CESAER

WHITE PAPER

ENGINEER OF THE FUTURE

ENGINEERING EDUCATION AT UNIVERSITIES OF SCIENCE & TECHNOLOGY IN EUROPE TO TACKLE GLOBAL CHALLENGES

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Rooted in advanced engineering education and research, CESAER is an international association of leading specialised and comprehensive universities with a strong science and technology profile that advocate, learn from each other and inspire debates. Our Members champion excellence in higher education, training, research, and innovation, contribute to knowledge societies for a sustainable future and deliver significant scientific, economic, social, and societal impact.

To support its advocacy efforts, CESAER Members produce many publications such as white papers and positions, to be found on cesaer.org.

Executive summary

In this white paper, we reflect on the evolution of engineering education to examine how it equips engineers of the future to contribute to a world in constant evolution. The introduction lays out contextual drivers for the development of this white paper, explains the reasoning for the development of this paper and contextualises it as a follow-up to previous publications of our association.

In chapter 1, we explain what is meant by ‘Engineer of the future’ and lay out the new expectations for engineers in a volatile, uncertain, complex and ambiguous (VUCA) world. We argue that faced with the challenges of the twenty-first century, the engineers of tomorrow are expected to have a strong scientific and technological foundation, and will greatly benefit from a broader interdisciplinary perspective, soft skills, and an entrepreneurial spirit. Additionally, we argue that the internationalisation of studies, including all formats of mobility, which is being partly reshaped by the European Strategy for Universities, is a valuable avenue to acquire soft skills and intercultural sensibility.

In chapter 2, we underline the great impact that the green and digital transitions have on engineering education and the need for engineering students to grasp the key opportunities emerging with the twin transitions. We recommend that the next generation of engineers be educated to take a holistic approach in their profession, in which the United Nations Sustainable Development Goals (UN SDGs) play a central role, and to develop and deploy innovative and disruptive sustainable solutions and products. We emphasise the importance of monitoring and evaluating the outcomes of sustainability initiatives in engineering education programmes and underline the need to support students’ initiatives. We note that engineering education in many countries today largely lacks a focus on shaping cultural perspectives and norms, and on tackling the broader societal engagement aspects of future engineers and argue that debates, community engagement and external experiences are good practices to address that. We consider that, to achieve key developments of the green transition to a circular economy, educators have to recognise the need for an interdisciplinary approach to ensure the ethical and equitable treatment of all involved in the production and sourcing of materials, the focus on extended product life or the reintegration of post-consumption products in manufacturing. Finally, we expose ongoing trends in the development of artificial intelligence (AI), and argue that AI should meaningfully be integrated into learning practices.

In chapter 3, we stress the importance of interdisciplinarity, within institutions, through inter-faculty collaboration, and innovative teaching approaches such as problem-based learning (PBL) and challenge-based learning (CBL). We consider that engineering education should also allow students to collaborate beyond their institutions, with third actors such as public administrations, non-governmental organisations (NGOs) and businesses. We underline that cross-faculty collaborations, novel approaches to problem-solving such as PBL and CBL, and frequent contact with a diversity of stakeholders are many ways to foster these skills among students. In that sense, we recommend that engineers should both be trained to collaborate in a narrow sense among fellow professionals, but equally crucial is the opportunity to collaborate across disciplines.

In chapter 4, we cover the importance of fostering a lifelong learning mindset as a core aspect of a future-oriented education and present some good practices in the development of lifelong learning activities. Furthermore, we argue that upskilling and reskilling of employees represent for companies an improvement in competitiveness in the market and talent management, and will allow engineers to continuously address fast-paced developing technologies and global challenges.

In chapter 5, we lay out how recommendations for a curriculum that ensures a broader perspective of the students, and that includes different methods of learning and teaching. We underline that the engineering curriculum should allow for student-centred education, engaging with a range of actors and having international opportunities, and aiming at contributing to finding solutions to societal challenges. We describe the so-called T-shaped model, which ensures a flexible balance between fundamental, generalist courses and courses specialised in emerging specific skills. We explain how engineering education can deal with innovation and complexity to foster critical thinking. Finally, we argue that the ability of students to analyse content critically, more than just to assimilate and synthesise, should be a defining aspect of engineering education.

Throughout the white paper, we share examples already implemented by CESAER Members, which can be used as inspiration and demonstrate that what is theorised and described in this paper is also suitable for practical implementation. Finally, we conclude by giving an overview of the recommendations of each chapter.

The overall intention of the paper is not to be a comprehensive and exhaustive ‘final word’, but to be a valuable contribution to a vibrant ongoing discussion around the developments shaping the future of engineering education that equips the engineers of the future with the right tools and competencies to fully contribute to tackling local and global challenges.

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Introduction

Societies change due to many factors and are confronted with emerging and complex challenges, including economic disparities, climate disruptions, the impact of current and new technologies, great shifts in the geopolitical landscape and global pandemics. These challenges require coordinated efforts of governments, industries, civil society, and of course universities. As cutting-edge science and technologies have transformative powers that can shape the course of societies, universities of science & technology have a special role to play. As key generators of scientific knowledge, technology and talent at their core, universities are crucial in providing solutions through research, education, and innovation.

Twentieth century solutions need to be updated to fit the twenty-first century. A transformation into a global knowledge society[1] based on a collaborative effort, individual creativity and personal development seems to be the key to success in facing a volatile, uncertain, complex and ambiguous (VUCA)[2] world in an ever more competitive global landscape. We should thus think of flexible student-tailored curricula, new teaching methodologies, modes of delivery and other approaches that keep up with the rate of technological and environmental changes and the needs of individual learners.

One of the factors impacting engineering, science and technology is the digital transformation, driven by fast-paced innovations, building on the growing fields of, among others, data analytics and artificial intelligence. Therefore, professionals will benefit from an engineering education providing them with knowledge and skills to deal with these transformations and innovations properly and responsibly. Universities have a role to play to prepare students for a society, and labour market, increasingly shaped by emerging disruptive technologies. Yet, not all institutions keep up with these rapid technological and environmental changes and their societal and economic consequences.

Given this context and from the perspective of CESAER's Task Force Learning and Teaching, we decided to elaborate a white paper on the 'Engineer of the Future' to present viewpoints and recommendations related to advanced engineering education in Europe. Since its foundation in 1990, our association has been closely monitoring and working on this topic. We notably follow up on the 2019 discussion paper ‘Science & Technology education for 21st century Europe’[3], developed by Aldert Kamp in collaboration with CESAER’s Task Force S&T Education for the 21st century. This updated white paper ‘Engineer of the Future’, while it also tackles the themes of digitalisation and interdisciplinarity developed in ‘Science & Technology education for 21st century Europe’, emphasises and develops the aspects of the green and digital transitions, lifelong learning, and the internationalisation of studies. These are topics increasingly brought forward by the developments in the European research and higher-education landscape.

Indeed, developments to achieve the European Education Area (EEA) and the European Research Area (ERA) have significantly launched a transformative journey increasingly connecting national research and higher education activities. Based on Article 179 of the Treaty on the Functioning of the European Union (TFEU) stating that "the Union shall have the objective of strengthening its scientific and technological bases by achieving a European

[1] https://www.igi-global.com/dictionary/knowledge-based-urban-development/16456
[2] Think Tank Arts et Métiers, Quels ingénieurs pour l’industrie du futur? December 2020
[3] https://www.cesaer.org/content/5-operations/2019/20191218-discussion-paper-st-education.pdf

research area in which researchers, scientific knowledge and technology circulate freely", the ERA strives to make Europe a competitive space for research and innovation activities, through favourable framework conditions and sustainable funding. With regards to higher education, article 165(1) of the TFEU states that “the Union shall contribute to the development of quality education by encouraging cooperation between Member States and, if necessary, by supporting and supplementing their action” per the subsidiarity principle. The EEA, elaborated through a package of measures in 2018 and 2019, is the EU's key initiative to foster cooperation and harmonization in the field of education within the member states of the European Union and seeks to foster mobility, inclusivity, and mutual recognition of qualifications in the context of the green and digital transitions. Flagship initiatives, such as the European Strategy for Universities are currently shaping major features of the European higher education landscape, by facilitating mobility, encouraging interdisciplinarity and exploring new digital opportunities. Given the importance of these latest developments, we decided to highlight in this latest white paper the progress in engineering education linked to, among others, these latest developments in internationalisation, sustainability, and lifelong learning.

We do not aim to propose the ‘one and only’ approach to a future engineering education, which does not exist as such. Although we do not seek to be restrictive in defining the ‘future’ and what is considered a ‘future-oriented approach’, we have the ‘near’ future in mind roughly defined as the next decade. Since even the nearest future may not be a smooth extrapolation of the recent past, it is impossible to propose a predictive time frame for future developments and challenges, and as impossible to suggest an ultimate solution for future-proof engineering education. Additionally, as different institutions are at different levels of implementation of future-oriented approaches, what is considered new in one university may have been implemented years ago in another one. Even after the harmonisation efforts initiated by the Bologna Process and the development of the EEA the landscape of higher education within the EU remains diverse and complex. Diversity in the local situations is, and should be, reflected in the educational offer. Differences in engineering programmes and trends are visible across borders and at national and even institutional levels.

As this paper covers a selection of approaches and ideas of CESAER Members regarding the current situation of engineering education, its ongoing developments and future trends, this document is not intended to be exhaustive nor to present a complete coverage of the subject matter and is Europe-centred, with a global perspective as a reference. The text covers engineering education at both the bachelor’s and master’s levels, encompassing the first two cycles of the Bologna process. The target audience of this paper is broad, starting from high-level management and leadership of universities of science & technology and engineering faculties, deans, and vice-deans for education, to all stakeholders involved in engineering education willing to understand ongoing changes, and to contribute to shaping future developments.

Chapter 1: Shaping engineers to face the challenges of tomorrow

1.1 New expectations for engineers facing a changing, complex, and uncertain world

Climate change, pandemics, shifts in the geopolitical order and new technologies are all driving forces reshaping the world, requesting from engineers an ability to navigate in an environment characterised by uncertainty and complexity. This environment is often referred to as the VUCA world, where this acronym stands for volatile, uncertain, complex and ambiguous. In light of this, engineers should not only be educated to use existing solutions but should also be equipped to seek novel solutions and approaches within an uncertain context, where critical thinking is a fundamental attitude, along with other cognitive approaches such as creative thinking, ethical thinking, and systems thinking[4]. As research-based education remains crucial, the evolution of education mirrors the evolution of research. The interconnection of knowledge creation and education is essential, where students not only gain from but also experience research and the research environment.

To be able to find new solutions to existing and emerging challenges, and to adapt their know-how to the needs of society, we need to educate responsible engineers with a strong research-based science and technology (S&T) background who are aware of the global challenges and are able to:

- understand a complex world;
- work in international and interdisciplinary environments;
- find and adapt relevant, innovative, ethical, sustainable, responsive, and responsible S&T solutions;
- perform cutting-edge research and innovation in a university or company setting;
- design, implement, evaluate, and improve tools, products, and engineering processes;
- manage, in the long run, either big companies or small and medium enterprises (SMEs), public administrations and research institutes in an ecological and digital transition phase.

In the early stages of the education of engineers, there is a general consensus that mathematics is crucial, being the foundation of problem-solving, of both computational and experimental modelling of systems and components, as well as of data processing in all applied sciences and engineering disciplines. However, a strong scientific and technological background is only one pillar of engineering education. To be able to design relevant solutions, engineers need to have a basic knowledge of a broader range of disciplines beyond ‘hard’ sciences, such as social sciences and humanities (SSH), management, law, and other disciplines.

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[4] Crawley, E. F., Hosoi, Anette ‘Peko’ and Mitra, Amitava ‘Babi’. (2018). Redesigning undergraduate engineering education at MIT–the New Engineering Education Transformation (NEET) initiative. In 2018 ASEE Annual Conference & Exposition. In *125th ASEE Annual Conference & Exposition*, Salt Lake City, UT, https://peer.asee.org/30923

Moreover, engineers also benefit from soft skills, allowing them to work with and in companies, as well as with governments, local authorities, NGOs, and citizens' initiatives. Examples of soft skills are communication capacities, teamwork ability, conflict management, open-mindedness, stress management, critical thinking, adaptability, agility, leadership, and emotional intelligence.

Team projects (monodisciplinary or interdisciplinary) and internships can introduce the acquisition of soft skills in the curriculum and allow students to transform them into professional and sustainable skills, i.e. skills they are aware of, and they can then reuse in their professional activities. This combination of knowledge, know-how and soft skills and the modernity of pedagogical methods that increase the 'learning by doing' part of the curriculum transform soft skills into professional skills and increase the employability of the students. Problem-based learning and the CDIO initiative[5] (conceive – design – implement – operate) also fit within this objective (see chapter 3).

Societal challenges and most modern technologies together with engineering systems are integrative and require collaboration and integration across a wide range of domains. Departments are based on historical developments and are not equipped to span all the knowledge required by today's challenges and systems, and neither is it possible to fit such knowledge into a five-year[6] programme. Moreover, the challenges and systems often evolve on timescales that are much faster than the timescales over which departments evolve, making it difficult for departments to offer programs that span the breadth demanded by today's systems and challenges. This calls for flexible, interdisciplinary educational programs that are focused on specific United Nations Sustainable Development Goals (UNSDGs), e.g., climate action (SDG13), and those become the seed for developing student communities focused on UNSDGs. These programmes do not need to be majors or minors offered by departments[7].

Therefore, to achieve all these goals in engineering education, engineering curricula have to be reshaped, to offer pedagogical activities beyond academic classes and practical exercises in the classroom (see chapter 5).

1.2 The transformation of teaching

The renewal of engineering education, however, will not happen by itself. Quite a lot is expected from the engineers of the future. As a consequence, even more is requested from their mentors. Thus, as we discuss ideas for future-ready engineering education, we cannot forget nor underestimate the pivotal role of academic staff and their readiness to rethink, redesign, innovate, and deliver high-quality engineering programmes tailored to the emerging challenges of today and tomorrow, including the characteristics of new student generations that will enter universities this decade.

Teachers, in that sense, have to be at least one step ahead of their students. It is not only about adjusting the curricula but also about pedagogical approaches, tools, and

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[5] http://www.cdio.org/
[6] Or 4-year program depending on the country.
[7] Lavi, R., & Salek, M. M., & Mitra, A., & Shepardson, R., & Lavallee, J., & Long, G., & Melenbrink, N. (2022). Revising the requirements of a cross-departmental project-centric undergraduate engineering program and launching a new sustainability and climate-themed track. In *129th* ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/41549

technologies. The rapid development of S&T, including the birth of new engineering disciplines and topics, enforces constant content updates. Digital natives, and future students of generation alpha (born after 2010), may expect a drastic change in the learning experience provided mainly by academics who grew up in earlier, largely pre-digital generations, who perhaps do not all yet have all the means of collaborative and active learning fully internalised. Nearly real-time adjustment of pedagogical methods and modes of delivery that stimulate the motivation of students and means of proper assessment of learning outcomes, such as those guaranteed by the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG)[8], induced by the AI era, remains challenging.

Will the teachers manage to follow content, tools, and pedagogical innovations happening faster than before while keeping their eyes on the quality of research and education? For that to happen, they need the means to improve their skills and build new competencies, plus a well-designed motivation system respecting the diversity of academic career pathways, including those focused on didactics.

Due to many challenges faced by the academic staff and universities, strengthening the role and position of academic teachers in the EHEA has rightfully become one of the priorities of the European Commission. The ongoing and future initiatives aiming at enhancing the quality of student experience via empowering and rewarding teaching achievements, such as a global Advancing Teaching[9] project, should have a positive impact on the attractiveness of the university teaching profession. Within this project, the Career Framework for University Teaching[10], designed to evaluate, reward, and support the careers of the teaching staff, considering all other often neglected contributions – such as service to the institution, was proposed. The framework was funded and commissioned by the British Royal Academy of Engineering and developed in partnership with pedagogical experts on the recent feedback collected from higher education institutions from across the globe.

Getting ready for the alpha generation of students via building new teaching competencies and innovating on the educational offer is one of the main focus points of some European University alliances. Examples include ENHANCE[11] and EuroTeQ[12] consortia which have a focus on engineering education. Sharing best practices and knowledge through international hubs and manifold innovative teaching and learning labs in Europe and the world, along with the outburst of open-access guides on innovative and engaging teaching, like The Big Book of Online Education[13] created by and for teachers from universities of S&T in Europe, is a visible trend.

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[8] https://www.ehea.info/page-standards-and-guidelines-for-quality-assurance
[9] https://www.advancingteaching.com/
[10] https://www.teachingframework.com/about/
[11] Sánchez-Ruiz, L.-M., and Llobregat-Gómez, N. (2023). Engaging into Alliances to Match the 2030 Science, Society and Students Needs. *Leadership in Education and Innovation in Engineering in the Framework of Global Transformations: Integration and Alliances for Integral Development*. LACCEI
[12] EuroTeQ Learning Lab, EuroTeQ Engineering University, https://euroteq.eurotech-universities.eu/initiatives/learning-labs/
[13] The Big Book of Online Education is an ebook published as a part of E-TECH, or Comprehensive Project for Distance Teaching Skills and Multimedia Resources for Technical Universities in Europe (2020-1-PL01-KA226-HE-096375), a project funded by the Erasmus+ Strategic Partnership programme. https://www.etechproject.com/the-big-book-of-online-education/

1.3 Internationalisation of engineering studies

In the context of globalisation, it is becoming increasingly important that engineers are educated to look beyond borders and be able to cooperate with international partners in large and diverse teams. It is therefore crucial that engineers gain a picture of the world during their education, are exposed to other points of views and learn to work under varying circumstances.

To achieve this goal, universities need to be engaged in a wide variety of national and cross-border partnerships. This enables students to have access to a wider range of international specialists and innovative research facilities, and to get to tackle issues in a different geopolitical, cultural, historical, and economic context.

Therefore, intercultural skills are a useful and necessary asset for students in science and engineering and the universities are in charge of developing these skills through a sufficient offer of internationalisation initiatives (e.g., internationalisation@home, promoting exchange programmes, summer schools, stimulating the influx of international students and internships abroad). Indeed, an academic institution must ensure that all its students, regardless of whether or not they go on an exchange abroad, acquire a certain set of international and intercultural competencies throughout their studies. The success of the Bologna process and commitments to achieve the EEA are fostering significant progress and mobility opportunities. European University Alliances, transnational Alliances of higher-education institutions developing together innovative offers of mobility and joint degrees[14], can serve as a framework for innovation in internationalisation and mobility.

Students working on projects together with engineering students from other countries is a relevant pedagogical activity to let them familiarise themselves with different professional cultures and develop their intercultural skills with foreign students. The ATHENS programme (see focus example chapter 1) is an example of an international programme developing intercultural skills.

[14] https://education.ec.europa.eu/education-levels/higher-education/european-universities-initiative

Focus example chapter 1: The ATHENS Programme: interdisciplinarity in short-term mobility
Twice a year - in March and November - the ATHENS network gathers about 2000 students from around Europe. They choose a course from a course catalogue and go then to the partner university delivering the course (around 30 hours / week + 2 ECTS). The course is an open door to other disciplines. It means that the student can choose a course in its specialty (e.g. civil engineering, telecommunication, chemistry) or a course in a totally different discipline (e.g. philosophy and ethics, fashion, interior and industrial design, tech diplomacy, music, science and history) to acquire new knowledge that could be useful or other skills (e.g. management of technology, quality engineering). Some of the courses are focused on topics related to sustainability (e.g. urban mining, climate change, biodepollution, water management). Students from the 15 European partner universities work together during one week in each course. Students are experiencing intercultural work, and they discover another country and another culture. Most of the courses are delivered in English. Social and cultural activities are also part of the programme and are compulsory. In Paris, for instance, students have the opportunity to visit museums, to have a guided tour of the city and to participate in activities organised by local students so that they can also meet them outside of the courses. http://athensnetwork.eu/

1.4 Recommendations

We conclude this chapter ‘Shaping engineers to face the challenges of tomorrow’ with the following recommendations to universities:

- recognise the growing expectations towards Engineers of the Future, including understanding an increasingly complex world, working in international and interdisciplinary environments, and designing responsible and sustainable S&T solutions;
- take a holistic view of the skills and competencies expected of the Engineers of the Future, including a strong scientific and technological background, basic knowledge of a broad range of disciplines beyond “hard” sciences and a range of soft skills;
- revalorise the work of the academic staff, providing means to improve their skills and build new competencies, and fostering a well-designed motivation system respecting the diversity of academic career pathways, including those focused on didactics;
- foster a wide variety of national and cross-border institutional partnerships, including but not limited to European networks such as CESAER, as well as European University Alliances;
- ensure that all students acquire a certain set of international and intercultural competencies throughout their studies by developing a sufficient offer of internationalisation initiatives.

Chapter 2: Transitioning to a sustainable world

2.1 The twin transitions

The green transition aims to achieve sustainability, and to combat climate change and environmental degradation. At the same time, the growing significance of digital technologies is transforming societies and economies. In the digital transition, the European Union aims to harness digital technologies for sustainability and prosperity, and to empower citizens and business. Successfully managing the green and digital 'twin' transitions is the cornerstone for delivering a sustainable, fair, and competitive future. There is no time to waste, and the twin transitions must be achieved together. To unlock their potential and to prevent negative effects, the green and digital transitions require a proactive and integrated management.

Towards a green & digital future, European Commission, Joint Research Centre, Muench et al., 2022

Beyond the conventional activities of universities of science & technology to equip their students with the right knowledge, skills, and competencies to contribute to society – including by increasing their employability – universities of science & technology now also actively contribute to the ongoing twin transitions, while navigating the challenges and opportunities caused by them.

2.2 Green transition

The importance of sustainability, both in how we organise higher education and what higher education teaches, is by now well established. Higher education institutions have, in recent years, invested significantly in making their operations more sustainable — such as encouraging the use of rail instead of air travel or moving towards more plant-based catering — with clear and measurable impact (see for example Ghent University's sustainability report[15]). Recently, the need to reduce carbon emissions and address rising energy costs has once again provided a strong reminder that universities themselves are not immune to global ecological challenges. Alongside such operational initiatives, sustainability has over the last decade been adopted across educational programmes at universities. Resources, programming and auditing tools that support transitioning to a sustainable campus are now widely available, such as the ones offered by the Association for the Advancement of Sustainability in Higher Education[16]. Efforts are often recognised through, for example, the International Green Gown Awards[17].

Engineers are important players in bringing about a sustainable and green techno-realistic[18] society, in which we endorse that technology has the potential to play a transformative and positive role in moving us towards a sustainable planet. While higher education has recognised the need to be a leading actor in the drive towards sustainability, the integration of a sustainable development agenda into teaching has been fragmented and uneven, and the impact of sustainability education is particularly hard to quantify. Still, engineering, in

[15] https://www.ugent.be/en/ghentuniv/mission/sustainability/sustainabilityreport2020.pdf
[16] https://www.aashe.org/
[17] https://www.greengownawards.org/international-green-gown-awards
[18] Techno-realism is a nuanced perspective on technology, countering discussions of technology as either purely positive (cyber-utopianism) or negative (neo-Luddism). https://cyber.harvard.edu/technorealism.html

collaboration with other disciplines, will play a crucial role in understanding and solving the complex problems and grand challenges faced on the way to a sustainable world. To this end, next generation engineers should be educated to take a holistic approach in their profession, in which the UNSDGs play a central role, in developing and deploying innovative and disruptive sustainable solutions and products.

2.2.1 Sustainability in engineering education

The objectives of the UNSDGs can be considered at all levels in universities, from the central mission of institutions to the education of students and staff. In their governance and strategy, universities should take a leading role in implementing the UNSDGs, and should do so in close interaction with academics, administrative and technical staff, as well as students. Since the 1990s there has been a broader move towards integrating sustainability in education, and in engineering education in particular. For instance, the formulation of the UNSDGs now allows courses to be aligned with one or more of the UNSDGs[19], with different courses or programmes together addressing UNSDGs and thereby taking an integrative and interdisciplinary approach.

Teaching and learning are expected to have a significant impact on achieving UNSDGs through introducing students to the basics of sustainable development (e.g. The Climate Fresk[20]) and moving towards a deeper understanding and implementation of UNSDGs in real-world projects and innovation. Activities proposed in engineering curricula — courses, practical sessions, research and challenged-based projects, and internships — should address the UNSDGs themes and issues relevant to the subject matter, with the aim to not only offer the skills to work towards a sustainable practice, but to install a sustainable development mindset in engineering students. The competencies (and learning outcomes) of engineering students should be evaluated against UNSDGs and can be made part of student certification. Education should allow for the involvement of stakeholders (e.g., companies, industries, government agencies) in conferences, projects, and internship proposals. These competencies in UNSDGs may also be acquired during extracurricular activities, for example in activities led by student associations or grassroot initiatives (community-based approaches created to address localised problems). A support and recognition system can be provided by higher education institutions to value the student’s commitment to UNSDGs.

As noted in the review of sustainability in engineering education by Gutierrez-Bucheli et al.[21] there, however, remains a significant gap between the expectations set for engineering education and its outcomes. They write “*Engineering education struggles to foster the associated intra- and inter-cultural learning characteristics expected within integrated sustainability education*.” Across each institution, there are dozens of initiatives to incorporate sustainability themes in engineering education, but evaluating the efficacy of these initiatives

[19] Lavi, R., & Salek, M. M., & Mitra, A., & Shepardson, R., & Lavallee, J., & Long, G., & Melenbrink, N. (2022). Revising the requirements of a cross-departmental project-centric undergraduate engineering program and launching a new sustainability and climate-themed track. In *129th* ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/41549
[20] https://climatefresk.org/
[21] Gutierrez-Bucheli, L., Kidman, G., & Reid, A. (2022). Sustainability in engineering education: A review of learning outcomes. *Journal of Cleaner Production*, 330, 129734.

remains difficult[22]. One way is to rely on professional and accreditation bodies. Various professional bodies have been advocating a global sustainability agenda for HEIs. From the World Federation of Engineering organisations (WFEO), and the Institute of Electrical and Electronics Engineers (IEEE) to national organisations, all recognise the contribution made by engineering education to sustainability and have set out broad plans to align engineering education with the UNSDGs. In some regions, such efforts are now recognised by an accreditation body, such as the French *Développement Durable et Responsabilité Sociétale* (DD&RS) label[23] or the UK's Green Gown label, awarded to higher education institutions when working towards achieving UNSDGs.

While the details of implementing sustainable engineering education differ between regions and institutions, all recognise the need for interdisciplinarity and acknowledge the need to transcend the technical perspective on engineering and connect with societal and environmental aspects of the engineering profession[24]. While early approaches (before 2010) to integrate sustainability in engineering education focused typically on ecology, most institutions now rely on an interdisciplinary and broad approach where conventional aspects from sustainability – environment, social, economic, and technical perspectives – are integral to teaching and learning, such as in the Transition Institute 1.5 at *l'École des Mines Paris - PSL* (see focus example chapter 2). Students are exposed to the integrative nature of sustainability through problem-based learning experiences, which draw upon interdisciplinary skills. Other approaches rely on internships, hackathons, or challenges brought by industry.

There are, however, more opportunities that can be grasped. One relates to the fact that current engineering education often focuses on technical literacy relevant to sustainability but does not necessarily engage with the opportunity to explicitly shape the cultural perspectives, in addition to the norms and values of future engineers[25]. It also does not include cognitive approaches for tackling complex challenges, e.g., critical thinking, creative thinking, systems thinking and ethical thinking, to name a few[26]. Engineers of the future will need an appreciation of societal engagement, of aesthetics and emotion on which the engineering profession impacts, and of ethics. While conventional problem-based learning can provide some ways to explore these themes, approaches more explicitly leveraging debates, reflections, and discussions are needed, and, for this, opportunities and spaces need to be created in which students can feel confident to engage with sustainability in its broadest

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[22] Thürer, M., Tomašević, I., Stevenson, M., Qu, T., & Huisingh, D. (2018). A systematic review of the literature on integrating sustainability into engineering curricula. *Journal of Cleaner Production*, 181, 608-617.

[23] https://www.label-ddrs.org/

[24] Bohmert, D., Cisneros Pérez, G., Dormeier, C., Drogoul, L., Foot, T., Garrido, A., Goudie, A., Madeira, A. C., Nygard, M., & Östling, M. (2023). Leading by example: Boosting sustainability through good governance adopted by universities of science & technology. https://doi.org/10.5281/zenodo.8382415

[25] Bohmert, D., Cisneros Pérez, G., Dormeier, C., Drogoul, L., Foot, T., Garrido, A., Goudie, A., Madeira, A. C., Nygard, M., & Östling, M. (2023). Leading by example: Boosting sustainability through good governance adopted by universities of science & technology. https://doi.org/10.5281/zenodo.8382415

[26] Lavi, R., Bathe, M., Hosoi, A., Mitra, A., & Crawley, E. (2021). The NEET Ways of Thinking: Implementing Them at MIT and Assessing Their Efficacy. *Advances in Engineering Education*, *Special Issue on Worldwide Leading Innovative Engineering Education Programs*. https://advances.asee.org/wp-content/uploads/vol09/Issue3/Papers/AEE-Innovative-Lavi-3.pdf

possible sense[27]. Extracurricular activities, community engagement, interdisciplinary learning spaces, and external learning experiences have been shown to work well in this respect.

Another opportunity that remains to be fully explored relates to the discrepancy between expected learning outcomes and actual learning outcomes that can sometimes be observed[28]. Many higher education institutions do not fully assess the sustainability outcomes of their teaching and learning, and, as a result, sustainability is often implemented in teaching and learning without a solid evidence base to inform adjustments needed. Programme designers, lecturers and administrators need to define metrics and instruments to continuously monitor the effectiveness of sustainability initiatives and should not be afraid to take action if the desired learning outcomes are not realised.

2.2.2 Student-driven initiatives

An essential element of having a sustainable society is the need to 'reduce and reuse' and move towards a sustainable cradle-to-grave or even cradle-to-cradle economy, where waste is eliminated or where waste products feed into other production processes or energy regeneration. Engineers, as key designers, and implementers of this future are an integral part of this effort. This requires students to take a holistic and systemic view of manufacturing. Many universities have integrated this already in their educational offer on economic, social, and ethical aspects of engineering. Sustainable development in education typically focuses on reducing the impact of sourcing (raw) materials, production, and manufacturing, and on reducing waste and downstream products of manufacturing and consumption. However, new opportunities in education present themselves, such as the recent focus on the ethical and equitable treatment of all involved in the production and sourcing of materials, the focus on extended product life (design for repair and separability of components), or the reintegration of post-consumption products in manufacturing. Increasingly, educators recognise the need for interdisciplinarity in achieving this: engineers, designers, economists, environmental scientists, bioengineers, and psychologists. Each has a contribution towards achieving a sustainable and circular economy. Most courses, next to conventional lecturing, now engage the students in problem-based learning, in which a case study is developed with students from different disciplines. The key here is that students understand that sustainability is often a set of interlocking complex problems which rarely have a single correct answer and that solving multicriteria problems requires collaboration between disciplines[29].

It is important to realise that the focus on sustainability in education is, to a large extent, student-driven. Through their increased awareness of broad themes in sustainable development, such as climate change, pollution or the pressure on biodiversity, students demand changes. First and foremost, they demand the institutions at which they study to set

[27] Paten, C. J., Palousis, N., Hargroves, K., & Smith, M. (2005). Engineering sustainable solutions program: Critical literacies for engineers portfolio. International Journal of Sustainability in Higher Education.

[28] Gutierrez-Bucheli, L., Kidman, G., & Reid, A. (2022). Sustainability in engineering education: A review of learning outcomes. *Journal of Cleaner Production*, 330, 129734.

[29] Sanchez-Romaguera, V., Dobson, H. E., Tomkinson, C. B., & Bland Tomkinson, C. (2016, September). Educating engineers for the Circular Economy. In *Proceedings of the 9th International Conference in Engineering Education for Sustainable Development*, Bruges, Belgium (pp. 4-7).

a positive example, from small initiatives, such as a wider availability of vegetarian catering, to ambitious long-term goals, such as the demand to reduce greenhouse gas emissions and to be carbon-neutral by 2030. This sustainability mindset is something university graduates carry forward when they take up professional roles across society and industry. Just as the increased awareness and cultural shift around diversity is predominantly led by graduates, the sustainability agenda is likely to become further established through initiatives from university graduates. Already during their education, students tend to show a preference for companies that have a clear sustainability profile. Hence it is not unreasonable to expect our current students to lead the vanguard in sustainability in their professional careers (see focus example chapter 2).

Focus example chapter 2:

The Transition Institute 1.5 (TTI.5°) at *Mines Paris - PSL*

The Transition Institute 1.5 is an initiative launched by *Mines Paris - PSL* with the support of its foundation. Specifically set up to contribute to the societal low-carbon transition, the ambition of the institute is to provide scientific advice to guide developments towards carbon by adopting a systemic, holistic approach to develop the levers of this transition towards carbon neutrality. The work is organised along four axes:

1. the transition design to identify the mechanisms and processes that contribute to triggering and implementing strong, rapid decarbonisation;
2. an electric planet to investigate the pertinence of a vision regularly presented as a desirable, even unavoidable, direction for the transition, i.e. the deployment of electricity;
3. an inclusive planet to look at the governance issues of this transition towards low-carbon societies and the inclusiveness of this governance, which also remains bound by certain physical constraints, so that all scales and all stakeholders in society are included while ensuring coherence between them;
4. the planet as an area of influence: equity issues, competition and geostrategy.

Research: This calls for interdisciplinary research that interacts with all stakeholders of society, simultaneously integrating social, political, economic, and technical constraints, via different temporal and spatial perspectives. TTI.5's work relies on the diverse disciplinary fields covered by Mines Paris – PSL research centres and, beyond that, from national and international partnerships.

Education: TT1.5-accredited specialised courses at master's level (min. 16 ECTS) and an internship or a research project (15 ECTS) as well as two contributions to the TTI 1.5 community (e.g. a summary note, a video or podcast, contribution to the TTI 1.5 blog, a presentation, writing the seminars' minutes etc.).

https://the-transition-institute.minesparis.psl.eu/en/

Focus example chapter 2: Student-led sustainability initiatives at Ghent University, Faculty of Engineering and Architecture
In 2018 the Faculty Council of Engineering Students at Ghent University started a student-led sustainability initiative. In this, the engineering students shape the path towards a more sustainable university and provide advice to the university on how education can integrate sustainability into the curriculum. The corollary of a student-led sustainability initiative is that the students have ownership of any changes to the curriculum or educational practice. A "by the students for the students" approach is likely to be more favoured than a centrally imposed course programme. This dovetails with the recent Green Office Movement, which aims to establish an office at universities that informs, connects, and supports students and staff to act on sustainability. While the aim of the Green Office Movement is to steer the university and the wider community towards sustainable and greener practice, it also nurtures a culture across European universities with a demonstrable trickle-down effect to institutional practice and education. https://greencommunity.be/

2.3 Digital transition

Engineering will play a crucial role in realising a techno-realist approach to sustainability and will shape the societal digital transition. Indeed, scientists and engineers are at the forefront of developing aspects such as data mining, data analysis, data security, the Internet of Things, modelling, simulation, visualisation in augmented and virtual reality, optimisation, and artificial intelligence. These aspects are also essential components of Industry 4.0., the rapid change to technology, industries, and societal patterns and processes driven by increasing interconnectivity and smart automation, resulting in real-time decision making, enhanced productivity, flexibility, and agility.

2.3.1 AI in engineering

Without a doubt, Artificial Intelligence (AI) will have a defining place in engineering. AI and related techniques are already firmly embedded in optimisation, search, and planning processes. For example, to optimise the design of engineered systems, such as aerospace components, building structures, or electronic circuits. AI is also widely used to support supply chain management, through predicting demand, identifying bottlenecks, and finding the most efficient routes for transportation.

However, in the last decade, AI has witnessed a sea change in performance and scope. AI can now offer meaningful contributions in engineering domains that previously were the exclusive realm of educated engineers. This is driven by several revolutions in the field: the availability of large amounts of data on which to train machine learning, the unprecedented availability of computing power through the use of networked on-chip parallel processing, interconnected systems through which AI solutions can be made available on the internet, and the use of novel machine learning algorithms.

Several categories can be distinguished, each with their specific use in engineering. Deep neural networks, for example, find applications in data interpretation and prediction and have shown exceptional performance in visual tasks, such as interpreting medical images or predictive maintenance. Generative AI, in which the AI produces data starting from a ’prompt’, has shown to be useful in generating natural language, audio and images, and can, for example, be used to assist architects in creating and enhancing computer-aided (CAD) designs and visualisations. Finally, reinforcement learning, in which the AI is taught to take actions based on data, has proven invaluable in energy management and smart grids, optimising the control of energy storage systems and energy consumers to balance supply and demand efficiently.

While these changes take place at an unprecedented pace, it is key to remind ourselves that, at the time of writing, these newer AI systems have only been around for a few years and that the engineering profession will witness more revolutions in the next decades.

These will shape the profession and education in ways that are difficult to predict. Still, a number of trends are clear. AI will be more accessible than ever before. Not only will it be almost imperceptibly integrated into the tools used by engineers, but it will also be easy to access AI through online services, reducing the need for in-house computational infrastructure and expertise. Another trend which is likely to continue is the bringing together of different separate AI systems into a single multipurpose system that can handle different kinds of data. These “multimodal” AI systems could, for example, allow an engineer to take a photo of a malfunctioning drive shaft, after which the fault is identified through an AI-aided procedure including suggestions for appropriate action and parts that need to be ordered to solve the problem.

2.3.2 AI in education

Engineers of the future will not only be AI users, but they will also be at the forefront of shaping AI. Students in computer science and related disciplines will need training on the technical intricacies of AI. Curricula and programmes across universities already have recognised the importance of AI and have responded by offering more AI subjects and specialities at earlier stages. However, as AI will affect all science and engineering disciplines, we will need to train students to use and understand AI in the broadest possible sense. Beyond the technology of AI, it also comes with its own ethical, sustainability and economic impact which students across all engineering disciplines need to be aware of. Already, this need is addressed at some universities by offering faculty-wide or even university-wide courses on AI. These courses offer just enough technical details to have an informed understanding of AI and complement this by discussing the societal and economic implications of AI.

In terms of education, AI will have a strong impact on teaching and learning. It should not be seen as a threat to conventional methods of research and learning, but instead as an opportunity to improve teaching and learning. Tools aiding teaching practice are already available. For instance, PowerPoint adds illustrations to slides to support visual communication, Wooclap[30] uses AI to generate questions and multiple-choice tests from learning material. Students rely on AI for their research and communication. Large Language

[30] https://www.wooclap.com/

Models[31] help students ideate and phrase their thoughts, Copilot[32] supports students during programming. Students will inevitably lose some skills due to AI, similar to the broader reduction in manual calculation skills observed following the introduction of the pocket calculator. A conversation is needed on which skills are important enough that we should ensure they remain part of the curricula, also following the further integration of AI, and where the teaching of that skill can instead be supplemented with other skills.

It should be noted that rapid technological and societal evolutions also bring with them challenges and threats. There are legitimate concerns about privacy, surveillance, data ownership and sourcing, shifts in resources and wealth, and the lack of policies, regulations, or legal frameworks to address these challenges[33]. Engineers of the future should, next to being trained in the technologies of the future, also be made aware of the challenges posed by these new evolutions and develop critical thinking towards the information delivered by AI. Finally, actions aimed to enhance digital skills must also address data literacy and put more focus on fostering transversal skills that complement increasingly advanced and 'intelligent' machines and algorithms.

2.3.3 Digital education in a sustainable society

The digital transition in education, spurred by the COVID-19 pandemic[34], has the potential to significantly contribute to a more sustainable society. One of the main ways it can do so is by reducing the carbon footprint of education. With digital learning, students and teachers have the possibility to participate remotely in hybrid classes, which can lead to a significant reduction in greenhouse gas emissions. Additionally, online textbooks and other learning materials can eliminate the need for printing, reducing paper waste and deforestation, though how substantial their contribution is to reducing carbon emissions is being discussed[35]. 'Digital twins', in digital learning and digital teaching, also allow for learning in context without the need for some physical (and perhaps expensive) resources.

Digital learning can increase access to education, which is another pillar of building a sustainable society. With digital learning, students in remote and/or underserved areas can more easily access high-quality education and training programs. This can help to reduce inequality and increase the number of people who have the knowledge and skills necessary to address pressing sustainability challenges. Key technologies such as virtual reality (VR), and augmented reality (AR) and their software applications also have the potential to

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[31] https://www.nvidia.com/en-us/glossary/data-science/large-language-models/
[32] https://github.com/features/copilot
[33] CESAER, & Royal Academy of Engineering. (2022). Key Technologies Shaping the Future. https://doi.org/10.5281/zenodo.5865414
[34] Mitra, A., Kassis, T., Lai, Y., Lavallee, J.A., Long, G.L., Nasto, A., Salek, M., Lavi, R., and Shepardson, R. (2021). Pivot to Remote Teaching of an Undergraduate Interdisciplinary Project-Based Program: Spring–Fall 2020. In *128th ASEE Annual Conference & Exposition* (virtual). https://peer.asee.org/pivot-to-remote-teaching-of-an-undergraduate-interdisciplinary-project-based-program-spring-fall-2020
[35] Gattiker, T. F., Lowe, S. E., & Terpend, R. (2012). Online texts and conventional texts: Estimating, comparing, and reducing the greenhouse gas footprint of two tools of the trade. *Decision Sciences Journal of Innovative Education*, 10(4), 589-613.

enhance S&T education and training experiences beyond the level normally possible in educational institutions[36].

To fully seize the opportunities and address the challenges of digitalisation in education and training, we recognise a need to pursue action along three lines[37]: (i) focus on quality and learning outcomes; (ii) incentivise universities to integrate key technologies in education and training; and (iii) adopt a long-term and future-oriented approach to digital education and training. Furthermore, flexible options and solutions allowed by digital technologies are encouraged. The need for a balance between online and in-person experiences is crucial, as in-person learning remains important for both the personal and academic experience. This is especially true for engineering education, for which the learning path includes a diversity of in-person and lab experiences.

[36] CESAER, & Royal Academy of Engineering. (2022). Key Technologies Shaping the Future. https://doi.org/10.5281/zenodo.5865414

[37] https://www.cesaer.org/content/5-operations/2020/20201125-position-on-digital-education-action-plan.pdf

2.4 Recommendations

We conclude this chapter ‘Transitioning to a sustainable world’ by suggesting the following recommendations to universities:

- train the next generation of engineers with a holistic approach encompassing the central role of UNSDGs in their profession, to empower them to develop and implement innovative and disruptive sustainable solutions and products;
- evaluate competencies and learning outcomes of engineering students against UNSDGs and include a support and recognition system that values such developments;
- broader technical literacy relevant to sustainability to also explicitly include aspects related to shaping cultural perspectives, norms and values of future engineers through debates, reflections, and discussions;
- train students to use and understand AI in the broadest possible sense, including its ethical, sustainability and economic impact, and its challenges, including by developing critical thinking towards the information delivered by AI;
- equip teachers with resources and guidelines to responsibly seize opportunities offered by AI to improve teaching and learning.

Chapter 3: Interdisciplinarity

3.1 Current state of engineering educational collaboration

For engineers of the future, collaboration as a continuous process is a natural precondition for solving problems, as a complex society calls for a variety of disciplinary attributes and knowledge for the elaboration of solutions. Herein, engineering education and their respective institutions are vital in providing educational structures, facilitating practices, and creating experiences for engineering students to become competent in approaching new collaborations in their professional lives. The calls for engineers of tomorrow to become sufficiently able to understand other perspectives, as promoted as part of the 21st-century skills agenda defined by the OECD[38], is having an impact on curricula designs. This includes as a part of the transformation into 'T-shaped' professionals: i.e. a combination of disciplinary specialisation (e.g. in chemistry, computer science, life sciences) and of cross-disciplinary competencies (e.g. analysis, evaluation, intellectual property, marketing, modelling, etc.) that can be used in different domains[39] (see chapter 5).

The field of engineering education research (EER) concurrently involves prospects towards preparing future engineering graduate students with competencies for dealing with the complexities, in which both social and technical skills complement each other, and the ability to cooperate and collaborate across professional backgrounds. Initially, before describing contemporary conceptualisations concerning proposed practices for engineering education institutions, it is, as Muller[40] describes, crucial to emphasise that engineering as a professional practice should be 'Janus-faced', that is, orientated towards both core-technical competencies (such as mathematics and natural sciences) and contextual practice-based knowledge as well. These can be characterized by external knowledge structures found in e.g., anthropology, sociology, or history, and are found increasingly applied in teaching in engineering-related contexts[41]. Engineers of the future should, therefore, be familiar with both their own disciplinary outset while having awareness of different disciplinary practices and how these can be incorporated into designs of technical and social solutions for the society. However, EER is still conceptualised as a largely emerging and novel field of research that draws upon general educational research[42]. Froyd et al.[43] confirm the potential risk of engineering education as a practice becoming siloed if the field progresses inwardly,

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[38] https://www.oecd.org/site/educeri21st/40756908.pdf
[39] On T-shape skills, for instance: Marialuisa Saviano, Francesco Polese, Francesco Caputo, Leonard Walletzky, A T-shaped model for rethinking higher education programs, Conference: 19th Toulon-Verona International Conference "Excellence in Services, September 2016
[40] Muller, J. (2012). Forms of knowledge and curriculum coherence. In *Educating for the Knowledge Economy?* (pp. 114-138). Routledge.
[41] Klassen, M., & Case, J. M. (2022). Productive tensions? Analyzing the arguments made about the field of engineering education research. Journal of Engineering Education, 111(1), 214–231. https://doi.org/10.1002/jee.20440
[42] Lohmann, J. R., & Froyd, F. (2010). Chronological and ontological development of engineering education as a field of scientific inquiry. Paper presented at the Second Meeting of the Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research, Washington, DC
[43] Froyd, J. E., Wankat, P. C., & Smith, K. A. (2012). Five major shifts in 100 years of engineering education. Proceedings of the IEEE, 100(Special Centennial Issue), 1344-1360.

resulting in either a lack of technical-contextual knowledge with stronger external knowledge or vice versa.

Interdisciplinarity as a conceptual idea is no novelty in educational research – the question is rather how it can best be achieved in practice. Van den Beemt et al.[44], in their review of interdisciplinarity in engineering education (IEE), found that terminologies of interdisciplinary teachings, desired outcomes, or paradigms used in EER are manifold. As an example, 'T-shaped' competencies and soft skills are correlated but exist independently when describing what engineering students will achieve through interdisciplinary teachings. Findings also entail visionary perceptions of IEE to involve skills for solving real-world complex problems, entrepreneurial competencies, social awareness, and improving interdisciplinary programs. This is not a trivial matter of course, as challenges exist throughout European engineering education institutions pertaining to facilitating the visions as mentioned earlier. Institutional barriers and structures seemingly combined with rigid curricular designs challenge interdisciplinarity in practice, and often it is avoided by students when presented, due to a myriad of processes that require stricter dedication[45]. European engineering study programs and courses are also rarely designed to incorporate the collaborative dimension of engaging with others. Reasons pertain to deprioritise engagement between study programs, lack of communication and logistics, and challenges in designing either multi- or interdisciplinarity in practice[46]. However, there are opportunities to overcome described issues in finding common ground[47]. For the sake of future engineering students, universities should be adequately prepared to incorporate and experiment with initiatives that involve thorough assessments of processes, designs, and programs, as these elements have been neglected. Additionally, universities should be equipped to collect and draw upon longitudinal data for future adjustments (graduate students reporting on course and programme content and teachings after they enter occupation).

As seen in contemporary initiatives supported by the European Commission such as the European Universities initiative, engineering institutions are requested to be entwined in collaborative efforts across and within faculties – both nationally and internationally. Examples of such efforts are seen in the establishment of STEM and SSH common research and teaching groups, where engineers interact and collaborate with academic staff from social sciences and humanities. This can be more easily achieved in comprehensive universities, where, e.g., students in civil engineering/architecture can easily interact with students and teachers from faculties of fine arts and history, or students in management engineering can do the same with students and teachers from faculties of economics and

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[44] Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., Van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. *Journal of engineering education, 109(3)*, 508-555.

[45] Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., Van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. *Journal of engineering education*, 109(3), 508-555.

[46] Christiansen, S. H., Juebei, C., & Xiangyun, D. (2023). Cross-institutional collaboration in engineering education–a systematic review study. European Journal of Engineering Education, 48(6), 1102-1129.

[47] Kimball, E., Rose, T., Ruiz, Y., & Wells, R. (2018). Common ground and upward bound: Lessons from a cross-institutional collaboration. *Reflections on connecting research and practice in college access and success programs.* Washington, DC: Pell Institute.

statistics. It would then be desirable that such basic, minimal interactions were triggered also in purely science and technological universities, in order to prepare interactions on a larger scale.

3.1.1 Examples of didactic approaches for students' collaborative and disciplinary training: problem-based learning and challenge-based learning

Problem-based learning (PBL) and challenge-based learning (CBL) are found in engineering education applied in contexts of collaborative processes. PBL is implemented for engineering students across engineering education institutions to bridge technical expertise with meta-cognitive competencies and problem-orientation skills. It involves a student-centred learning approach which can entail a focus on developing cognitive strategies, generic skills, collaborative- and domain knowledge through projects (or case studies), experiential- and group-based learning, and a curriculum re-structuring with courses being aligned and connected with student projects. A challenging task would be to try to develop such possibilities for basic undergraduate courses, such as calculus, geometry, or chemistry. Examples of outcomes produced in PBL-learning environments are the possibility to transfer disciplinary differences through the identification of common complex problems, and the development and training of students' cognitive and non-cognitive knowledge and skills. PBL has also been included in the paradigm of mission-driven innovation in engineering education across Europe, enabling solutions to be designed through overarching goals and missions pertaining to the UNSDGs. However, for PBL to endure in education, it is recommended for the institutions to collaborate, and develop educational programs, or partnerships with external companies applying a PBL-inspired direction to recognise that a systemic implementation into the curriculum will bring forth endurance and support over time – both for teachers, students, and industry. A rather unique example of the joining of disciplinary differences in a STEM-SSH initiative can be found at Aalborg University and its IAS-PBL creation (see focus example chapter 3).

Focus example chapter 3: Institute of Advanced Study on Problem-Based Learning at Aalborg University
The Institute of Advanced Study on Problem-Based Learning serves a myriad of functions spanning across educational design and inter- and extracurricular activities concerning problem-based learning. The structural conditions of the university provide a foundation from which PBL is the centre. Since the university has integrated PBL across all faculties, students from both engineering, social sciences, and the humanities are influenced throughout all their studies by PBL. This provides a common approach for both engineers and social- and humanistic scientists across the university's multiple curricula. IAS-PBL is described as a hub for research, knowledge sharing, competence development, collaboration, and experiments with PBL. IAS-PBL further involves an internal organisation concerning digital transformation and digitally assisted learning tools, which supports teachers in innovative ways of delivering PBL-related teaching and it also entails a cross-campus element by involving staff from each campus. **https://www.iaspbl.aau.dk/**

Challenge-based learning (CBL)[48] is another engaging multidisciplinary approach to teaching and learning that encourages students to leverage the knowledge and technology they use in their daily lives to solve real-world problems. Similarly to PBL, CBL is collaborative and hands-on, asking students to work with peers, teachers, and experts in their communities and around the world to ask questions, develop a deeper subject area knowledge, accept and solve challenges, take action, and share their experiences. The challenges are real-world problems that are introduced by an external stakeholder, which require an interdisciplinary approach. Students work in interdisciplinary groups that focus on teamwork and continuous reflection. The evaluation is authentic and evidence-based and takes place both at the individual and group levels. The deliverables may vary among the groups and innovation and creativity are important aspects of the evaluation. Again, a key task would be to develop such an approach for undergraduate courses as well.

The Challenge Learning Framework emerged from the "Apple Classrooms of Tomorrow—Today" (ACOT2) project initiated to identify the essential design principles of the 21st-century learning environment. We present here an adapted framework, developed at the University of Twente, available at https://www.utwente.nl/en/cbl/what-is-cbl/

These conceptual frameworks for engineering students to apply in a course- and project work can potentially lead to innovative student solutions, as seen in the 4TU collaboration among Dutch technical and engineering universities[49]. While there can be differences in designing and assessing student collaboration, whether multi- or interdisciplinary, the continuous knowledge-sharing among current and coming students is deemed crucial to overcome the obstacle of drawing upon prior research resulting from student projects.

3.2 Collaboration across sectors and institutions - mission-driven innovation and industry partnerships

The complex challenges that students face after graduation increasingly require a multidisciplinary approach during their studies. A university should therefore strengthen interaction between students as part of their study programme, both within their own field of

[48] https://www.challengebasedlearning.org/framework/
[49] https://www.4tu.nl/cee/innovation/

study and beyond the borders of their field. As part of their education, engineering students should become acquainted with other profiles than solely that of an engineer. Although problem-based learning often requires teamwork, often all team members have the same technical engineering background and are therefore not representative of the teams in which they will work during the whole of their future careers. In addition, the objectives of problem-based courses are often relatively rigid and offer little possibility of failure. Study programs should therefore further explore the possibility of organising cross-disciplinary events such as hackathons, bootcamps, and project weeks as part of the curriculum, where an idea or concept is developed into, for example, a mini business case in which students work in teams with peers from other programs on potential solutions for socially relevant issues.

The arguments for establishing partnerships and collaboration with external institutions, companies, and governments are plentiful and examples can be found across numerous countries. The promotion of beneficial outcomes for all stakeholders of collaborative initiatives between universities and the public and private sector has been advocated for by the European Union, and concrete efforts are funded through e.g. Interreg Europe or the European Education Area. Universities, and herein engineering education institutions, are also explicitly depicted as vital stakeholders in the framework of mission-driven innovation. Following seminal work by Marianna Mazzucato[50], mission-driven innovation was conceptualised around the grand challenges of society (pertaining to the UNSDGs – e.g., climate, equal education, poverty) which are broken down into missions (broad descriptions that are directed towards a challenge) and mission projects (sub-parts needed to accommodate a mission) steering research and innovation solutions. While mission-oriented research & innovation has both positive and negative sides as implemented at the EU level, adopting a mission-driven approach in engineering education can help emphasise the importance of collaborating across sectors, disciplines, and nations. Governing the missions in a higher education setting requires universities to expand their routines to involve a practical arrangement of industrial partners[51], regional and national interests, and the faculties and departments.

By developing a portfolio of projects (at a student level), experimentation on solutions to the overarching missions and challenges set forth is thought to create both successes and failures – however, this is part of the mission-driven conceptualisation. Engineers, as previously mentioned, should be able to accommodate solutions for the complexities in society in collaboration with others. Therefore, by applying mission-driven projects, students can bridge their disciplinary expertise with others through collaborative processes. It further serves as an opportunity for industry partners and students to draw parallels to one or more of the UNSDGs.

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[50] Mazzucato, M. (2018). Mission-oriented innovation policies: challenges and opportunities. *Industrial and corporate change*, 27(5), 803-815.

[51] Crawley, E. F., Hosoi, A. E., Long, G., Kassis, T., Dickson, W., Mitra, A. (2019). Moving Forward with the New Engineering Education Transformation (NEET) program at MIT-Building community, developing projects, and connecting with industry. In *126th ASEE Annual Conference & Exposition*, Tampa, FL, https://peer.asee.org/33124, June 2019

3.3 Recommendations

We conclude this chapter 'Interdisciplinarity' by suggesting the following recommendations to universities:

- make use of contemporary initiatives supported by the European Commission such as the European Universities initiative to foster common interdisciplinary learning & teaching groups;
- develop an evidence-based assessment of processes, designs, and programs of innovative pedagogical experiments;
- explore the development of innovative pedagogies such as problem-based learning and challenge-based learning, also at the undergraduate level;
- foster cross-disciplinary interaction between students as part of their study programme through a variety of cross-disciplinary events tackling socially relevant issues, for example through mission-driven projects.

Chapter 4: Lifelong learning

4.1 The importance of lifelong learning

Lifelong learning has become a universal challenge in an era driven by market and technology dynamics. A literature review shows the following examples and initiatives worldwide:

- the Alice Springs (Mparntwe) Declaration in Australia[52], with one of the major goals being the transformation of all young Australians into successful lifelong learners;
- the Council resolution on a new European agenda for adult learning 2021-2030[53];
- China's intention to transform its educational system to collaboratively reduce the gap between the provided training and the needs of industry in the context of digital transformation and the leverage of new technologies[54];
- the Lifelong Learning Accounts (LiLAs)[55] in the United States (US), a way for employers and employees to co-finance education and training.

Science and technology jobs are subject to changes along the career path. These changes are not uniquely affected by the advent of new technologies but also by the roles and positions that will appear during the career, which will require the acquisition of new abilities and skills.

Lifelong learning must be understood as the continuous and long-term learning process required by a professional to stay tuned to the technologies and roles that will be needed throughout the professional path. Although the risk and period of becoming outdated during the professional career depends on the discipline, there is a need to further develop the concept of perpetual or forever learners. Education leaders at universities should nurture students on the willingness of having the attitude to continuously refresh their knowledge.

We can consider an initial premise for the need for lifelong learning from the following quotation, attributed to Richard Riley, former US Secretary of Education: "*We are currently preparing students for jobs that don't yet exist … using technologies that haven't been invented … in order to solve problems we don't even know are problems yet*."

When speaking about lifelong learning as a way to respond to technological, economic, and societal changes, two concepts can be highlighted: upskilling and reskilling. The former is linked to learning new skills and personal competencies to optimally adapt to one's current position, while reskilling emphasises the new capacity required for a new job and is mainly driven by technological changes.

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52 https://www.trb.nt.gov.au/news/2020/alice-springs-mparntwe-education-declaration

53 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021G1214(01)

54 Dans. E. (2021). How China Is Transforming Its Economy Through Lifelong Learning, Forbes, Jan. 26, 2021. Available: https://www.forbes.com/sites/enriquedans/2021/01/26/how-china-is-transforming-its-economy-through-lifelonglearning/?sh=7267d1b45030

55 The Lifelong Learning Accounts Act (LiLAs) (2009). Available: https://alec.org/model-policy/the-lifelong-learning-accounts-act/

In this context, lifelong learning must not be conceived as to be adopted only by experienced professionals but also to junior profiles. On the one hand, engineers in a first job will see a lifelong learning strategy in their company as a benefit. On the other hand, upskilling and reskilling of employees represent an improvement in competitiveness in the market and talent management, while supported by professionals with consolidated experience in the organisation.

Lifelong learning education is one of the pillars of education systems. As expressed by the fourth UNSDG, quality education and lifelong learning for all ensures a full productive life to all individuals and fosters the achievement of sustainable development. Lifelong learning is a matter of offering people equal chances to participate fully in society and to get high quality jobs. This is especially important for engineering and technical positions, where new jobs are being defined continuously, making reskilling and upskilling through lifelong learning vital to promote equal opportunities for all.

The European Network for Accreditation of Engineering Education (ENAEE)[56] uses Programme Outcomes (POs) to describe the knowledge, understanding, skills and abilities which a graduate must be able to demonstrate. Based on the achievement of these outcomes, an accredited engineering degree programme is awarded a EUR-ACE® label. ENAEE reserves one of these POs to lifelong learning and specifies that the learning process should enable master's graduates to demonstrate the ability to engage in independent lifelong learning and the ability to undertake further study autonomously as essential outcomes of master's programs.

However, in a broader context, although job market dynamics, increasing digitalisation, skills gaps, ageing and migration will be driving forces for the provision of lifelong learning in engineering programs, considerations such as citizenship, migration, or sustainability will play a major role in the upcoming lifelong learning strategies.

4.2 The link between lifelong learning and active learning

Lifelong learning should not be understood only as continuing education without any connection to previous university studies. Acquisition of lifelong learning competencies must be an inherent component of engineering study programmes[57]. To leverage this change, Hadgraft[58] establishes a need to shift the mindset of lecturers and students to integrate the development of lifelong learning competencies.

The appropriate development of lifelong learning competencies in study programmes must combine the use of discipline and context-specific learning experiences and the explicit teaching of the lifelong learning competencies.

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[56] https://www.enaee.eu/

[57] Van den Broeck, L., Craps, S., Beagon, U., Naukkarinen, J., Langie, G. (2022). Lifelong learning as an explicit part of engineering programmes: what can we do as educators? In SEFI 50th Annual conference of The European Society for Engineering Education. "Towards a new future in engineering education, new scenarios that European Alliances of tech universities open up". Barcelona: Universitat Politècnica de Catalunya, 2022, p. 774-781. DOI 10.5821/conference-9788412322262.1327.

[58] Hadgraft, R. G., & Kolmos, A. (2020). Emerging learning environments in engineering education. *Australasian Journal of Engineering Education*, 25(1), 3-16.

Active learning strategies described in section 3, i.e. project and challenge-based learning, are needed to foster the acquisition of lifelong learning competencies. In addition, self-regulated learning, understood as the ability to control one's learning environment, has proven to be an effective tool for lifelong learning as it fosters strategies to help students to be in charge of their own learning by allocating their time and resources and adapting strategies to achieve learning outcomes with effort and persistence[59].

4.3 Good practices in the design of lifelong learning activities

To be able to accommodate the requests by companies in developing students' generic competencies, in addition to their professional skills, requires academic practitioners to reflect on their teaching consciously and continuously – e.g., are there new knowledge fields, teaching methods, or technological inventions that should be understood and delivered in a teaching context to support students' learning processes? Drawing upon interdisciplinary collaborative skills, this also demands practitioners to potentially design and practice the learning content in collaboration, to ensure both a connectedness and relatedness that can be transferred and transformed in practice. Lifelong learning is a concept that differs from traditional linear knowledge acquisition, as graduate students are instead found dependent on their ability to seek additional information or practice new concepts and methods after their employment (up- or reskilling). In higher education institutions, this calls for an awareness, willingness, and effort to design curriculum models that incorporate these notions.

The European agenda on transforming engineering education and preparing engineering graduate students requires not only well-designed curriculum models but also the training of educators and researchers alike to be competent in delivering e.g., problem-based learning and teaching and supporting students' project work. Research on how these organisations have had an impact on the facilitation of collaborative processes across disciplines points, amongst other elements, at the critical awareness of the abilities of staff to accommodate and structure courses that assess collaborative skills in graduate students.

4.4 Micro-credentials

Micro-credentials represent a way to flexibly organise lifelong learning in small bites with a set of well-defined learning outcomes and thereby attract more diverse groups of learners, including students from non-conventional backgrounds seeking to change or update their skills portfolio and actively engage with new technologies. These outcomes should be complementary to existing degrees and committed to responding to technological and societal changes. Offering such short forms of learning would, therefore, be a way to respond to the needs of society and part of the societal mission of a university.

In its recommendation on a 'European approach to micro-credentials for lifelong learning and employability'[60], the Council of the European Union recommended defining an EU standard on micro-credentials, aligning national and European qualifications, and using ECTS as a

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[59] Shuy, T. Self-regulated learning. Teaching Excellence in Adult Literacy (TEAL) Center, U.S. Department of Education, Office of Vocational and Adult Education (OVAE), 2010.

[60] https://www.consilium.europa.eu/en/press/press-releases/2022/06/16/council-recommends-european-approach-to-micro-credentials/

measure of learning outcomes and workload as well as to support the accumulation of micro-credentials, and to reinforce a scalable recognition system for employment and purposes underpinned by digital platforms.

The definition of micro-credentials in science and technology should be designed considering at least the following aspects: focus on interdisciplinarity or specialisation, contents aligned with in-demand skills and competencies and flexible combination of on-site, online, and blended methodologies to make micro-credentials compatible with professional activities.

Most of the lifelong learning activities provided by universities have a duration of less than three months with online and blended approaches even if other models are available (e.g. advanced master programs of at least twelve months in France). Students with diverse profiles and backgrounds join the activities, but professionals do not represent the largest population of students. Evaluation of the activities is carried out using various methods (exams, individual or group-based projects, questionnaires).

The expected adoption of a common well-structured concept of micro-credentials, like the one recommended by the Council of the European Union – the European approach to micro-credentials – should make international collaboration regarding short-term offers much easier and more attractive. From the perspective of collaborating universities and students, clearly defined international standards and definitions of learning outcomes, course contents, mode of delivery, and expected workload of students will facilitate the recognition process.

Focus example chapter 4: Examples of lifelong learning activities from ENHANCE[61] and EELISA[62]
In ENHANCE, micro-credentials are an essential part of the Alliance education offer. ENHANCE micro-credentials are flexible and attractive, and lifelong learners from outside the alliance can take part in the Massive Online Open Courses (MOOCs). ENHANCE micro-credentials are continuously under development in cooperation with industrial partners, local governments, and non-profit organisations. The catalogue offers micro-credentials on data literacy, digital transformation, climate actions, sustainable entrepreneurship, higher education teaching, and the MOOC responsible innovators of tomorrow. The EELISA credential can be described as a micro-credential that recognises the engagement and impact linked to UNSDGs. It recognises the student's ability to grasp and impact societal challenges through mission-driven activities proposed by EELISA partners. These activities are innovative and transformative learning experiences for the participants, primarily the students. Each activity focuses on one to two UNSDGs, and students receive a badge with a level of impact spending on the learning outcomes (discovery, knowledge, commitment, action, and transformation) and activities offered include hackathons, collaborative workshops, and contests.

61 https://enhanceuniversity.eu/
62 https://eelisa.eu/

4.5 Recommendations

We conclude the chapter ‘Lifelong learning’ by suggesting the following recommendations to universities:

- incorporate active learning methodologies in engineering study programs to enable the acquisition of lifelong learning competencies;
- raise awareness among lecturers and students on the importance of acquiring a lifelong learning mindset in the context of engineering disciplines;
- design and shape lifelong learning activities as a natural step forward in the engineering educational long-term pathway;
- foster the accreditation of vocational, non-formal and informal learning and the recognition of the skills acquired;
- promote international collaboration in the higher education ecosystem (including universities, employers, accreditation agencies and governments) to design flexible lifelong learning pathways to widen opportunities for early career stage engineers and later career stage engineers, considering their needs over their career cycle.

Chapter 5: A future-oriented engineering curriculum

5.1 General framework

The engineer of the future is expected to take up a variety of roles. In addition to acquiring an in-depth technical basis, which remains the core of every engineering programme, the engineer-entrepreneur should be able to take on a broader role within the business world and society. They must, therefore, know the broader financial and economic context. They must be versed in business management and stakeholder involvement and have the skills to engage a team, motivate people and achieve results. A T-shaped engineer realises that they are part of a larger network and that an intensive multidisciplinary collaboration is the only way to success. The engineer-innovator must learn to deal with successes and setbacks (in particular through learning lessons from unsuccessful collaborations, projects, innovations, products, etc.). They have learned how to deal with sudden shocks (e.g. COVID-19 pandemic, war on the European continent, and energy crisis) and show resilience and flexibility in the face of uncertainty. Furthermore, the engineer-visionary looks beyond current problems and dares to set the mark, for example by asking what is desirable within five years rather than what needs to be solved now. In doing so the engineer-visionary contributes to a more positive image of the engineer and engineering education.

5.2 A broad perspective of the curriculum

The world is changing, and the rise of interdisciplinary and collaborative approaches in solving global challenges is attracting a broader and more diverse set of students who see engineering as a powerful force in these efforts. As a community, engineering educators recognise that transforming educational experiences is crucial both to meet global needs and to increase access for all capable future engineers[63]. The next generation curriculum for engineers will have to ensure a broader perspective being significantly transformed from a traditional one oriented to various engineering fields (e.g. mechanical, chemical, and electrical) to a more open one focussing on next generation engineering skills. These may be viewed as a chain starting from analysis in engineering science and problem solving to engineering design and ability to realise products as well as to the ability to manage complex interconnected systems and working in teams with strong interpersonal relationships and ending with the ability to advocate and influence the market, entrepreneurship, management performance and education and mentoring. All these ambitions implemented through the next generation engineering curriculum will allow students to build links between the world of learning and the world beyond in addition to innovating constantly in a world of permanent changes. Students will learn to integrate knowledge in more systemic ways, experience world problems holistically, and make new connections possible between separate fields.

In several reports, new concepts for the engineer of the future have been proposed. Two examples are given in annex A and annex B.

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[63] Bates, R., Mitra, A. and Townsend, J., Guest Editors, Advances in Engineering Education (AEE) (2021). *Special Issue on Worldwide Leading Innovative Engineering Education Programs*, Spring 2021, Vol 9, Issue 3, https://advances.asee.org/overview-special-issue-on-worldwide-leading-innovative-engineering-education-programs/

5.2.1 Student centred education

A reshaped education should be student-centred, aiming towards a skill-based approach in which the students are active participants in designing their pathway of study and research projects. This makes the students actors in their education and allows them to shape their own learning trajectory by offering them a broad range of courses outside their major discipline (Edwards, 2011). It means, among other things, that in addition to their broad (and necessary) basic education, students have sufficient windows of opportunity to tailor their curriculum based on their individual competencies and interests.

5.2.2 Comprehensive engagement

Comprehensive engagement is crucial to foster the consciousness and understanding of diversity and inclusiveness. The curriculum should be embedded in an inclusive and diverse environment that involves external actors, particularly civil society representatives (public authorities, local authorities, NGOs) and companies.

Aiming for an inclusive environment should be implemented in the governance of higher education institutions, where representatives of companies are members of the board of governors which oversees continuous improvement of the curricula. Additionally, an inclusive education environment could imply boosting internships, meetings with companies for presenting the jobs within the company, discussions with alumni working in the company, entrepreneurship tracks or modules, apprenticeships allowing students to spend part of their time in a company and the other part at school, S&T projects put forward by companies and specific specialty courses. Altogether, building these environments allows future engineering students to be closer to the needs of society, to environmental challenges and to the economy at large.

As part of their education, engineering students should become acquainted with other profiles than solely that of engineers. Although many universities are currently developing different learning formats focused on stakeholder engagement and inter- and transdisciplinary learning, there is still a lot to be done. As cross-disciplinary learning events such as hackathons and project weeks, become embedded in the curriculum, students also need to learn how to deal with complex situations, uncertainty, and different knowledge systems. Universities, on the other hand, need to adapt their organisational structures to accommodate the engagement with external communities or industrial partners, make cross-faculty collaborations beneficial in terms of funding and academic rewards (career development). Flexibility of the curriculum structure might be another issue that needs to be addressed to reap the benefits of collaborations on socially relevant issues within the curriculum structure.

Specific entrepreneurship tracks are also possible within the engineering curriculum, for example in place of a final year project (master 2 level). Consequently, engineering students can make the results available for society, for those results to be exploited as soon as possible.

5.2.3 The T-shaped professional

Today, many engineering curricula are built vertically, with courses primarily related to the specific disciplines of the diploma. Transversal intersections with other areas are rarely included in a comprehensive way, thus narrowing the enrichment of the education of the students and limiting the acquisition of transversal competencies.

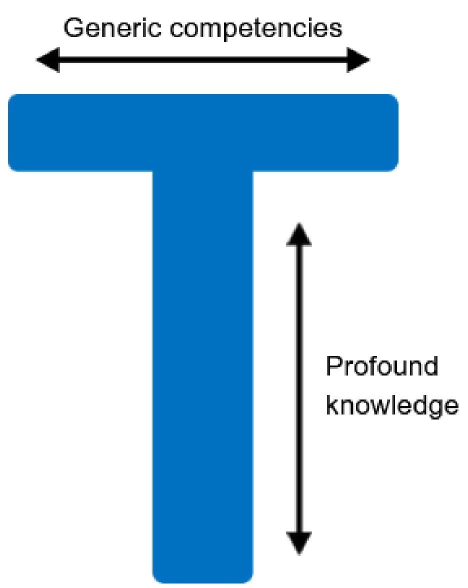
Looking ahead, a more flexible balance between fundamental, generalist courses and courses specialised in emerging specific skills must be ensured. Among fundamental disciplines, a solid fundamental focus on 'theoretical teaching' of sciences like mathematics and physics should be intertwined with a stronger emphasis on emerging data-driven disciplines like AI. The specialty disciplines should have a high percentage of elective courses as well as a high number of training hours, adapted to technologies of the future. The exact balance between the fundamental and specialty courses is discipline-related.

The model of the T-shaped professional focuses on whether a study programme offers a well-thought balance between acquiring 'profound knowledge' encompassing discipline-specific knowledge, interdisciplinary knowledge, contextual or situational knowledge and skills, on the one hand, and increasingly important 'generic competencies' on the other. The latter consists of three clusters.

The first cluster, 'intrapersonal skills', includes competencies such as those related to scientific integrity, lifelong learning, self-leadership and taking up social responsibility.

The 'interpersonal skills' cluster refers, among others, to international and intercultural competencies, sensitivity to diversity, written and oral communication skills, collaboration, and leadership.

In the 'creative and innovative skills' cluster one encounters skills such as critical thinking, creative and problem-solving thinking, entrepreneurial skills, and sustainability competencies.



The T-shaped professional

Digital competencies ("confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society"[64]) fit into each of the three clusters and create additional opportunities for learning and innovation since digitalisation and the further development and use of AI are only increasing, especially since the outbreak of the COVID-19 pandemic.

5.3 Progressive and adaptive methods of teaching and learning for enhancing creativity

5.3.1 Pedagogical approaches

Ideally, the engineer of the future should be able to manage a project from the start to the end, proposing not only the technological tools and products but also proposing and evaluating a business model. To do so, the curriculum should rely on different pedagogical approaches such as problem-based, challenge-based (see chapter 3 on problem-based learning and challenge-based learning), and research-based education like lectures, practical exercises (learning by doing), innovative teaching methods and tools (e.g. serious games) as well as project management, teamwork and internships. International experience as well as internships in labs or companies should also be embedded in the curriculum (see chapter 1). Student initiatives that contribute to the development of transversal skills, such as participation in student associations (e.g. sports, humanitarian associations, junior enterprises, and organisation of job fairs with companies), or in social engagement activities should be encouraged. We provide below some examples of curricula already implemented by CESAER Members, which combine the different elements mentioned in this white paper and can be used as inspiration (see focus example chapter 5).

5.3.2 Dealing with innovation and complexity

New approaches in teaching and learning should be considered, given that information is readily and early available and may be quickly exchanged. Especially with the arrival of ChatGPT and similar tools, we need to educate students to critically assess and validate the available information. Evaluative judgement of ‘good’ performance standards within and beyond engineering and decision-making skills are becoming more important. Hence, adaptability, and critical thinking are of key importance.

While it is impossible to predict future developments and needs of any field in detail for the long term, history shows that change is the only constant. Thus, engineers will need to be trained to nurture, embrace, and adapt to change. Key to future-oriented engineering and science training programmes at all levels is the implementation of flexibility through a variety of modular learning and teaching approaches. Emerging teaching and learning practical principles suggest that the training process itself should be safe, accessible, and sustainable by design.

[64] https://op.europa.eu/en/publication-detail/-/publication/297a33c8-a1f3-11e9-9d01-01aa75ed71a1/language-en

Focus examples chapter 5:

Examples of curricula 1

ParisTech

Diplôme d'ingénieur **(Master of Science in engineering)**

Engineering studies in France are quite specific as far as a lot of engineering schools like ParisTech schools admit students in the final year of bachelor. Indeed, 80% of the students admitted study the first two years in so-called 'preparatory classes', either maths/physics, or physics/chemistry, physics/engineering, maths/biology. Therefore, a sample of the education programs could be: bachelor third year, master first year, master second year. In the end, students get the 'engineering degree' recognised as a master-level diploma.

The education programme is composed of a strong science and engineering basis, with additional SSH courses so that students can understand the complex environment where they will work and develop soft skills. Team projects and individual projects as well as internships and international mobility (at least twelve weeks, but mostly from six months to one year) are full part of the education programme and are evaluated as such. B2 level in French and English is mandatory to get an engineering degree. A gap year is possible, mostly between the second and the third year.

Moreover, the students regularly meet companies at school (e.g. presentations by alumni) or visit business units. There are a lot of opportunities to get concrete information about the companies' activities and the jobs they offer.

The students are mostly encouraged to participate in one, or even two student associations (e.g., student union, arts, sport, Junior Enterprise, humanitarian activities, science for pupils) so that they can also develop soft skills and implement the competencies they acquire during their studies (e.g., team management, project management, communication, development of business relationships, finances, human resources).

https://www.cesaer.org/content/3-task-forces/2022-2023/task-force-learning-and-teaching/white-paper-engineer-of-the-future/curriculum-paristech.pdf

Focus examples chapter 5:

Examples of curricula 2

Gdańsk Tech

Engineering and Management of Space Systems M.Sc. – EMSS Curriculum

The Joint International Master Double-Degree programme was created in collaboration with the International Council On Systems Engineering (INCOSE) and is subject to its accreditation. It is an international initiative, jointly developed and managed by Gdańsk Tech, responsible for providing deep background knowledge and skills, and Hochschule Bremen, specialising in a project and problem-based approach. This programme is further supported by industry experts, including Airbus and other companies related to the space sector, who provide mentoring and internships.

The programme is interdisciplinary and offers several optional specialisations, including Space Technologies (ST), Computer Science (CS), or Electronics Engineering (EE). It integrates Social Sciences and Humanities (SSH) into STEM education.

Classes within the programme are delivered by a mix of academic teachers and industry professionals. After completing three or four semesters of studies, students can earn two degrees.

The programme is taught in three languages: English as the primary language of instruction, with options for instruction in Polish and German. This multilingual approach fosters linguistic and intercultural skills among students.

https://www.cesaer.org/content/3-task-forces/2022-2023/task-force-learning-and-teaching/white-paper-engineer-of-the-future/curriculum-gdansktech.pdf

5.4 Recommendations

We conclude the chapter on ‘A future-oriented engineering curriculum’ by suggesting the following recommendations to universities:

- ensure that engineering curricula allow for a broader perspective focussing on next generation engineering skills, such as the ability to manage complex interconnected systems, the readiness to work in teams with strong interpersonal relationships and the ability to advocate in society and influence the market;
- design student-centred engineering curricula, in which the students are active participants in designing their pathway of study and research projects and can personalise and tailor their curriculum based on their individual competencies and interests;
- embed the curriculum opportunities in an inclusive and diverse environment that involves external actors, particularly civil society representatives (public authorities, local authorities, NGOs) and companies through internships, meetings with companies, entrepreneurship tracks or hackathons;
- balance fundamental disciplines focus on ’theoretical teaching’ with specialty disciplines with a high percentage of elective courses and adapted to technologies of the future;
- implement different methods of teaching and learning and rely on different pedagogical approaches such as PBL and CBL, as well as international experience and internships;
- focus on fostering adaptable and critical thinking and adapting evaluation methods and milestones to accommodate the new complex learning environments.

Conclusions

While we encourage the reader to refer to individual chapters and their recommendations, we collect here some selected overarching recommendations and key takeaways from the paper.

For engineers of the future to meet evolving expectations, universities should take a holistic approach towards engineering education, emphasising a solid scientific foundation, but fostering curiosity for other fields, as well as soft skills. To do so, universities increasingly benefit from stronger ties with national and international partners and should ensure that diverse formats of international experiences are offered. Additional means should be invested in valorising the academic and teaching staff, improving their skills, and fostering their motivation.

To train engineers of the future empowered to create responsible and innovative solutions, universities should give a central role to UNSDGs, including evaluating their competencies and incorporating a recognition system that values their commitment to sustainability. The focus should extend beyond technical literacy and shape cultural perspectives, norms, and values through debates, discussions, and reflections. Finally, students should be prepared to use AI with a critical approach, and teachers will need guidelines to responsibly harness AI opportunities.

To prepare engineers of the future for intercultural and interdisciplinary collaboration, universities can make use of contemporary initiatives of transnational collaboration, and develop innovative pedagogies such as problem-based learning and challenge-based learning, including for undergraduate, as well as cross-disciplinary events tackling socially relevant issues.

To equip engineers of the future to be lifelong learners, universities should integrate active learning methodologies into engineering study programs, enabling the development of lifelong learning competencies and mindsets among lecturers and students. Recognition of acquired skills through vocational, non-formal, and informal learning should be fostered.

To educate engineers of the future, curricula should be student-centred and allow for broader perspectives, by being embedded in an inclusive and diverse environment that involves external actors through internships, meetings with companies, entrepreneurship tracks or hackathons. Finally, curricula should balance fundamental with specialty disciplines, foster adaptable and critical thinking, and adapt evaluation methods and milestones to accommodate the new complex learning environments.

Taken together, it is important to underline that the engineer of the future is above all a team player. With other engineers and with non-engineers. The broad list of recommendations in this white paper should therefore not be misinterpreted such that it calls upon all individual engineers to be experts in everything. Instead, it takes an institutional and sector-wide perspective, underlining that the engineers (plural) of the future should, together, be empowered to continue to be active, trusted and constructive professionals who invent, design, analyse, build, test and maintain objects, machines, structures and systems that solve problems and serve the needs of society.

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Annexes

The following annexes present additional efforts and insights in (re-)thinking and (re-)developing engineering education.

Annex A - The Shift Project (France)

The Shift Project and INSA Group "Training the 21st century engineer", 2022[65].

The Shift Project and the INSA Group presented a set of papers including a Manifesto and a Methodological Guide on training the engineers of the 21st century.

Excerpt of the executive summary:

"*The Shift Project calls on all stakeholders who train, employ, or represent engineers to reflect together on how engineers can contribute to a socio-ecological transition project. This manifesto makes several proposals:*

It poses the need to adopt a vision of the socio-ecological transition, based on preferences collectively defined according to a search for the general interest, in a controllable and normative approach.

It invites us to reflect on the role of the engineer, historically, currently and in the future, and on the evolution of engineering professions in a resilient society: the disappearance, appearance or evolution of professions must be anticipated for medium and long-term employability.

It attempts to identify the room for manoeuvre available to engineers at the professional, individual, and collective levels, whatever their position.

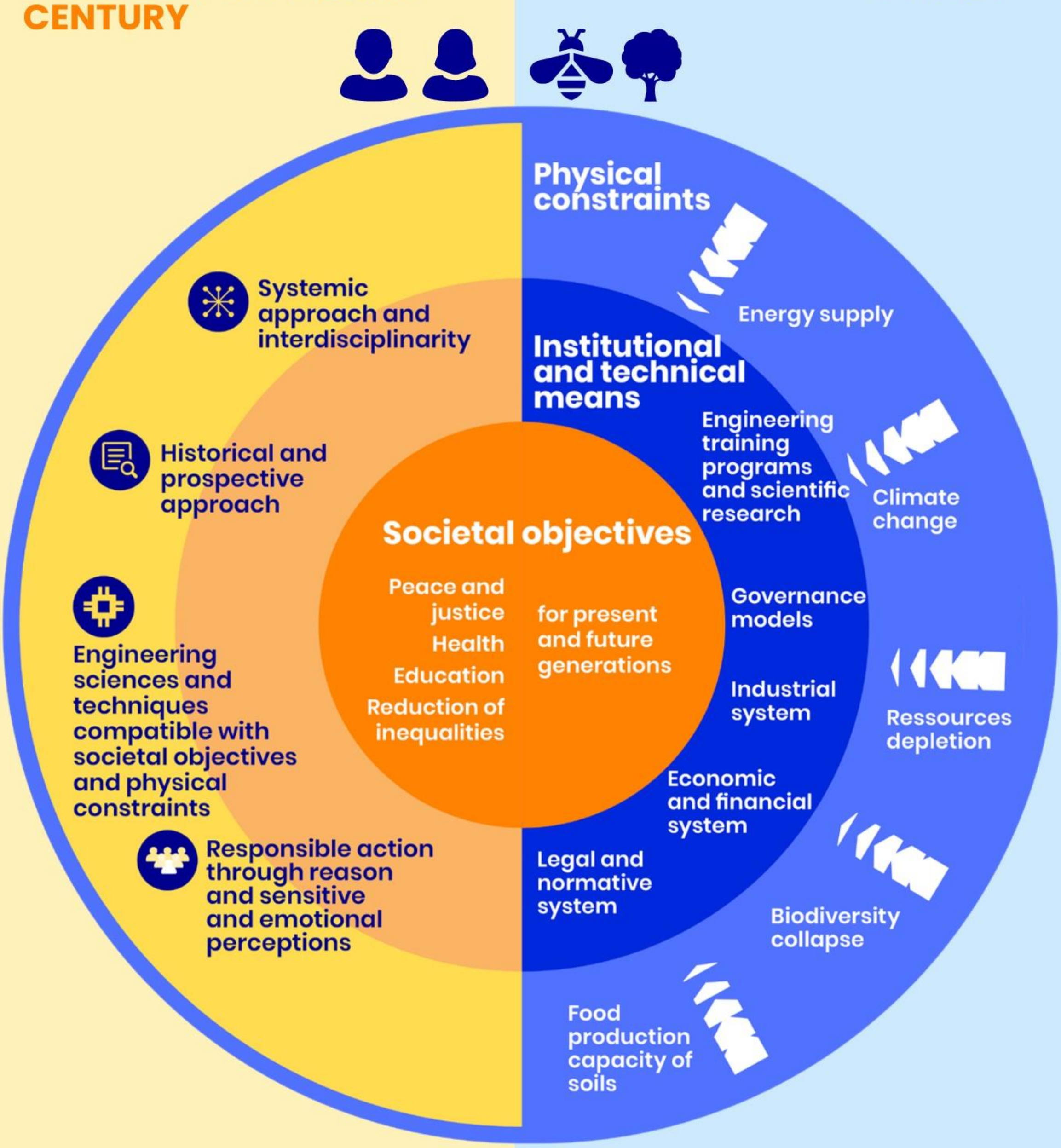
It proposes to discuss a base of knowledge and skills necessary for all engineers to play their role in the socio-ecological transition.

It hopes to provide a draft response to a strong expectation on the part of students, but also teachers, as well as to the growing need of companies for new skills to successfully carry out their transition."

[65] https://theshiftproject.org/wp-content/uploads/2022/06/ResDec-Climatsup-INSA-version-Web-ENG.pdf

THE CIVIC-MINDED ENGINEER FOR THE 21ST CENTURY

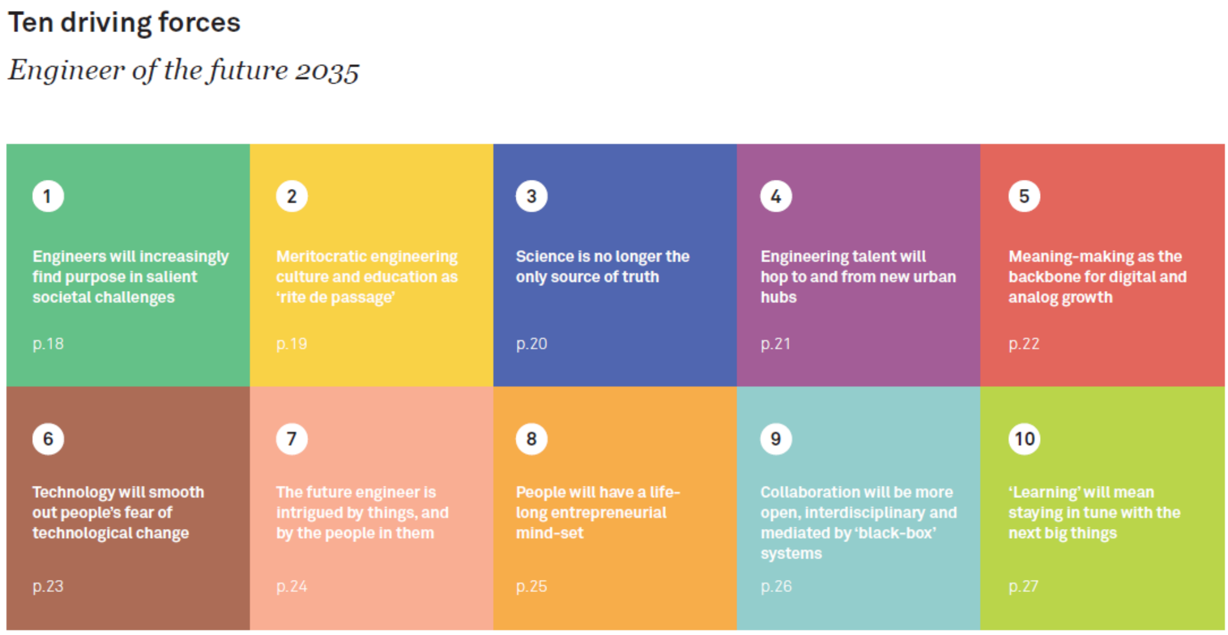
THE SOCIO-ECOLOGICAL STAKES



Annex B – Engineer of the Future (The Netherlands)

In their report, Klaassen, Van Dijk, Hoope and Kamp have identified ten contextual factors (driving forces) that will play a role in shaping the work of engineers of the future and explain how these driving forces interact.

We list here below these 10 driving forces as found in their report[66].



Additionally, Klaasen et al. identify three dimensions that shape the future diversity in engineering behaviour (source of engagement; trust in collaboration; development cycles). In that context, the authors identify eight engineering roles that are meaningful for students and with which they can identify.

1. Origineering
2. Swarmineering
3. Engagineering
4. Ingraineering
5. Tinkeneering
6. Perfectioneering
7. Imagineering
8. Fundamentaneering.

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[66] Klaassen, R., Van Dijk, M., Hoope, R., & Kamp, A. (2019). Engineer of the Future: envisioning higher engineering education in 2035. Delft: TU Delft Open. Available at https://www.4tu.nl/cee/publications/engineer-of-the-future.pdf

Annex C – The EELISA European engineer

The EELISA Engineer Profile

A model to shape today's higher education and impact tomorrow's society

EELISA and Engineering

As an alliance of Higher Education Institutions encompassing many graduate engineering schools and technological universities, EELISA aims to develop a general European engineer profile. While most international standards for engineer profiles underline the importance of core scientific concepts such as understanding, practice, design, research, knowledge, methods, and complexity, few point out the utility of mobility, diversity, and multiculturalism during the degree to help promote learning. Furthermore, "engineer" may have different meanings among different European countries.

The ambition of EELISA is to develop a common European engineer profile rooted in society, with increased inclusiveness, cross-disciplinarity and commitment. Such a profile includes high-level technical and scientific core competencies but also encompasses environmental, social, and multicultural skills taking benefits from the European context of diversity and mobility, in order to address the new challenges of a global society (namely the green and digital transition) and the expectations of companies.

The EELISA European Engineer Profile

To elaborate such a profile, the work was based on:

• A deep literature review based on the Web of Science database

• A web questionnaire sent to academic staff, students, and external stakeholders

• An in-depth interview of senior managers of leading European companies (subcontracted to a consultancy firm)

The EELISA Engineer Profile can be described through four general pillars and is based on a new system which would be a hybrid or sui generis educational system different from existing ones.

➢ High level of scientific, theoretical, and digital skills:

This part of the profile involves core skills with theory-based understanding of the basic sciences in each field of engineering, for example mathematics, computing, etc., as well as excellent digital skills and their use to develop products, processes, and systems. Students are exposed to theoretical problems and to the formulation of possible solutions based on engineering fundamentals, in a design framework. Here, training in research methodologies and relevant literature is key to help evaluate the data or processes using state of art methods. The above-mentioned high-level skills are the backbone of the European engineer profile.

➢ Addressing sustainability:

European engineers will need to understand how the techniques they develop are compatible with the planet's boundaries and that they should not generate irreversible situations. Especially, they will need to consider the entire life cycle of products and services they design and produce. This implies a critical and thorough analysis of the socio-environmental risks that pertain to the development of new technologies.

➢ Interculturalism: an engineer embracing the European project:

Just as practical learning may help to understand engineering fundamentals, adding mobility, both physical and virtual, in a degree program can help facilitate understanding and incorporating soft skills on a personal level. By being exposed to different professors, university environments and cultures, students will become more aware of different societal issues, ethical problems, and cultural dispositions.

➢ Business and communication skills and critical thinking: practical and applied knowledge.

Because engineers are at the interface between science, techniques, and society, they will be exposed to economic, organisational and managerial issues, requiring training related to communication skills, decision-making and independent learning (learning on the job) to better integrate the views of multiple stakeholders into their decision and creative processes. Because they evolve in a society, where knowledge comes from a wider variety of sources, they need to develop an independent mindset and critical judgement capacities.

How will the EELISA European Engineer Profile be beneficial?

In a context of increasing global competition to innovate, this profile will take advantage of the richness and diversity of the European higher education ecosystem by stimulating mobility during studies, and interconnectedness for a rich lifelong learning experience.

The EELISA European engineer profile can be created by a combination of different life experiences, acquired knowledge, exposure to real and changing world problems, constraints, and social context, mindful of the ethical consequences of the engineering solutions and trained to understand and communicate with other professionals, in diverse cultures and environments.

Finally, the ambition in EELISA is to go beyond an exposure to diverse cultures and different ways of thinking. The core of this Alliance is to nurture an atmosphere of cooperation and common values around cohorts of students that will stay interconnected, will embrace the European engineer vision of EELISA and develop across geographies and over time a shared vision of Europe and its values.