exposed to shifts in institutional priorities (Ammon et al. 2023, Mott & Peuker 2024).

As the development of various modules at the faculty in recent times has affected almost all of these measures recently, providing a list of examples would be excessive at this point. Instead we will rather refer to the overarching development of the degree programmes using the Mechanical Engineering degree programme as an example. This section aims to demonstrate how socially relevant competencies are integrated into the programme structure. A detailed documentation of individual syllabuses, lesson plans or examination formats is beyond the scope of this contribution, which focuses specifically on curriculum architecture and institutional transformation processes.

The following concept was recently presented for the revision of the Bachelor of Mechanical Engineering programme, which ensures the integration of the topics of sustainability, ethics and social responsibility to the extent of 12 CP:

For this purpose, the existing module '*Introduction to Mechanical Engineering*', which is strongly practice-orientated, will be expanded by 3 CP to cover the basics of the topics mentioned, which can be built upon in the further course of the degree programme. This module is specifically intended for the start of the degree programme in order to use the students as multipliers for this content on the one hand and to avoid students dropping out at an early stage through the integration and relevance of socially relevant topics on the other.

Furthermore, a 6 CP compulsory elective area *sets* (sustainability, ethics, transfer, social issues) will be created, in which competences in the areas of sustainability, ethics, transfer and social issues will be taught.

The Projects module area, which is included in the Bachelor's degree with 6 CP, is now also intended to impart competences in the area of *sets*. In addition to the basic requirements, such as 1. practical complex planning engineering activities in mechanical engineering, e.g. product development or production planning, 2. teamwork (3 to a maximum of 6 team members), 3. development of a project plan, 4. project management, 5. development and documentation of solutions, 6. colloquium/presentation; the modules attended here must add the following additional requirements:

- System environment analysis to identify sustainability-relevant requirements
- Development of appropriate sustainable solutions
- Holistic, critical thinking
- Application of methods for evaluating sustainability
- Self-reflection

In order to ensure that students also learn to deal with AI in a reflective manner during their studies, the compulsory elective area of information technology has been divided into two areas, *programming* and *AI and data competence*. Modules are to be selected from both areas. The concept is currently being further developed by the degree programme working group, with the involvement of students.

It should be emphasized that the introduction of these 12 CP does not increase the overall credit volume of the degree program. Instead, these competencies are structurally redistributed within existing program requirements. The intention is not to add further workload, but to enhance relevance, motivation, and coherence of learning experiences through meaningful integration.

It is also worth mentioning that the *Gesellschaft von Freunden der TU Berlin e. V.* (Technische Universität Berlin n. d.) awards an annual prize for exemplary teaching. This prize recognises and promotes innovations and examples of good teaching practice at TU Berlin, as well as making them more visible both internally and externally. The award, which is endowed with 4,000 euros, is presented annually with a different focus. In 2024, the focus was on the integration of sustainability aspects into basic courses of the Bachelor's degree programmes. Among other things, the award recognised the lecture on drive technology in the field of mechanical engineering, which was continuously developed by the lecturer into the lecture '*Sustainable Drive Technology*' with the support of the students. Here, what was called for in the AllgStuPO above was achieved: integrating the cross-cutting topic of sustainability in such a way that the subject-related learning objectives are retained, but nevertheless systematic references to climate protection, energy saving and waste avoidance are established. The lively, open-ended discussions on the topics in the course led to an above-average evaluation of the lecture by the students.

This year, the prize will be awarded on the topic of AI in teaching. The aim is to honour courses that focus on a critical, reflective approach to AI. It will be interesting to see.

So far, promising concepts and formats have been developed, and many courses have been revised to include the teaching of transferable and transdisciplinary skills alongside technical skills. More will follow because, as mentioned earlier, our goal is to train engineers who are aware of their social responsibility and can act sustainably and reflectively, developing the skills they need to start their careers successfully. Some of our degree programmes are currently being revised to adapt to the evolving skill sets required of future engineers. Once these have been updated, the next curricula will be revised, as this ongoing goal requires courses and curricula to be constantly further developed and aligned with the current needs of the world of work and society.

Limitations and Transferability

The ENG+ framework is intentionally designed as a modular and competence-oriented model, which in principle allows for adaptation to different institutional contexts. Nevertheless, its transferability is subject to several limitations. At TU Berlin, ongoing budget constraints and hiring freezes have considerably slowed down implementation, as curriculum redesign, cross-faculty cooperation and new teaching formats all require time, staffing and organisational support. This illustrates a broader pattern in engineering education reforms, where ambitious visions for ethics and sustainability frequently encounter structural barriers such as limited resources, rigid regulations and competing priorities in faculties (Martin et al. 2021, Ammon et al. 2023, Telsang & Kulkarni 2014).

Moreover, the TU Berlin model is embedded in a specific regulatory and cultural environment, including a university-wide study regulation that mandates ethics and reflection components and a strong tradition of collaboration between engineering, humanities and social sciences. Institutions operating under different governance structures, accreditation regimes or disciplinary cultures may not be able to replicate this configuration one-to-one. Instead, they might selectively adopt elements of ENG+ - for example, the distinction between advancing and complementing strategies or the six integration measure – while developing their own organisational arrangements. Future research could therefore focus on comparative case studies that examine how similar frameworks evolve in contexts with different resource levels, incentive structures and national higher-education policies (Ammon et al. 2023).

Lessons Learned and Challenges

In the following section, we want to describe the main obstacles in the development of the curricula, as well as our measures to deal with them and give same recommendations based on our experiences with the development of curricula for socially responsible acting engineers.

These are the main obstacles we have encountered in recent years:

1. Not all technical subjects are suitable for integrating ethical or social reflection in a meaningful way (e.g. basic maths).
2. Conservative subject-specific understandings make it difficult to open up the curriculum to new topics; teachers who see the teaching of technology as the sole educational goal often underestimate the importance of reflection and responsible behaviour.
3. Teachers need time, support and further training in order to integrate ethical content in a high-quality manner.
4. A lack of incentive systems makes it difficult to motivate further development and existing performance measurement models hinder freedom for innovative teaching.

And here are our ways to deal with them:

Re 1: There is no need for integration in every module. Forced integration does not have the desired learning effect on students. On the other hand, the overall concept of the degree programme should ensure that knowledge of socially relevant topics and the necessary skills described are acquired during the course of the degree programme.

Re 2: Constant dripping wears away the stone. In recent years, we have never tired of describing the relevance of the content and skills described for the engineering degree programme, holding discussions and presenting best practices. The faculty's annual teaching retreat with expert input, workshops on transfer and discussion rounds, as well as the monthly Think Tank Technology Reflection, which took place at the beginning, served this purpose.

Re 3: Yes, it takes time. Fortunately, many of our faculty's lecturers are highly motivated and constantly developing their courses. To back this up, the university's own central organisation, Scientific Continuing Education and Cooperation (ZEWK) (Technische Universität Berlin n.d.), and the Berlin Centre for Further Education (BZHL) (Technische Universität Berlin n.d.), with which we liaise frequently, provide appropriate additional instruction for instructors.

Re 4: In the meantime, obstacles to the implementation of interdisciplinary teaching formats, such as crediting to the teaching load, have been removed. Consideration is currently being given to further incentivisation, for example through the faculty's own recording of student numbers for the distribution of resources. What is certain is that the prize for exemplary teaching has already created a certain incentive through the visibility achieved. The introduction of a similar award within the faculty could therefore also provide a clear incentive.

We would like to summarise a few recommendations based on our experience over the last few years of developing the degree programme towards the competence profile of a responsible engineer.

- A central mission statement for the entire university and the amendment to the General University Regulations (AllgStuPO) set a clear commitment to the relevance of socially relevant topics in all degree programmes and created binding rules for all university members. This creates a certain pressure to change and develop the degree programmes.

- At the beginning of a change process, it seems important to gain an overview of what already exists and to visualise best practices from which others can learn.
- On the other hand, it seems important to involve as many participants as possible and to enable low-threshold discussion spaces in order to gain acceptance from teachers and students and to develop new concepts together. In particular, this means identifying the needs of students and taking them seriously.
- Our annual faculty teaching retreats as well as the cross-status group and cross-faculty think tank described above served both purposes.
- Exchanges with other universities, such as at international conferences on engineering education or in smaller groups, or advice from experts, were also extremely useful for us to gain ideas for curriculum development. In addition to attending conferences on engineering education, we at the Faculty of Transport and Mechanical Systems took advantage of a year-long consultation process organised by the Hochschulforum Digitalisierung (n.d.) to further develop our degree programmes, as well as a low-threshold digital exchange with University College London as part of our Think Tank Technology Reflection, for example.
- And last but not least: do good and talk about it. The constant communication of development processes, including small steps, within and outside the faculty creates transparency and motivation for everyone by emphasising what has already been achieved.

We hope that these recommendations will inspire you to take the first steps and make it easier for you to further develop the study programmes at your university.

Conclusion

The challenges of the 21st century require engineers who are not only technically competent but also socially responsible, ethically reflective, and capable of acting within complex and dynamic systems. Engineering education must therefore evolve beyond a narrow focus on disciplinary knowledge. As this article has argued, fostering competencies in areas such as ethics, sustainability, digital literacy, diversity, and scientific integrity is not an optional add-on, but a core component of educating future engineers.

The ENG+ framework is intentionally designed as a modular and competence-oriented model, which in principle allows for adaptation to different institutional contexts. Nevertheless, its transferability is subject to several limitations. At TU Berlin, ongoing budget constraints and hiring freezes have considerably slowed down implementation, as curriculum redesign, cross-faculty cooperation and new teaching formats all require time, staffing and organisational support. This illustrates a broader pattern in engineering education reforms, where ambitious visions for ethics and sustainability frequently encounter structural barriers such as limited resources, rigid regulations and competing priorities in faculties.

Moreover, the TU Berlin model is embedded in a specific regulatory and cultural environment, including a university-wide study regulation that mandates ethics and reflection components and a strong tradition of collaboration between engineering, humanities and social sciences. Institutions operating under different governance structures, accreditation regimes or disciplinary cultures may not be able to replicate this configuration one-to-one. Instead, they might selectively adopt elements of ENG+ – for example, the distinction between advancing and complementing strategies or the six integration measures – while developing their own organisational arrangements. Future research could therefore focus on comparative case studies that examine how similar frameworks evolve in contexts with different resource levels, incentive structures and national higher-education policies.

Against this backdrop, the approaches discussed in this paper – ranging from curriculum development and interdisciplinary collaboration to structural reforms – illustrate that meaningful change is possible when academic institutions commit to cultural as well as pedagogical transformation. Even though resistance and structural barriers persist, the examples presented demonstrate that new forms of teaching and learning can be implemented in ways that are both context-sensitive and scalable. At the present stage, systematic evaluation data on learning outcomes or long-term impact are not yet available, as many of the curricular reform steps are still in early phases of implementation. Nevertheless, strong qualitative indicators for relevance and acceptance can already be observed, particularly through sustained student engagement in curriculum committees and in the Think Tank Technology Reflection. Students have repeatedly emphasized the importance of ethics, sustainability, and digital responsibility for their future professional roles, thereby actively reinforcing the reform agenda.

In light of these developments, it becomes evident that universities can no longer rely solely on static curricula. Instead, they must create learning environments that are flexible, inclusive, and globally oriented – supported by a shared commitment to continuous renewal and responsiveness to societal change. This requires shared responsibility, structural support, and institutional spaces for experimentation, dialogue, and reflection.

We invite all colleagues and institutions engaged in engineering education to share ideas, experiences, and practices–because shaping the engineers of tomorrow is a collective task that can only be successfully addressed together.

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