REDESIGNING NORWEGIAN ENGINEERING EDUCATION 1: BENCHMARKING AND PRINCIPLES FOR DEVELOPMENT

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ABSTRACT

This is the first part of the three-part paper *Redesigning Norwegian Engineering Education*. It presents and discusses results from a recently completed educational development project at NTNU, *Technology Education of the Future* (Norwegian acronym *FTS*), which was established in August 2019 and completed at the end of 2021. FTS has developed a framework for NTNU's educational portfolio designed to ensure that the university's technology and engineering programs will be aligned with technology development, societal challenges, and industry needs beyond 2025. The initial phase consisted of an outside-world analysis focusing on future global and national needs, major technology trends, and recent and expected developments in the higher education sector. Through literature studies, interviews, workshops, stakeholder meetings, study trips, and participation in international meetings, we identified international state-of-the-art and expected trends in engineering and technology education, expectations and feedback from employers and alumni, and governmental expectations for the higher education sector. These insights were subsequently "triangulated" with input from faculty and students, a group of educational experts from Nordic universities, and official university strategies and policies. Based on this triangulation process we proposed desired competence profiles for future bachelor, master, and PhD students in engineering, and initial recommendations for program and portfolio development. (The competence profiles are described in this paper.) Our proposals were subsequently subjected to a hearing and dialogue process. Based on all collected input as well as a SWOT analysis, we then proposed an overarching vision and 10 systemic principles designed to support the vision and the competence profiles when further developing FTS programs. (The vision and principles are presented in the paper.) The FTS principles are well aligned with the CDIO Standards and have been adopted by NTNU's Rector as a platform for future educational development.

KEYWORDS

NTNU, Education redesign, Technology, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

The *Norwegian University of Science and Technology* (NTNU) educates about 85 % of Norway's 5-year integrated MSc engineering graduates, and about 30 % of its BSc engineering graduates. The project *Technology Education of the Future* (acronym FTS, after the Norwegian name *Fremtidens teknologistudier*) was established by NTNU's vice-rector of education in August 2019, with a mandate of developing a framework for NTNU's educational portfolio in technology to *ensure that NTNU's portfolio of technology and engineering programs is well aligned with technology development, societal challenges, and industry needs for the future beyond 2025.* In the project context, the term 'technology' refers to engineering, technology-oriented natural science, informatics, architecture, design and urban planning. The project submitted its final report in early January 2022.

In the project's initial phase we performed an outside-world analysis where future global and national competence needs, important technology trends, and recent and expected developments in higher education were gauged. Through literature studies, interviews, workshops, stakeholder meetings and study visits, we identified i) international state-of-the art and important trends in engineering and technology education, ii) expectations and feedback from employers and alumni, and iii) government expectations for the higher education sector. These insights were then "triangulated" with input from iv) faculty and students, v) a reference group from Nordic universities, and vi) official university strategies.

Based on this triangulation process we proposed *competence profiles* for future bachelor, master, and PhD students in the FTS study program portfolio (around 150 study programs in all), and *initial recommendations* for program and portfolio development. One of the recommendations was to align such development with the CDIO standards; another was to strengthen NTNU's active participation in international communities for technology and engineering education development. Our proposals were then subjected to an interactive hearing and dialogue process, where both internal and external stakeholders gave feedback and advice. In parallel we performed a *SWOT analysis* of the present state of NTNU's technology programs, measured against international state-of-the-art and the desired future scenario (Bodsberg & Øien, 2021). The SWOT methodology and results are described and discussed in Part 2 of this paper. Similarly, the overall *stakeholder involvement process* is described and discussed in Part 3.

All internal project reports are only available in Norwegian. The three parts of this paper address an ambition to share our results with the international community. The next sections of this first part will discuss the outcome of the outside-world analysis, the proposed competence profiles, the vision, and the principles proposed to support future development.

SUMMARY OF OUTSIDE-WORLD ANALYSIS AND BENCHMARKING

Sources and methodology

Table 1 sums up some key supplementary sources used in our outside-world analysis and international state-of-the-art benchmarking *that are not explicitely referenced in the text*. Space does not permit going into details about how each of these sources contributed to the overall picture, hence we have chosen not to list them as formal references but include Table 1 for completeness. We have found a strong level of consistency regarding recommendations for overall strategic direction for the future when comparing all these different perspectives.

Table 1: Supplementary sources for the outside-world analysis and benchmarking (in alphabetic order)

Supplementary sources to the formal paper references
A Whole New Engineer (David Goldberg and Mark Sommerville, ThreeJoy Associates, Inc., 2014)
CDIO's website www.cdio.org, and various books and papers from the CDIO community
Meld. St. 27 (2015–2016) - Digital Agenda for Norway. Recommendation from the Norwegian Ministry of Local Government and Modernisation, 27 January 2017
Meld. St. 4 (2018–2019) - Long-term plan for research and higher education 2019–2028. Recommendation from the Norwegian Ministry of Local Government and Modernisation, 5 October 2018
Norwegian Strategy for Skills Policy 2017 - 2021
Notes and minutes from FTS workshop '*NTNU Meets Working Life'* (15 January 2020)
Notes and minutes from FTS workshop with NTNU's *Advisory Board for Working Life Collaboration* (30 October 2019)
Notes and minutes from various bilateral dialogue meetings and seminars between FTS and companies, organizations, NTNU faculty and students (August 2019 – June 2020)
Notes and minutes from FTS study visits to a number of international universities and colleges in the US and Europe (2019 – 2020)
Notes from discussions with and various information received via FTS's Nordic reference group
Report from interviews with selected key players in Norwegian society (May – June 2020)
Skills Outlook 2019: Thriving in a Digital World (OECD report, 2019)
Summary report from FTS student workshop (30 January 2020)
Technology Outlook 2025 (DNV GL report, 2016)

Societal and technological trends influencing competence needs

A variety of sources (e.g. (United Nations, 2019) and (World Economic Forum, 2018)) consistently indicate that the future will be dominated by big, complex challenges (wicked problems), rapid, large and mainly technology-driven changes in skills needs and the labor market, and increasing uncertainty about exactly which future scenarios will play out. In particular, addressing the world's *sustainability challenges* becomes a basic premise for social and business development in all sectors and domains, nationally and internationally.

Enabling and digital technologies are expected to develop ever faster, and increasingly also converge. Increasing technology dependence also leads to increasing vulnerability to failures in infrastructure and misuse of the technologies. The rapid technological development, and the complexity and seriousness of the challenges to be solved, make *ethical dilemmas and trade-offs* in technology, society and business both more complex and more important than in the past. Technological and social developments also mean that technologists, engineers and employees with science competence will become more important for, and increasingly recruited to, more societal sectors and business areas than has traditionally been the case.

In sum, the above trends can be summarized in the term *VUCA World* - a world characterized by "Volatility, Uncertainty, Complexity and Ambiguity" (Kamp, 2016). In light of these trends, key innovation drivers in the future will be the need for sustainable resource use, climate change, policies and regulations that require innovation in technological solutions, and digitalization, digital transformation and digital technology development. Digitalization and technology development in turn entail faster changes in the labor market and job content, and development of new business models, market players and industries. Old jobs will change content, or be eradicated due to digitalization, automation and robotization. New jobs will be created, but probably with an (at least temporary) mismatch in skills. *Innovation skills, adaptability* and *entrepreneurial thinking* will therefore increase in importance.

The unique contribution and added value of human beings in a work context is pushed upwards to more complex tasks, which again increases the importance of qualities and skills such as *analytical thinking and innovation; active learning and learning strategies; creativity, originality and initiative; critical thinking and analysis; complex problem solving; leadership and social influence; emotional intelligence; and reasoning, problem solving and conception of ideas (ideation)*. *Digital competence* in a broad sense, including algorithmic thinking, 'data literacy' and security competence, will be important for all technologists and engineers. Technology – and competence - will also become faster outdated, which creates an increasing need for more people to continuously develop their competence during their lives. *Ability for lifelong learning* will thus be a key competence.

A summary of international state-of-the-art characteristics in technology education

The FTS mandate specifies that the project should ensure that NTNU's technology programs *"maintain a high international quality of education and take on international trends in the education and labor market"*. A survey of international trends and global best practice in technology education was therefore conducted as a starting point for discussion and recommendations on further quality development in the FTS portfolio. The following points broadly sum up the project's findings (based to a large extent on a variety of sources in Table 1, (Kamp, 2016) and (Graham, 2018)) with respect to common characteristics of world-leading technical education institutions and study programs:

- Strong academic staff with high demands on teachers' professional and scientific competence – and research that supports educational quality
- Ambition to develop socially responsible graduates with comprehensive competence
- Culture, system, and high ambitions for continuous improvement and faculty competence development, also pedagogically
- Emphasis on contextual learning, with a focus on creative aspects
- Constructive alignment between competence goals, assessment and learning activities
- Trust in and facilitation of students' responsibility for their own learning
- Learning culture and learning activities that promote motivation, commitment, initiative, cooperation, identity and deep learning
- Program adaptation (as much as can be achieved within available resource limits) of generic/basic/foundational courses, e.g. in mathematics, statistics, physics, IT
- Facilitation of broad and diverse interdisciplinarity, also towards nontechnical fields
- Emphasis on long-term work relevance and interaction with working life
- Good facilitation, integration and utilization of digital and physical infrastructure
- Agility and flexibility.

THE FTS COMPETENCE PROFILES

As seen earlier, competence expectations for future engineers include more than pure academic and technical knowledge. Such knowledge is still the essential foundation on which other competence dimensions must be built, but it must be integrated closely with a rich set of other key competences. This philosophy is of course also central to the CDIO community. The world needs engineers with skills, attitudes and values that can contribute to an ecologically, socially and economically sustainable future – and act as *change agents* for a better world.

An *FTS competence profile* consists of 12 program-type-level competence goals that students are expected to achieve by graduation. FTS has proposed such profiles for *bachelor engineer, 5-year integrated master* and *PhD* programs, the level of each competence goal depending on the program type. The competence goals are classified into five categories, with *digital competence* and *sustainability competence* 'embedded' across the categories – as in Table 2.

Table 2. Overview of FTS competence profiles (example for Bachelor of Engineering)

<table>
<tr><td rowspan="6">Sustainability competence
('embedded' across categories/goals)</td><th>Category</th><th>Competence goals</th><td rowspan="6">Digital competence
('embedded' across categories/goals)</td></tr>
<tr><td>The knowledge foundation</td><td>• Demonstrate academic and technical knowledge and perspective</td></tr>
<tr><td>The toolbox</td><td>• Ability to analyze engineering problems
• Ability to use relevant methods and tools
• Ability to obtain and critically evaluate information</td></tr>
<tr><td>The professional core</td><td>• Design and implement sustainable solutions
• Know research and contribute to technology development
• Contribute to innovation</td></tr>
<tr><td>The social framework</td><td>• Consequence analysis, risk analysis, scenario thinking
• Ability to apply and reflect on norms for ethics and sustainability
• Ability to work purposefully and collaborate well in diverse teams
• Ability to communicate, lead dialogue, discuss professionally</td></tr>
<tr><td>Learning ability</td><td>• Demonstrate ability and willingness for lifelong learning</td></tr>
</table>

The competence profiles describe the program types' learning goals, which in turn govern design, content, and pedagogy of the study programs. To ensure that the profiles' range and ambition meet requirements from national laws and regulations as well as international accreditation bodies, we assessed and calibrated them against

- the requirements for student outcomes from the American accreditation organization ABET,
- the European accreditation system EUR-ACE's description of «minimum threshold» Program Outcomes for bachelor's and master's programs in engineering,
- Sweden's national examination schemes for *ingenjör* and *civilingenjör* studies,
- learning outcome descriptions prescribed for bachelor-level engineers in the Norwegian framework regulations for engineering education,
- subject-independent learning outcome descriptions for bachelor's, master's and PhD levels in the Norwegian Qualifications Framework for Lifelong Learning.

Table 3: The three description levels for FTS competence goal on *innovation*, for program types Bachelor of engineering, 5-year integrated Master, and PhD

Program type	**3-year Bachelor of Engineering**	**5-year integrated Master (Engineering, Technology)**	**PhD (Engineering, Technology)**
Generic formulation of competence expectations	*After completing their studies, graduates should be able to …*	*After completing their studies, graduates should be able to …*	*After completing their studies, graduates should be able to ...*
Sample competence goal: *Innovation, entrepreneurship, business understanding*	**Contribute to innovation:** *… Participate in innovation projects, and know the principles of technology-based business development* *Elaboration:* The candidate must be able to contribute to innovation in new or established organizations through participation in engineering innovation projects. The candidate must show knowledge of entrepreneurship and how technology-based business development takes place.	**Contribute to innovation and show business understanding:** *… Initiate or lead innovation projects, and apply the principles of technology-based business development* *Elaboration:* The candidate must be able to contribute to innovation in new or established organizations by initiating or leading technological and engineering innovation projects. The candidate must demonstrate entrepreneurial mindset, the ability to apply the principles of technology-based business development, and general business understanding.	**Initiate and lead research-based innovation:** *… Assess the need for, initiate and lead major research-based innovation projects, and implement technology-driven innovation processes* *Elaboration:* The candidate must have all the competence of a Master in the field, and in addition ... ... be able to assess the need for, initiate, and lead the implementation of major research-based innovation processes and projects. The candidate must be able to carry out technology-driven innovation processes based on scientific methodology, sustainable business understanding, and entrepreneurial thinking.

It is also important to note that each competence goal is described on three "levels" – title, introduction and elaboration. See Table 3 above for an example, for one specific competence goal. Table 3 also illustrates the differences in competence level between bachelor's, master's and PhD graduates for this particular goal.

THE FTS VISION

Based on all collected input during the stakeholder involvement process, we proposed the following overarching vision as a desired 'ultimate outcome' of the project:

NTNU's technology programs educate creative world-class graduates – who are able and willing to contribute to a better world and a sustainable future.

The vision covers all study programs in the FTS portfolio (i.e., "graduates" include engineers, natural and computer scientists, mathematicians, architects, designers, and urban planners). It is anchored in NTNU's main strategy (NTNU, 2018), emphasizes NTNU's focus areas of sustainability and quality, and focuses on the creative dimension as a distinguishing characteristic of graduates from FTS programs.

THE 10 FTS PRINCIPLES

We subsequently developed 10 overarching *principles* designed to aid future development of NTNU's program portfolio and support the vision and desired competence profiles. These principles are well aligned with (and to a significant extent inspired by) the CDIO standards and are recommended by FTS as guidelines for further development of NTNU's technology programs. They are categorized into five *quality areas*, as illustrated by Figure 1 (placed on the next page in order to avoid splitting it in two). A set of *icons* have also been developed, in order to aid communication of the principles. Using a term from the *Theory of Change* community, realization of the FTS principles can be viewed as *necessary preconditions* for realizing the overarching FTS vision. The principles were formally adopted by NTNU's Rector in June 2021 as a platform for future development. Some words of explanation follow for some terms used in Figure 1. We also point out links between the principles and the CDIO Standards.

Notions of competence

By *holistic and integrated competence*, we mean that the FTS competence goals cannot easily be 'decomposed' into 'orthogonal' columns (like knowledge, skills and judgment) as is done e.g. in the EQF framework. Each competence goal potentially spans over several interacting 'dimensions' (Fadel et al., 2015). Neither are the competence goals within a profile independent of each other – they make up a whole. To paraphrase the *Norwegian Committee on Skill Needs* (Kompetansebehovsutvalget, 2018): *"Competence is both the sum of, and the interaction between, skills, knowledge, understanding, characteristics, attitudes and values – which together are mobilized and create the ability to solve tasks and master challenges in specific situations."* This notion of competence is closely linked to CDIO Standard 2.

The concept of *sustainability competence* (Øien & Bodsberg, 2020) consists of a *knowledge component* that must be customized for each study program, in interplay with a set of *key competences* (OECD, 2017). Sustainability competence must therefore be 'embedded' across the 12 competence goals in the FTS profiles. The knowledge required for each study program must be detailed during specification of the competence goal *Demonstrate academic and technical knowledge and perspective*. The key competences central to sustainability competence can be integrated into the remaining competence goals.

Quality area		FTS Principle	Icon
Candidates' competence	I	*Holistic competence:* NTNU's technology programs must actively facilitate candidates' development of holistic and integrated competence, based on a solid disciplinary foundation, including sustainability competence and digital competence at a high level.	
	II	*Cross-disciplinary collaboration:* NTNU must actively facilitate technology candidates' development of solid interdisciplinary collaboration competence, and the development of a diversity of knowledge profiles across the entire student population, while enabling individual students to achieve adequate depth in their respective program areas.	
The pedagogical learning environment	III	*Contextual learning:* Contextual learning should be used as an underlying pedagogical principle in NTNU's technology education	
	IV	*Student-active learning, relevant assessment, healthy learning culture:* NTNU's technology programs should use knowledge-based, student-active and engaging forms of teaching and assessment, which are aligned with the overarching competence goals of the study programs, promote a healthy learning culture, and result in effective in-depth learning.	
	V	*Teaching staff competence development:* NTNU should set clear expectations for, and provide solid support for, competence development for teaching staff.	
Program design and quality development	VI	*Holistic program design and portfolio development:* The quality of NTNU's technology education should be developed through a program-driven approach, in combination with strategic development and portfolio management across programs and program types.	
	VII	*Continuous improvement and quality culture:* NTNU's quality work in technology education should stimulate development of study programs towards world-class educational quality, by focusing on continuous improvement and systematic quality culture development.	
Collaboration – nationally and internationally	VIII	*International collaboration on education quality:* NTNU should give high priority to strategic and operative international collaboration on the development of technology education, with the aim of becoming an internationally visible and recognized university in this area.	
	IX	*Systematic collaboration with working life:* NTNU's technology programs should emphasize systematic collaboration with society and working life, with the aim of promoting work relevance, laying a foundation for lifelong learning, and ensuring that students can gain relevant work experience through their studies.	
Physical, digital and psychosocial learning environment	X	*Infrastructure for learning, health and wellbeing:* NTNU should develop its learning environment, especially its campus and infrastructure – both physical and digital – in a direction that supports the other FTS principles I-IX and promotes learning, health and well-being among students and staff.	

Figure 1: The 10 FTS principles

Similarly, *digital competence* (Øien & Bodsberg, 2020) consists of a knowledge component that must be customized for each study program, in interplay with a range of non-technical professional competences – see e.g. (European Commission, 2019) and (Gulliksen et al., 2020). The knowledge component must be addressed when specifying the competence goal *Demonstrate academic and technical knowledge and perspective* for each study program. The nontechnical professional competences that are key to digital competence can be integrated into the remaining FTS competence goals.

Contextual learning

This notion is closely linked to CDIO Standard 1. Characteristics of contextual learning are (Crawley et al., 2008)*:*

- *«New concepts are presented in real-life situations and experiences that are familiar to students*
- *Concepts in problems and exercises are presented in the context of their use*
- *Concepts are presented in the context of what students already know*
- *Examples include believable situations that students recognize as being important to their current or possible future lives*

Learning experiences encourage students to apply concepts and skills in useful contexts, projecting students into imagined futures, e.g., possible careers in unfamiliar workplaces».

Program-driven approach

This notion is closely linked to CDIO Standards 3-5 and 7. The concept *'program-driven approach'* implies that competence goals at the program level are the starting point for program development – and thus a binding policy for program design, implementation and operation. This implies that the program competence goals should guide development of program design, course content, pedagogical methods, and infrastructure – not the other way around.

Quality culture

This notion is closely linked to CDIO Standard 12. The European University Association (EUA) defines *quality culture* as (EUA, 2006): "*An organizational culture that intends to enhance quality permanently and is characterized by two distinctive elements:*

- *A cultural/psychological element of shared values, beliefs, expectations and commitment towards quality*
- *A structural/managerial element with defined processes that enhance quality and aim at coordinating individual efforts."*

Other remarks

The FTS principles III – V are closely linked to CDIO Standards 8 – 11, while FTS principle X is linked to CDIO Standard 6. In (Øien & Bodsberg, 2021) each of the principles I – X is detailed in more depth, to clarify and elaborate on what the principle means in the FTS context. Space limitations do not permit us to include these details here. In addition, (Øien & Bodsberg, 2021) provided a list of ideas for *possible methods and measures for realizing each principle*. This was intended as a possible starting point for practical implementation within the various study program types in the FTS portfolio.

THE ROAD AHEAD: INSTITUTIONAL FOLLOW-UP AND IMPLEMENTATION

In January 2022 we submitted the FTS project's final report. There we propose an overall framework for implementation, including around 50 concrete recommended actions spanning the five FTS quality areas, recommendations for resource prioritization, and advice on change processes for realizing the FTS profiles and principles in practice. Among other things we propose actions related to periodic program re-design, faculty competence-building and pedagogical development, strengthening of educational leadership, systematic quality work and portfolio development, improved learning support infrastructure and alignment of administrative systems to support learning, learning space development, and re-prioritization of strategic resources. These recommendations will be addressed in detail in future papers.

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BIOGRAPHICAL INFORMATION

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