Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

Faculty perspectives on Future Engineering Education

Henrik Worm Routhe[a], Maiken Winther[b], Marie Magnell[c], Lena Gumaelius[d] and Anette Kolmos[e]

Aalborg University [a-b-e], KTH Royal Institute of Technology [c-d]
Corresponding Author's Email: maikenw@plan.aau.dk

ABSTRACT

New societal challenges have emerged, and the Sustainable Development Goals present a concise summary of the engineering grand challenges (National Academy of Engineering, 2007). Further, the global society face challenges such as digitalization, future sustainable development and industry 4.0 engineering education is expected to respond by educating engineers with the relevant knowledge and competences useful in dealing with these complex problems both in terms of technology, climate and society (Kolmos, 2021). Engineers need to see themselves as global citizens embracing the human challenges, and engineering institutions need to prepare graduates to be able to work on solutions to these complex problems. Future engineers need to understand the impact of new technologies both on an individual level as well as at a systemic and societal level. Not least to understand how technologies can contribute to solutions for future complex societal problems.

The question is how engineering education will respond? What are the strategies for developing the academic disciplines and the future engineering competence profiles, and which changes emerge in curriculum when adapting to future emerging technologies and complex problem solving? Five Nordic Universities have participated in this study (Denmark, Finland, Iceland, Norway and Sweden). From each university four professors have been interviewed. The professors represent four different engineering disciplines: mechanical engineering, civil engineering, biotechnology and energy engineering. These disciplines are common engineering disciplines, offered at the selected universities.

All engineering education in the Nordic countries follow the Bologna structure with three year Bachelor and two year Master education. The aim of this study is to study and compare how different faculties anticipate and predict future changes within their discipline.

The findings indicate that there are differences among the four disciplines. The engineering programs with a more core science component such as energy and bio technology anticipate less differences in the future curriculum compared to mechanical and civil engineering. All disciplines anticipate that emerging technologies such as big data and AI will influence the curriculum, and especially production/mechanical and civil engineering also point out new learning objectives like systems understanding.

Having in mind that engineering education is a broad field the aim of this study is not to highlight a single coherent outcome but to highlight approaches and understandings for how to prepare future engineering education from an engineering faculty perspective.

KEYWORDS
Nordic STEM, Engineering education, future complex problems

Introduction

New societal challenges like climate change, biodiversity, and the Sustainable Development Goals (SDGs) have emerged. Engineering institutions need to prepare graduates to be able to work on understandings and solutions to these goals. An engineer might think that their work is only relevant to clean water, energy, industry, smart cities and responsible production. However, technology underpins the entire society and technology should contribute to improving all the SDGs as well as poverty, hunger, health, equality, work and economic growth, climate action, life on land and in water, peace, and partnerships. Engineers need to see themselves as global citizens and embrace the human challenges.

The new emerging technologies will change human interactions, including the way engineering education is organised. There will be an expected increase in the use of the emerging technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and robotics, and these will saturate all corners of society from the daily life of citizens to industrial production and global collaboration. Future engineers need to understand the impact of these new technologies for the individual as well as at a systemic and societal level, not least to understand how the technologies can contribute to a solution to one or more of the SDGs.

As the global society face challenges such as the SDGs, engineering education is expected to respond by educating engineers with the relevant knowledge and competences to come up with adequate solutions. There is no doubt that engineering and science will be essential in solving these issues and in redirecting the global society for a sustainable world.

We need to educate engineers who are able to deal with these complex problems both in terms of technology, climate and society (Kolmos, 2021). The question is how faculty in engineering education respond?

Regardless of wether we are approaching the future from the fourth industrial revolution or from a sustainability angel, there will be a need for interdisciplinary collaboration. Industry 4.0 is embracing all digital technologies and thus bring drastic changes to both industry and society. The application of new technologies such as the Internet of Things (IoT), Artificial Intelligence (AI) and robotics, advanced materials, additive manufacturing, multidimensional printing, bio and neuro technologies, virtual and augmented realities and many more are just some of the new technologies which characterise the fourth industrial revolution (Lorenz, Rüßmann, Strack, Lueth, & Bolle, 2015). The Boston Consulting group emphasize that the interaction among the single technologies is necessary for an efficient and automated production and if engineering education should be exemplary and match the needs of companies, there would be a need for interdisciplinary collaboration across a number of programs and disciplines. At the university level, this will involve collaboration among computer science, robotics, automation, production, management, electronics and not to forget materials as necessary elements in the education of engineers.

In Japan the concept of Industry 4.0 has been brought into a new concept of Society 5.0 to indicate that the emerging technologies are not only about industrial efficiency, but indeed also about how the digital technologies are connected to people and systems which are all connected in cyberspace and by the application of AI (Nahavandi, 2019; Onday, 2019).

The development of new technologies as well as the ability of using existing technology is of vital importance when addressing the Sustainable Development Goals such as poverty, hunger, health, water and energy. To achieve this desired development engineering education needs to respond to these challenges and educate graduates who can handle these challenges. A need for a more holistic, system-based and interdisciplinary approach to engineering knowledge and engineering learning appears significant. Obviously, there is a need for more attention to understand and integrate interdisciplinarity to be able to analyse and develop sustainable solutions to these complex problems, and for students to learn methods for how to deal with complex, real-world problems such as the sustainability problems.

Faculty approaches

A limited amount of research exist on faculty approaches to future engineering education. Few studies have been conducted on how faculty perceive employability or so-called work-related learning aiming to prepare students for the engineering profession. A Swedish study indicates that academic faculty are relatively positive towards including employability issues in the curriculum. Especially faculty members with prior work experiences valued employability and the study also finds that faculty members consider preparations for the engineering profession an essential part of engineering education (Magnell, Geschwind, Gumaelius, & Kolmos, 2014).

A US study reports considerable differences in how three different stakeholder groups regard employability: the graduates, the faculty educating them and the human resource managers who are recruiting the graduates (Rosenberg, Heimler, & Morote, 2012). The three stakeholder groups gave a rather diverse view on the skills needed for the job, the skills learned in education and the additional need for training. The academic knowledge together with critical thinking got the highest priorities for the faculty.

Another study also clearly indicates that faculty across academic departments do have very different perceptions across the different engineering branches of how to integrate employability into engineering going from *add-on strategies to integration by pedagogies to a value and competence perspective* (Magnell & Kolmos, 2017). This reminds us that engineering embraces many different scientific profiles from life sciences like biotechnology, to physics based engineering like energy to construction and industry based engineering branches like civil engineering and production.

Few studies have been conducted on faculty perceptions on the integration of sustainability. A Swedish study on academic staff perceptions show a large variation in perceptions of sustainability from waste separation to a complex understanding and integration of sustainability challenges (Sammalisto, Sundström, & Holm, 2015). The study also indicates that if sustainability should become an institutionalized part of the curriculum, the role of the top management is crucial in the acceptance and implementation process.

In another study, Shepard and Furnari (2013) identified different views among faculty members varying from, on the one hand, strong arguments for integrating sustainability issues in the curriculum to, on the other hand, an emphasis on academic freedom and the right to choose what and how to teach.

The few studies on faculty perceptions are more focused on looking back, or on looking at the current situation, than looking ahead. Students' perceptions and learning is much more researched, even if the formal and the taught curriculum is constructed by faculty who will normally be at the university for lifetime. So, the faculty perceptions are incredibly important for the future of engineering education.

For this study, the overarching aim is to find out how engineering education responds to contemporary challenges such as the need for the development of a Sustainable society and the transformation into a digital society and which changes can be anticipated for the next coming 10-year period?

Methodology

The study is based in the Nordic context, which is interesting given that this constitutes a relatively homogeneous group of countries that partly share culture and geographical environment. At the same time, these countries have completely separate political systems, which means that universities and education have nevertheless developed quite independently of one another. The study focuses on perspective provided by the university faculty. Professors from five Nordic universities, each representing one Nordic country, Denmark, Finland, Iceland, Norway and Sweden are included as participants. The professors represent four different engineering disciplines; mechanical engineering, civil engineering, biotechnology and energy engineering. These disciplines can be seen as common engineering disciplines and were offered at all selected universities.

Anticipation of the future and levels of implementation

Imagining the future can be difficult. The anticipation of the future is usually based on our existing knowledge of the presence and our expectations for the future which may be regarded as emerging trends – new areas that will grow. Lustig (2017) has formulated three horizons which can be applied as indicators for finding/analysing emerging trends (Lustig, 2017). The First Horizon is the current dominating trend of today – what are we doing. The second horizon represents the short- to medium-term development for the future. The third horizon is about what is emerging and will be tomorrow's trend, where the pockets of the future will be visible. Here it is difficult to find a real pattern - or just to imagine what the emerging trends can be. It might be difficult to distinguish between horizons. The second horizon overlaps and link the current practice and the new elements of the third horizon and is a transition space. In order to be able to draw attention to the third horizon in the interviews, respondents were asked to both reflect upon how the present engineering education practice meets the challenges of today and how they imagine this to change in the long-term future, 10 years ahead. However, even when several of the institutions were undergoing changes, this proved to be challenging. It is difficult to imagine future trends and the interviews cover both what the respondents actually anticipate of the future, and the present challenges.

Context of the study

The universities offer engineering education of a similar structure, as all countries have adapted the Bologna agreement, in which 29 European countries agreed upon a system where students complete a 3–4-year bachelor’s degree which may then be followed up by a 1-2 years master’s degree (Case 2017). The learning outcomes are similar but not identical, as the Bologna model aims for students should be able to transfer between universities and countries throughout their studies. Most students do not enter the job market after their bachelor’s degree but rather finalize their master’s degree before entering the job market.

The universities vary in size, and in what educational model they have adapted. Three of the five universities describe themselves as a university that offers students an educational model that is special to their engineering education, but no more special than that the model works within the Bologna model.

Settings

Four professors at each of the five partner universities were selected to participate in a semi-structured interview. Out of the 20 interviewees, the majority hold a position as full professors and the others associate professors representing the following four engineering disciplines. 1. Biotechnology engineering 2. Mechanical (or industrial economy or production) engineering 3. Energy engineering 4. Civil engineering. They were chosen as either having a managing position in education at the university or a strong research position. The engineering disciplines were chosen because they constitute common engineering disciplines that have existed for a relatively long time. They also represent different types of engineering disciplines, where production, energy and civil engineering are seen as disciplines originating from the needs of industry, while biotechnology, chemistry and mechanics are more closely related to the traditional academic subjects. These disciplines were also available at all the participating universities, albeit under slightly different names and descriptions. As the effect of digitization was one of the challenges that the study intended to investigate, it was chosen not to include computer engineering as one of the disciplines to be investigated.

Interviews

Most interviews were conducted by two persons from the project team: one main interviewer and one representative from the university of interest. On average, each interview lasted about one hour. Before the interview took place, the informants were provided with the interview protocol, including the questions and short texts presenting the three contemporary grand challenges the informants were asked to specifically reflect upon, sustainable development, digitalization of society and future employability. In this study, only sustainable development and digitalization is considered. They were also asked to give their personal perceptions of how the development of their research field was affected by the implementation of knowledge linked to the grand challenges.

The following questions formed the basis of the interviews.

1. How do you think the challenges affect the development of your discipline?
2. How do you think the challenges will affect the educational programme(s) you are involved in?
3. What do you expect the situation to be 10 years from now?
4. How will students learn engineering in the future?
5. Are there other challenges ahead that we have not mentioned?

The interviews were transcribed verbatim and were analysed with the help of the NVivo software. Due to the aim of this research an iteration between data-driven and concept-driven coding have been used. In the preliminary phase of the coding data was the driver of the coding, giving a possibility to detect and elaborate on important topics and elements from the interviews. Three coders have been coding the interviews, securing a wide perspective on findings from the interviews. Based on the three coding, six thematic concepts were highlighted. Data was then yet again coded, branching the interviews into these 6 thematic concepts, “Digitalization in education”, Sustainability”, “Industry 4.0”, “Employability”, “Interdisciplinarity” and “The future Engineer”. For this paper, focus has been on elaborating on the role and education of the future engineer and in particular on the themes sustainability, Industry 4.0. In doing so, it has been possible to create an overview of how the different interviewees envision the future of engineering education, creating a matrix of methods, approaches and competences for the future. As the interviews have been conducted with different universities and people from different programs, the aim of this research has not been to compare or find a common way of viewing the future of the engineer. Instead, the aim has been to highlight differences and similarities across different disciplines and countries providing understandings and approaches for how the broad field of engineering will be developed in the future.

Findings

The themes Sustainability and Industry 4.0 can be considered drivers for change, whereas the theme “Future engineering competences” is considered to represent the faculties’ present and future response to challenges such as sustainable development and opportunities such as Industry 4.0. There is consensus in the interviews that the need for Sustainable development and Industry 4.0 is and will change society. However, different opinions are expressed, concerning the change on teaching and future curricula. In the following two tables, an overview is presented.

Table 1: Findings according to country and discipline

Name of university	Interview 1	Interview 2	Interview 3	Interview 4
Aalborg University • Sustainability • Industry 4.0	Civil • Boundary condition – demand. Sustainable context. • New tools 3D Modelling, 3D printing	Bio • No big change (no push) • Big data – from lab to data analysis. Personalized medicine.	Energy • Agenda- Everything more sustainable • Big data, Energy "handling"	Production • Moral obligation. In our genes. • Analyse data (lack of it skills) Big and small. Transform from operation to monitoring, controlling. AI.
Aalto University • Sustainability • Industry 4.0	Mechanics • Academic advisor, student centred education. Focus on what the want to focus on. • More computations. A lot of data from tests	Bio • No demand. Not related to the core. New materials. Separate life. Teacher cooperation • Robotics, more programming, 3D..	Construction • Big issue. Using natural resources. Sustainable materials. Life-cycle-analysis. • Material technology, life-long-learning	Mechanical • Defined by law that companies make profit. No push for sustainability. Needs to be – no options – more panic • Both optimistic and pessimistic. Don't know how far it will go. Disappointing experiences.
KTH (Royal institute of Technology) • Sustainability • Industry 4.0	Production • Broad topic. Life cycle. Systems engineering. Track things – Big data, AI – cyber sec. More cross disciplinarity – no siloes • Getting competent people. Eco-syst.	Bio (technology) • A new sort of cross disciplinary program with clear focus on climate change or environment. Delayed response in well respected disciplines Math, physics. New education related to sustainability. • Life-long-learning	Civil • Environmental impact in building. – heating, life cycle, moisture, • More programming, Information models. Tools 3D objects.	Energy • More generalists less specialists. More holistic view on systems – needed in managed sustainability. They need to have good understanding for natural sciences. But also social sciences. • New materials. Education is not keeping up with speed in industry and society.
Reykjavik University • Sustainability • Industry 4.0	Civil • No push. Cheap warmth – less isolation. Getting more rain. Hydro power and geothermal. Few electrical cars – because of distance. • 3D modelling, AI, Strict building regulations last for 50 years.	Mechanical • No push. Ethics of engineers is important. Sustainability aspect in study • Collaboration – user is always human. Automatizing of things	Bio medical • No push. Just more and more need for education about sustainability. No interest a little bit of the track for biomedical engineering. Can be some project, can be a theme or something in different courses. • Big data, e-health	Production • No push. The sustainability has become much more acceptable than it was when I was in school. Life-cycle-analysis • AI, Data (huge amount), controlling data
University of Stavanger • Sustainability • Industry 4.0	Civil • Not change much. Need basis theoretic and that will be the same. New materials. Focus needs to change in education • BIM, 3D printing	Mechanical • New materials, new methods of creating energy. • 3D printing, programming	Bio • Cope with them both in a theoretical and practical aspect. New ethics. • More is robotized (pipetting). More programming	Mechanics • No push. Will change when shaping the curriculum according to society. Discussing how can digitalization in education contribute to sustainability. • Digitalized manufacturing Robotised. 3D printing.

Table 2: Findings according to discipline and issues

Study Programme	Sustainability	Industry 4.0	Future Competences (how to achieve the challenges)
Bio	• No big change (no push) • No demand. Not related to the core. New materials. Separate life. Teacher cooperation • A new sort of cross disciplinary program with clear focus on climate change or environment. Delayed response in well respected disciplines Math, physics. New education related to sustainability. • No push. Just more and more need for education about sustainability. No interest a little bit of the track for biomedical engineering. Can be some project, can be a theme or something in different courses. • Cope with them both in a theoretical and practical aspect. New ethics.	• Big data – from lab to data analysis. Personalized medicine. • Robotics, more programming, 3D.. • Life-long-learning • Big data, e-health • More is robotized (pipetting). More programming	• No major changes to what they are doing now (courses, implementation of sustainability etc.) • More international collaboration • Life long learning • Knowledge of how to cope with complex problems • Strong disciplinary skills (the transdisciplinarity can be there but the disciplinary skills comes first) • More T shaped engineers in the future • Multi-disciplinary, multi-cultural projects
Civil	• Boundary condition – demand. Sustainable context. • Big issue. Using natural resources. Sustainable materials. Life-cycle-analysis. • Environmental impact in building. – heating, life cycle, moisture, • No push. Cheap warmth – less isolation. Getting more rain. Hydro power and geothermal. Few electrical cars – because of distance. • Not change much. Need basis theoretic and that will be the same. New materials. Focus needs to change in education	• New tools 3D Modelling, 3D printing • Material technology, life-long-learning • More programming, Information models. Tools 3D objects. • 3D modelling, AI, Strict building regulations last for 50 years. • BIM, 3D printing	• Holistic academic engineers (understand the detail in combination with the whole system) • Each engineer will have to know the context → not durable with just a synthesizer at the end. • System thinking + fundamental core skills • Workmanship (planning processes, systematical thinking) • Life long learning (stop imagining we can teach everything)
Energy	• Agenda- Everything more sustainable • More holistic view on systems – needed in managed sustainability. They need to have good understanding for natural sciences. But also social sciences.	• Big data, Energy "handling" • New materials. Education is not keeping up with speed in industry and society. • Balance between new things – too many thing – shallow – a combination.	• Use of linkedin/internet for networking • System thinking skills • Critical thinking skills • Solving problems in new ways • More generalists less specialists.
Production	• Moral obligation. In our genes. • Academic advisor,student centred education. Focus on what the want to focus on. • Broad topic. Life cycle. Systems engineering. Track things – Big data, AI – cyber sec. More cross disciplinarity – no siloes • No push. The sustainability has become much more acceptable than it was when I was in school. Life-cycle-analysis	• Analyse data (lack of it skills) Big and small. Transform from operation to monitoring, controlling. AI. • More computations. A lot of data from tests • Getting competent people. Eco-syst. • AI, Data (huge amount), controlling data	• Being able to handle data • Move away from the narrow specialist (have the deep dive but still keep the context broad to keep the generalism) • The T or ∏ shaped engineers • We need to have both the engineers with the deep dive and the system thinkers. • More interdisciplinary team work • Combine fundamental skills with contextual knowledge
Mechanical	• Defined by law that companies make profit. No push for sustainability. Needs to be – no options – more panic • No push. Ethics of engineers is important. Sustainability aspect in study • No push. Will change when shaping the curriculum according to society. Discussing how can digitalization in education contribute to sustainability. • New materials, new methods of creating energy.	• Collaboration – user is always human. Automatizing of things • Digitalized manufacturing Robotised. 3D printing. • Programming skills • 3D printing, programming	• Technical skills • The disciplines themselves are likely to change • System thinking is lacking • Always a need for very specialized engineers • Life long learning

Sustainability

In terms of sustainability, clear differences are seen among the countries. The push for sustainability seems to be dependent on what country the informant represents rather than what discipline they represent.

A country such as Iceland seems to be less inclined to push for including sustainable development in education than some of the other countries. This fact is seen across all the disciplines. Iceland geographical conditions, with relatively long distances between places, have resulted in low numbers of electrical cars and the geological conditions in Iceland offer opportunities for using inexpensive energy such as hydropower and geothermal heating, compared to the other Nordic countries. As a result, for example indoor heating is very cheap, thus influencing civil engineering to a degree where less isolation is needed. Nevertheless, ethics of engineers is considered important for mechanical engineering education, and there is a responsibility to include sustainable aspects in the study programmes. More and more education in sustainability is needed and sustainability has been more accepted as a part of education during the last years.

Similar to Iceland, Norway seems to push very little for sustainability in the disciplines; however, the study indicates that there is a need for this to change, and as for mechanical engineering, it will change when the curriculum is shaped according to what society expects. Still, focus is on basic engineering knowledge, such as how mechanical systems work. For civil and energy engineering in Norway, new materials will be introduced and new methods for creating energy will emerge, however, the basic theoretic are expected to stay the same.

In Finland, there is no general push for sustainability either, but in mechanical engineering there are considerations that students should be able to choose courses to create an education based on their interests. For civil engineering in Finland, Sweden and Denmark there is a push for sustainability. In Finland it is considered a big issue, involving use of natural resources, sustainable materials and Life-cycle-analysis. In Sweden there is an environmental impact in building – heating, life cycle, moisture etc. and in Denmark it is mentioned as a boundary condition - a demand where the end user and funding agencies want a context that is sustainable. Opposite to this, civil engineering in Norway sees no push or change regarding sustainability. Students must learn the basic theoretic and this will stay the same regardless of external influences.

In terms of production there is a certain push in Sweden and Denmark. In Denmark, it is regarded a moral obligation, something that should be in their genes. But it is complex and they often have discussions about not knowing the consequences of the decisions made on sustainability. However, Danish students should not be leaving university without knowing they have an obligation and also have some opportunities. In Sweden, sustainability is considered a broad topic, involving important areas such as life cycle, systems engineering, the ability to track things (Big data, AI – cyber security) etc. and a need for more cross disciplinarity without siloes.

Looking at biotechnology and sustainability in particular, many similarities are found across the countries. Sustainability is not considered the core of the discipline, hence there is no push and less expectation for changes. In Finland, for example, no one is asking for more environmental microbiology, they want to have things that are more related to what they feel is the core. In general, all countries, focus more on “white” biotechnology rather than green biotechnology. Sustainability is considered an enormous area with many aspects to take into account. From Norway it is noted that even if there are potentials of solving problems, sustainable research comes with ethical limitations. For example - GMO – genetic modifications may be used to a higher degree for achieving sustainable solutions, however not all countries allow handling with GMOs.

Within the field of Energy, two professors from Sweden and Denmark have participated in this study. In Sweden, sustainability creates a focus on educating engineers who are able to have a holistic view on the systems working with. Fundamental knowledge of natural systems must be aligned with insight and knowledge from social science. In Denmark, the agenda is to make things more sustainable. The technology solutions for doing so are implemented. There are no new technologies that can really radically change the thinking, but there needs to be more effort put into opening the eyes for the students. Energy engineering in Sweden mentions more generalists less specialists and a more holistic view on systems is needed in managed sustainability. The students need to have a good understanding for natural sciences, but also for social sciences.

Industry 4.0

Compared to the challenges of sustainability, the challenges or opportunities concerning Industry 4.0 seem more similar among the countries. Big Data, AI, robots are all concepts that are connected with Industry 4.0. However, the ability to access Big Data affects the engineering disciplines differently. Personal medicine, e-health, biodata, energy management, test data and production data, etc. are some of the areas the informants mention as future areas. The development of 3D printing and 3D modelling is mentioned as important in several disciplines, especially civil engineering sees a great potential when it comes to BIM (Building Information Modelling).

Along with the appearance of new technologies and new tools, new routines and methods will follow, which will eventually influence the disciplines. In Denmark, this change is already present within biotechnology. More work is robotized, such as pipetting, and there is an ongoing transformation from students' lab work to data analysis. The use of Big Data has been part of biotechnology in Sweden and Norway for a long time. In production, the manufacturing process has been digitalized and a transformation from monitoring to controlling data becomes very crucial. For civil engineering and construction new materials emerge. Moreover, Energy engineering in Sweden describes new materials and the problem that education is not keeping up with speed in industry and society.

Future Engineering Competences

With an overview of focus points and challenges in relation to the themes sustainability and Industry 4.0, the professors identify a demand for changes in the curricula, embracing the demand for new engineering competences in the future. Here the significant differences are to be found among the disciplines more than among the countries. In general, difficulties concern the inclusion of new competences, as present curriculum is already filled with courses, project work and assignments spanning the full semester. Within biotechnology in particular, it seems crucial to keep the basic elements of physics and mathematics in the curricula, providing students with fundamental knowledge through existing courses. Biotechnology stresses the necessity of a strong disciplinary foundation and sees it as a part that cannot be neglected or reduced. Highlighting a necessity to come up with new tools and methods for how to expand and keep the professional edge. For the mechanical programs, it is stressed that the disciplines themselves are likely to change, but technical skills are mentioned as essential. Society will always need very specialized engineers who can nurture the basic foundation of the subjects, securing engineers to be able to handle and unfold the basic elements of the systems working in.

More of the disciplines regard holistic engineers, with strong system thinking skills, as essential for the future. In the future, more interdisciplinary teamwork will be required, and the ability to combine fundamental skills with contextual knowledge will be essential. Engineers will have to understand the details in combination with the context, giving the engineers a more holistic understanding of the problem with which they are working. Interviewees within the field of Civil Engineering in Denmark state the importance of holistic engineers who are able to combine their fundamental core skills with contextual system thinking. The future engineer must be able to bind the bits and pieces together in a broader context. The field of production also emphasizes the importance of a contextual understanding as an essential competence when entering the industry afterwards. It is concerned with providing students with deep disciplinary knowledge though still keeping the generalism at a level where the students are able to connect and interact with other disciplines. Creating a matrix combining vertical deep fundamental knowledge with horizontal interactions and contextual understandings across disciplines.

Even though biotechnology states the importance of deep fundamental competences, biotechnology in Finland also sees a need for educating engineers to be more skilled in using tools and methods for the future complex problems we are facing today. People are concerned with the unresolved issues we are facing, and it is emphasize to the importance of teaching engineering students to cope with these complex societal challenges and to translate these abstract, wicked challenges into manageable problems. It is about moving away from focusing only on educating the "I-shaped" engineers but to also focusing on educating "T-shaped" engineers with connections, understanding, respect and better capabilities for co-working with experts from other fields.

Production states the importance of data handling in the future. Engineers must have a profile that moves away from the narrow focused specialist towards more T shaped profiles or ∏ shaped engineers. Working with Big data is considered important for almost every discipline. Engineers should have professional knowledge about data, having in mind how to handle and analyse data, work with new tools like 3D modelling and develop efficient programming skills. For some of the disciplines there is a gap between the need and the competences available at present. Production in Denmark mentions a lack of skills concerning data analysis, and production in Sweden mentions the challenge of getting competent employees in the future. The combination of an extreme technology push for new markets and of getting hold of the right competences creates a need for life-long learning. Mechanical engineering in Iceland talks about automatisation, robots and programs and the relation to the user that is always a human being and how is it going to react to these new things. Therefore, the social and psychological effects of the industrial revolution need to be considered as well. Production in Denmark does not distinguish between small or big data but highlights the importance of engineers with competences to analyse the state of the system and know how to work based on data. Another digital aspect highlighted as important in the future is the use of Linkedin and the internet in general. Energy from Denmark emphasizes the importance of teaching future engineering graduates to use the internet in a smart way, applying and building strong professional networks around the world. Both in terms of knowledge sharing, research and competence development.

Conclusion

There are differences among the educational policies in the Nordic countries which become visible in the policies for the integration of sustainability in engineering education. Engineering is not just engineering. Engineering disciplines differ in how they approach the future engineering education. Engineering disciplines range from disciplines focused on basic sciences such as chemistry, physics, energy – all closely related to natural phenomena – to engineering disciplines established to solve problems or to fulfil needs and demands from society and industry. The study shows differences in how engineering disciplines respond to the external factors of sustainability and industry 4.0. Due to both disciplinary differences and differences among the countries, there are differences in the approach to sustainability. Basic sciences such as biotechnology stresses the importance of keeping a focus on core, fundamental competences essential for engineers now as well as in the future. As opposed to this, civil engineering is stressing the need for more holistic engineers in the future, able to apply a system thinking approach to problem solving. In general, all disciplines appear to have difficulties adding more to present curricula; this seems to be a barrier, and the universities struggle to find the right balance between deep fundamental knowledge in combination with interdisciplinary system thinking. However, more of the respondents in this study highlight the importance of students being able to learn-to-learn, to be able to adapt and develop their competences in a lifelong learning process. Methods and curricula must enable engineering students to understand and cooperate across disciplines and by that tearing down the walls between disciplines. An engineering profile that resonates well with the T-shaped engineering profile, which focuses on understanding the details of the problem in combination with an overall understanding of the system working in.

References

Case, J. M. (2016). The historical evolution of engineering degrees: competing stakeholders, contestation over ideas and coherence across national borders. *European Journal of Engineering Education, 42*(6), 974-986.

Everett, M. C. (2016). Interdisciplinary Studies: A Site for Bridging the Skills Divide. *Journal of Effective Teaching, 16*(2), 20-31.

Kolmos, A. (2021). Engineering Education for the Future. In UNESCO (Ed.), *Engineering for Sustainable Development* (pp. 121-128). Paris: UNESCO.

Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. L., & Bolle, M. (2015). Man and machine in Industry 4.0: How will technology transform the industrial workforce through 2025. *The Boston Consulting Group. from* https://www.*bcgperspectives.com/content/articles/technology-business-transformationengineered-products-infrastructure-man-machine-industry-4*.

Lustig, P. (2017). *Strategic Foresight: Learning from the future* (Vol. 7): Triarchy Press. Kindle Edition.

Magnell, M., Geschwind, L. A., Gumaelius, L. B., & Kolmos, A. (2014). *Faculty approaches to working life issues in engineering curricula.* Paper presented at the 121st ASEE Annual Conference & Exposition.

Magnell, M., & Kolmos, A. (2017). Employability and work-related learning activities in higher education: how strategies differ across academic environments. *Tertiary Education and Management, 23*(2), 103-114.

Nahavandi, S. (2019). Industry 5.0—A human-centric solution. *Sustainability, 11*(16), 4371.

National Academy of Engineering. (2007). Grand Challenges for Engineering, from http://www.engineeringchallenges.org/

Onday, O. (2019). Japan's society 5.0: going beyond industry 4.0. *Business and Economics Journal, 10*(2), 2-7.

Rosenberg, S., Heimler, R., & Morote, E.-S. (2012). Basic employability skills: a triangular design approach. *Education+ Training, 54*(1), 7-20.

Sammalisto, K., Sundström, A., & Holm, T. (2015). Implementation of sustainability in universities as perceived by faculty and staff–a model from a Swedish university. *Journal of Cleaner Production, 106*, 45-54.

Schwab, K. (2016). Shaping the Fourth Industrial Revolution. January 11, 2016. In.

Shepard, K., & Furnari, M. (2013). Exploring what university teachers think about education for sustainability. Studies in Higher Education, 38(10), 1577-1590.