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Engineering education in change. A case study on the impact of digital transformation on content and teaching methods in different engineering disciplines

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ABSTRACT
This study investigates the question of how Engineering education in the Nordic region responds to the challenge of educating future engineers who are ready for professional practice in a digital world. Particular interest is put on identifying who is responsible for the implementation of digital knowledge and what and how subject content is addressed. Our study draws on Bernstein’s pedagogical device model (Bernstein, B. 2002. “Editorial: Basil Bernstein’s Theory of Social Class, Educational Codes and Social Control.” British Journal of Sociology of Education 23 (4): 525–526). The study focuses on the questions of if/how digital transformation leads to change of engineering education content and/or pedagogical approaches. Narratives of 20 university teachers have been collected and analysed. Findings reveal three areas of consideration; there is a connection between how digital knowledge is valued and how the subject is introduced in engineering education, differences in digital knowledge can be linked to the generation gap and, universities are seldom seen as the driving force for digital innovation. It is concluded that education must reflect on the purpose for which digitalisation takes place, continuous training targeting digital transformation should be offered to senior teachers and, universities need to provide increased focus and dedicated time for educational development.

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Digitalisation; digital transformation; engineering education; Nordic universities; qualitative study

1. Introduction

Today’s global society faces a number of grand challenges that must be properly addressed if society is to evolve towards a desired future. Many factors influence the direction of the changes needed, and a range of different actors have different perspectives on these challenges. Technology development is often presented as an area that is both influenced by and part of the solution to these grand challenges. Engineering and engineering education are therefore important pieces of the puzzle of addressing these challenges. To ensure that future professional engineers acquire skills needed, is a necessity (Abdulwahed et al. 2013; Baruh 2012; May and Strong 2006; Sunthonkanokpong 2011; Teknikföretagen 2020).
In this pre-Covid study, one of these grand challenges is in focus; the digitalisation of society and how it is met by engineering education institutions. The overarching aim is to explore engineering education’s propensity to adjust operations in order to ensure that future engineers working with the digital transformation are educated in a desirable way.

We are mainly interested in describing and understanding actors and factors that are important for (1) the process of establishing digital transformation knowledge in engineering education, (2) the legitimacy of digital transformation knowledge in engineering education, (3) the teaching of digital transformation itself, i.e. how the content of the discipline is transformed into activities for teaching and learning.

An additional aspect of the digital transformation in engineering education of interest to our study is the question of whether the teaching practice per se will be affected by the pedagogical opportunities implied by digitalisation? The following research question is put forward:

What insights could be obtained regarding the development of engineering education due to the digital transformation based on analysing the narratives of 20 university teachers?

Within the framework of the study, sometime-related reflections on views expressed regarding educational change in the short and long term (today and the coming 10-year period) will also be made.

The study is based in a Nordic context. The selection of participants has been guided by the proximity principle. The five participating universities are part of a network that has been built within the framework of a research collaboration, named the Nordic Engineering hub (2022). Three of the four authors of this paper are members of this network. This combination of inside-outside perspective provides (handled with care), the benefit of a pre-understanding of prevailing decision-making processes. The Scandinavian countries constitute a relatively homogeneous group of countries that partly share culture and geographical environment. At the same time, these countries have completely separate political steering systems, which means that universities and education have nevertheless had the possibility to develop quite independently of one another. The study focuses on the perspective given by the university faculty. Teachers from five Nordic universities, each representing one Nordic country, Denmark, Finland, Iceland, Norway, and Sweden are included as participants. The teachers represent four different engineering disciplines: mechanical engineering, civil engineering, biotechnology, and energy engineering. These disciplines can be seen as common engineering disciplines in the Scandinavian context that were offered at all selected universities.

This study is a subset of a broader investigation that also explores challenges such as sustainability and employability. An initial publication, Worm Routhe et al. (2021) provide a comprehensive overview of the findings.

Qualitative research aims at describing and understanding a phenomenon (here, the development of engineering education in terms of digital transformation). Carried out well, the recognition factor based on a qualitative study is high (Asplund 1970; Skogh 2001). A broad description and an increased understanding of the process of digital transformation in engineering education in the Nordic region may therefore have potential to be of interest in contexts outside the Nordic countries.

2. Background

2.1. Engineering education – balancing between ‘old school’ and demands for interdisciplinary approaches

Engineering is central to many of our major societal challenges. The question of if this means that engineering education is effectively adapted to ensure that professional engineers acquire skills needed to tackle these challenges, is debated. Several studies claim that education in general needs to be updated and adjusted in order to deliver graduates who can handle the great challenges of our time (Abdulwahed et al. 2013; Baruh 2012; May and Strong 2006; Sunthonkanokpong 2011).

From time to time, the higher education sector receives criticism for being conservative and not adapting to contemporary changes quickly enough (Baruh 2012; Berge, Silfver, and Danielsson 2019;
Teaching takes place in accordance with subject disciplines that are often the same as they have been for a very long time. Regarding the engineering education of today, the labour market has expressed that universities are far too slow to change for the good of society, implying that today’s engineers do not possess the qualities they need to work in contemporary society (Eberhard et al. 2017).

A counterargument to this statement, sometimes claimed by the third-level education sector itself, is that a slow change may be desirable since universities offer a stable knowledge base, which should not be affected by the short-term needs of financial ventures but rather contribute to societal development in a more long-term and sustainable way. Throughout history, contradictions between actors have led to engineering education undergoing various stages of development, balancing between focusing on adapting to the needs of the labour market, the market-driven mode, and focusing on its strong academic identity, the academic mode.

Today, another transformation trajectory for universities – the hybrid mode – is commonly applied. Here theoretical and practical components of engineering work is combined with social and cultural understanding (Jamison, Christensen, and Botin 2011). Jamison, Christensen, and Botin (2011) depict this hybrid mode as engineering education with an academic focus combined with a market driven focus and hereby developed into something more holistic where social and cultural understanding are important factors. This hybrid mode resembles what other authors describe as holistic engineering education or heterogeneous engineering education, approaches that are also seen as the solution to integrating social perspectives into engineering education (Buch 2016; Date and Chandrasekharan 2018). All these newer approaches to engineering education are seen as desirable as they intend to provide better conditions for educating graduates who can handle not only technical problems but also interdisciplinary societal challenges.

2.2. Engineering education in a Nordic context

Universities in the Nordic countries are relatively autonomous in determining the content of engineering education. As all four countries participate in the Bologna Process they are linked to each other regarding the learning outcomes. This allows students to switch universities and countries within Bologna between undergraduate and postgraduate levels. In all countries (Icelandic Qualification Framework for Higher Education 2022; National Curriculum Regulations for Engineering Education in Norway 2022; Swedish higher education ordinance 2022; The Finish Higher Education Qualification Framework 2022) except Denmark, national general learning outcomes are decided upon, while in Denmark, educational content is controlled by measuring the employability of graduates (Act on universities in Denmark 2022). The general learning outcomes used for engineering education are although relatively similar for the Nordic countries (including Denmark). The level in which the outcomes are described is rather abstract. Instead, this is an issue that is dealt with when the learning outcomes are translated in levels down to learning outcomes and content at programme and course level (Kvilhaugsvik 2020). Only the Norwegian and Icelandic learning outcomes contain a national level statement stating that the graduated engineer needs to have specific digital skills. How engineering education is designed in terms of digital transformation therefore depends on how processes are managed within universities.

2.3. Digital transformation and its impact on engineering education

The definition of what is included in the term digitalisation varies. According to Verhoef et al. (2021), who take an interdisciplinary approach, digital transformation takes place through several different phases. Stage one, named digitisation, includes the actual transformation from analogue technology to digital technology. Stage two, named digitalisation, includes the development of IT solutions to improve existing systems and processes. Stage three, named digital transformation, is the most pervasive phase which also includes how completely new processes, disruptive technologies, and
solutions are developed based on the first two phases. In a literature review conducted by Bongomin et al. (2020) disruptive technologies were identified as future key technologies including; the Internet of Things, Big Data, 3D printing, cloud computing, autonomous robots, virtual and augmented reality, cyber-physical systems, artificial intelligence, smart sensors, simulation, nanotechnology, drones and biotechnology.

Today we are still in the middle of the digital transformation and developments are taking place in society in different ways in all three phases. In this paper, the terminology described by Verhoef et al. (2021) is used. However, since references and interviewees use their interpretation of the word digitisation, digitalisation and digital transformation, certain adaptations to this terminology have had to be made.

The fact that disruptive technologies are now available for industrial as well as public applications places a great demand on engineers to have the right knowledge and skills to develop new applications in these areas. A Swedish report conducted by the industry association of technology companies states that ‘The overall technology trend that affects the need for skills the most right now is digitalisation’ (Teknikföretagen 2020). In a report from VDI (association of German Engineers) (Gehrke et al. 2015), experts from Germany and the USA discussed qualifications and skills they assume to be absolutely necessary (must have), good to have (should have) or desirable (could have) for future engineers. The ‘must have’ category covers IT knowledge and abilities, data and information processing and analytics, statistical knowledge, organisational and process understanding and the ability to interact with modern interfaces (human–machine/human–robot). Other studies may categorise required technical knowledge differently, but there is an overwhelming consensus that knowledge in digitalisation is crucial for the workforce of the future (Benešová and Tupa 2017; Bongomin et al. 2020).

The digital transformation in today’s society is rapid but also quite unpredictable. This means that today’s students need a broad repertoire of expertise. Several studies show that there is an increased need for students to develop personal/generic skills during their education to be able to keep up with this technical evolution. In the study described above (Gehrke et al. 2015), the following personal competences were assigned to the must-have category: adaptability and ability to change, team working abilities, social skills, communication skills, and self- and time management. In a literature review, Coşkun, Kayıkçı, and Gençay (2019) present a German study (Luo and Störmer 2018) that identify the following future requirements: interdisciplinary thinking, decision and problem solving, cultural and intercultural competence and lifelong learning. The list goes on, and although not entirely in line with each other, the studies exhibit similar patterns, where general competences are considered desirable for the future.

The effect of digital transformation in engineering education has had and will have consequences not only on the subject content but also on the teaching-learning aspect. With regard to subject content, Johnson and Ramadas (2020) argue that digital knowledge should be included in the curriculum as special courses. Universities and especially industry-production engineering education needs to ‘embrace new capabilities derived from data science, computer engineering, and other emerging disciplines’ (Sackey and Bester 2016, 113). Not everybody should be computer engineers but rather some knowledge originating from this area needs to be integrated in other engineering disciplines as well.

Adjusting the subject content and thus the curriculum means the educational context changes to include the opportunity to practice and develop generic skills. With regard to content adjusted pedagogical work methods examples are given where the students are increasingly allowed to solve open problems, or even wicked problems, instead of providing students with defined problems. These open problems should preferably have a societal connection, where the students are able to test how the challenges of working life may appear in Industry 4.0 (Bonfield et al. 2020; Catal and Tekinerdogan 2019; Coşkun, Kayıkçı, and Gençay 2019; Kamp 2020; Schuster et al. 2015; Teknikföretagen 2020). Some authors note that students benefit from work in virtual laboratories (VL) and attending online courses, where the physical environment is not limiting (Coşkun, Kayıkçı, and Gençay 2019; Richert
et al. 2016). Vergara et al. (2020) emphasise the possibilities of VL use in university teaching and staff training and support the wide implementation of VL in education and training. Schuster et al. (2015) point out that ‘companies who know how to collaborate in virtual environments efficiently will have a strong competitive advantage compared to those who do not’ (5).

The issue of if and how digital tools should be included in the pedagogical work toolbox within engineering education (streamed lectures, simulations, distance learning, digital laboratory work and presentations), is yet another aspect. Reports show that challenges arise when the new y and z generations (‘native born’ digital students) encounter institutions marked by the older generation’s often more limited digital experience. New pedagogical approaches with more emphasis on intertwining technology and media into education have affected engineering education, as programmes are being built upon the new Industry 4.0 knowledge and skills (Mason, Shuman, and Cook 2013). Teachers are changing their teaching approaches, for example, using flipped learning and similar methods built on online technology (Gommer, Hermsen, and Zwier 2016; Hwang, Lai, and Wang 2015; Mason, Shuman, and Cook 2013; Matthiasdottir and Loftsson 2019) and many teachers have experience of using videos (Bhadani et al. 2017) and different online teaching formats (Mason, Shuman, and Cook 2013). VLE (virtual lab environments) allowing virtual world tools to have proven to be promising pedagogical tools where students can practice both their technical competences but also develop their generic skills in a digital environment (Richert et al. 2016). In addition, over the past years, the COVID-19 pandemic has encouraged online course formats (Loftsson and Matthiasdottir 2021; Yen 2020).

In this section, we have presented a selection of research on digital transformation, where examples are given regarding how actors and factors have differently approached the challenge of developing digital transformation in engineering education. The aim of this study is to explore in more depth the actors and levels of decision-making for introducing digital competences and skills in engineering education. The theoretical basis for this work is presented in the next section.

3. Theoretical framework

The question of ownership regarding the selection, implementation and transformation of subject areas of knowledge judged to be future key-areas or competences is interesting, but not easily answered. Who in fact possess the power and control over this process?

As universities are themselves shaped by wider society, the power relations that become embedded within higher education institutions may actually hamper and constrain the ways in which universities contribute to development and social change. (Taylor and Boser 2006, 112)

In our study, the process of establishing digital competences in engineering education is studied. At what level, within engineering education universities lies the responsibility for the different stages in this process? Who has the legitimacy to decide, delegate, pedagogically define and implement digital transformation in engineering education? We are in particular interested in describing and understanding this process as a whole. Our choice of a theoretical model, originally developed by the sociologist Basil Bernstein, responds to this aspiration.

The focus of Bernstein’s research is on the voice (in society) of pedagogical communication. His pedagogical device approach (Bernstein 1990; 2000) facilitates a holistic view on the process of educational change by studying how knowledge, power and control come together in teaching–learning processes. The model describes the ordering and disordering principles of pedagogic knowledge (Singh 2002) and can thus be seen as a useful tool for studying the process of transforming knowledge into learning in an educational context. According to Singh (2002), Bernstein’s device ‘constituted the relay or ensemble of rules or procedures via which knowledge (intellectual, practical, expressive, official, or local knowledge) is converted into pedagogic communication’ (2).

The model of the pedagogical device was described and interpreted by Paul Ashwin (2009) to be used for analysing the integration of disciplinary knowledge in education. Ashwin (2009) claims that
the model provides tools to describe the process of the change that takes place when new knowledge is introduced into an established educational context. Bernstein’s framework uses the analytical construct of ‘classification’, which refers to the boundaries between the categories of knowledge: strong (a content area that stands for itself, without having to be associated with an already existing discipline), weak (the area of knowledge represents part of an already well-defined discipline) and very weakly classified/non-disciplinary (the area of knowledge is perceived as a competence to be trained, e.g. in project courses). These boundaries determine how a new area of knowledge is valued in an educational context. Specifically, it is in the legitimation of these boundaries that power is exerted (Bernstein 2000; Case 2011).

The present study explores the process of change that occurs when digital transformation is introduced into engineering education (a new disciplinary knowledge introduced to an established educational context). For Bernstein, the process of introducing new knowledge involves three steps, where each step is seen as the next move in a hierarchical process, meaning that the second set of rules are derived from the first set of rules and the third set of rules are derived from the second. The three steps are as follows:

1. First, the distribution rules relate to the processes that affect what subject content will be included in education: the legitimacy of knowledge (and by extension what new knowledge is actually introduced), the power relations between involved actors, and the effect the involved actors have on the content.
2. Second, the re-contextualisation rules describe how the new disciplinary content is included in the curriculum (classification and framing). They describe whether the new knowledge area is presented in a scientific/academic way, as knowledge needed in every-day situations (personal need) and/or as knowledge needed in professional life.
3. Third, the rules of evaluation consider which pedagogy is applied when integrating this new knowledge (what are considered valid realisations of knowledge acquisition, how the curriculum is transformed into teaching–learning activities).

Depending on the prevailing research traditions, educational research is labelled in different ways (see Nordic, Continental, or Anglo-American research traditions, for more detail). Hence, the terms curriculum studies, general didactic, or pedagogy evoke several associations, which leaves room for an interpretive space that contains both status differences and more or less well-founded conclusions regarding research focus. However, the classical curriculum theory questions – what should be taught, who should teach, and how the chosen teaching should be taught – can be said to be timeless and frameless. The content that follows from these questions, that is, the organisation forms, the teaching arrangements and the ways in which learning outcomes can be controlled and assessed, is addressed (under different headings) by educational research in most countries (Håkansson and Daniel Sundberg 2012).

Bernstein’s pedagogical device model is designed for studies on the process of introducing new knowledge content in education. The pedagogic device model is applicable regardless of level of education. Depending on the educational context and the nature of the (new) knowledge in question, implementation decisions may have to be made at a national level (curricula, national degree objects), while in other cases decisions may be made within a university or university college.

Figure 1 visualises Bernstein’s pedagogical device model. The figure illustrates how the three curriculum theory questions (WHAT, HOW, WHO) are formulated and reformulated in the various steps of the process. Regardless of educational context, the implementation of a new subject content starts with the actor responsible for formulating new knowledge (WHO), where power and knowledge are ‘closely related to who has the right to impact knowledge and which knowledge is considered valid’ (Bernstein 2000).

In Figure 1, the initial step (WHO to WHAT) is placed slightly above the other steps. Although power and control are included to some degree in all three steps, it is the initial step that sets the
framework for what is to be transferred to the recipient(s) (‘whom’), in this case, students in engineering education. Proposals and requirements, also from actors outside decision-making institutions (e.g. industry, politics), make requests and demands that a new area of knowledge should be introduced. However, the owner of the decision-making process (implementation or not) is the actor responsible for formulating subject content (WHAT).

In the second step of the process, the subject area in question is specified and formulated (WHAT). This includes a chain of decisions regarding the transformation of the legitimate knowledge into pedagogic discourse (HOW).

In the third step, the overall pedagogical discourse (HOW) is transformed into teaching practice, including deciding who is qualified to teach, framing desirable knowledge and competences (e.g. lab work vs lectures, assessment requirements, and follow-up methods).

4. Method

This research study is designed as a qualitative-interpretive case study (Marshall and Rossman 2011). It is interpretive since the digital transformation is tacit in nature (Becerra, Lunnan, and Huemer 2008). According to Yin (2009), this research method is commonly used for exploration when ‘a how or why question is being asked about a contemporary set of events, over which the investigator has little or no control’ (13). Furthermore, a case study tries to broaden and generalise theories (Yin 2009). This case study strives to expand the theoretical lens of educational change in engineering education through digitalisation based on a case described through Bernstein’s pedagogical device (Bernstein 1990; 2000). Digital transformation as a contemporary phenomenon entails empirical inquiry that is investigated in a holistic nature.

4.1. Context

The selection of participants has been guided by the proximity principle. All participants work at universities participating in the ’Nordic Engineering hub’ between five universities in the Nordic countries, namely Aalborg University, Denmark, Aalto University, Finland, KTH Royal Institute of Technology, Sweden, Reykjavik University, Iceland and University of Stavanger, Norway. All five universities offer engineering education with a similar structure, as all countries have adapted the Bologna agreement, in which 29 European countries agreed upon a system where students first
complete a 3–4-year bachelor’s degree which can be followed up with a 1–2-year master’s degree (Case 2017). The learning outcomes are similar but not identical, as the aim of the Bologna model is for students to be able to transfer between universities and countries throughout their studies. A majority of engineering students do not enter the job market after completing their bachelor’s degree but finalise their master’s degree first. As described in Table 1, the universities vary in size, ownership and funding as well as in what educational model they have adapted.

Three of the five universities describe themselves as a university offering students a specific university-unique model of education that works within the Bologna model. The most famous one is probably the Aalborg PBL model, as Aalborg university has offered engineering education with problem-based learning since 1974 (Kolmos, Fink, and Krogh 2006). Reykjavik University has formed its own model, where students take 12 weeks of courses followed by three weeks of projects that reflect the content of the courses they have just finished, a model that was developed in 2002 and has been in place since 2012 in all departments. The model at University of Stavanger is a mixture of the Bologna model and the Washington accord model (which applies in the Anglophone world), as all students have a common first year of basic engineering before they choose their specific engineering discipline. The University of Stavanger started its engineering education in 2005. Aalto University and KTH, the Royal are the oldest entities with strong research traditions compared to the other three and do not emphasise any specific pedagogical approach.

4.2. Settings

Twenty university teachers were chosen to participate in semi-structured interviews, four from each of the five partner universities. Of the 20 interviewees, the majority (14) hold a position as full professors, while the others (6) hold positions as associate professors, representing the following four engineering disciplines: (i) biotechnology (5), (ii) mechanical (or production) (8), (iii) energy (2) and (iv) civil engineering (5).

In line with our intention to target individuals with insight in the processes of change within their university, most of the informants have some sort of managing position within education at the university. No distinction was made by the informants regarding their exact position/level in the power hierarchy of their respective universities. Our intention was to find participants in management positions as we believe they have a better understanding of the processes of change at their respective universities. To varying degrees, teaching is/has been included in the participants’ duties (e.g. lectures, course responsibility). The chosen engineering disciplines were selected because they constitute traditional engineering disciplines. They also represent different types of engineering disciplines. Mechanical engineering is definitely the most diverse discipline which originates from classical mechanics, oriented towards production. The discipline encompasses the development, design, production, commissioning and operation of products, systems, and processes. Students in this discipline can often choose different specialisations, including programmes more leaned towards classical mechanics to programmes leaning towards computer-aided techniques as

<table>
<thead>
<tr>
<th>Name of the university</th>
<th>Country</th>
<th>Number of students (2020) total/EE stud.</th>
<th>Structure of EE</th>
<th>Type of university</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aalborg University</td>
<td>Denmark</td>
<td>20,000/8000</td>
<td>PBL methodology</td>
<td>Public owned</td>
</tr>
<tr>
<td>Aalto University</td>
<td>Finland</td>
<td>12,000/3500</td>
<td>Most programmes have established multidisciplinary first-year projects 2 semesters per year and 20 weeks per semester</td>
<td>Foundation based</td>
</tr>
<tr>
<td>KTH (Royal Institute of Technology)</td>
<td>Sweden</td>
<td>13,600/most students</td>
<td>2 semesters per year and 20 weeks per semester</td>
<td>Public owned</td>
</tr>
<tr>
<td>Reykjavik University</td>
<td>Iceland</td>
<td>3800/1418</td>
<td>12 weeks of courses followed by three weeks of projects</td>
<td>Privately owned (publicly funded)</td>
</tr>
<tr>
<td>University of Stavanger</td>
<td>Norway</td>
<td>12,000/2800</td>
<td>A common first year for all EE students</td>
<td>Public owned</td>
</tr>
</tbody>
</table>
mechatronics. These four disciplines were available at all the participating universities, albeit under slightly different names and descriptions. However, in the study, participants from energy engineering are represented only from Denmark and Sweden, in Norway, Finland, and Iceland two university teachers representing different branches of mechanical engineering were interviewed as substitutes for energy engineering. As the effect of the digital transformation was the challenge that the study intended to investigate, computer engineering was not included as one of the disciplines to be investigated even though all of the universities had a programme named computer engineering. In summary, there are differences between the Nordic countries in parts of the university’s management, organisation, and delegation. However, to deal with power structures and hierarchies within universities, in society and in the business community is common to involved actors in the Nordic countries, and possibly to actors in other parts of the world.

4.3. Interviews

The interviews were conducted face to face in the vicinity of the participants’ workplace at the university by one or two researchers from the project team. On average, each interview lasted about one hour. Before the interview took place, the participants were provided with the interview protocol, including the following questions:

1. How do you think the challenge of digitalisation affects the development of your discipline and the educational programme(s) you are involved in?
2. What do you expect the situation to be 10 years from now?
3. How do you prepare your students for the future using today’s educational resources?
4. How will students learn engineering in the future?

In order to minimise the risk of influencing the participants’ answers, we chose to consistently use the term digitalisation during all interviews without distinguishing which phase of digital transformation that could/might be relevant. In the discussion section, we go back to the broader definition previously presented (Section 2.3).

4.4. Analysis of data

The procedure for analysing the data obtained from the semi-structured interviews was carried out in two phases: an inductive followed by a deductive analysis phase (Patton 2002). The interviews were first transcribed verbatim and repeatedly read by the interviewing researcher. The first phase involved research team members independently reading and coding the interviews according to an open categorical coding procedure (Creswell 2013) producing a number of groups. In the second phase, the researchers analysed the participants’ views by examining the perceived groups of data through a pre-existing framework (Patton 2002). For this, the three categories used in Bernstein’s model of the pedagogical device were utilised. N-Vivo software (Alfasoft ®) was used for sorting and categorising the data.

4.5. Trustworthiness

The requirement for credibility is a priority. We have sought to report our theoretical and methodological choices in a transparent manner. This includes presenting a clear link between the research questions, our theoretical framework and our findings. The cohort of 20 participants, representing the various disciplines and countries, was considered sufficient to reach an acceptable level of trustworthiness.

Finally, describing a phenomenon (here, participants’ views on educational change) using a qualitative research approach is not the same as examining the extent of the phenomenon. This work
should thus be seen as an attempt to describe, understand, and explain a sample of university teachers' views and experiences, not how frequent these views and experiences are in the population of university teachers in Nordic engineering education (see Asplund 1970; Skogh 2001).

5. Findings

During the initial categorisation phase, it became evident that the categories were contingent on engineering disciplines. Consequently, the outcomes from each engineering discipline are presented separately to highlight the distinctions that surfaced in various branches of engineering education. Towards the conclusion of this section, a summary is provided encompassing observations that are common across all engineering disciplines.

5.1. What does digital transformation mean for the engineering disciplines?

5.1.1. Future digitalisation – biotechnology

The university teachers representing biotechnology expressed that the digital transformation has played a significant role in the development for a long time. Bioinformatics is a subject in which big data has been handled for many years. The methods in the laboratory are digital. In fact, in recent years the trend has been toward most of the laboratory work being controlled via computers. Looking ahead, our participants claimed that big data will have an even greater influence. Personal data will be collected ‘around the clock’, which means that there are great opportunities to develop completely new application areas. Personal medicine is one such area that is in its infancy. While expressing a need to train engineers who have knowledge about the technological forefront, a certain scepticism was expressed. Biotechnology is a relatively new engineering discipline in which there is still relative uncertainty about having to update education, as this often means to throw out the old and bring in the new. This is seen as a considerable challenge for the next five to ten years.

5.1.2. Future digitalisation – civil engineering

The digital transformation means change in several different aspects of civil engineering. First and foremost, future digitalisation includes the development of software tools, which facilitate the ability to follow the whole construction process systematically. This makes it easier to perform life-cycle analyses for materials used in the processes and aids design and calculations. However, several of the university teachers said that new tools are constantly being developed and that the digital tools that are used in industry today are often not yet available in the engineering education programmes, which is something that needs to be changed. Software commonly used in professional work environments is considered essential for integration into education, aiming to familiarise students with the design culture prevalent in the professional sphere. Looking 10 years ahead, one professor stated:

… Most of all, I hope that we can give the students tools to take with them so that they can work efficiently … It is about having an unbroken chain of information from the early stages of planning until … through like all the different stages: the detailed planning process, the feasibility study process for a building, land allocations, building permit applications. (Swe 3)

Technology for 3D printing is another example of a process development that has had a great effect on civil engineering. This new technology opens opportunities for the use of new materials. Knowledge of new building materials is and will remain important in the foreseeable future as well.

5.1.3. Future digitalisation – mechanical engineering

Mechanical engineering has for years evolved with the digital transformation and today this discipline offers programmes that focus on computer-aided manufacturing, automation, robotics and
Al. Within this field, a relatively long time ago, the interdisciplinary sub-discipline, mechatronics, emerged as a result from the digital transformation. The increase in automation and AI within almost all technical processes has also led to a greater demand for mechanical engineers who are able to perform, or at least understand, some programming. One of the participants said, ‘I think programming becomes a vital ingredient for engineers to be able to use these things, to control them instead of just being controlled by them’ (Ice 4).

The answers reveal a difference between university teachers who work close to software development and those working closer to traditional mechanics, that is, with machines and hardware. Teachers in the first category recognised the necessity of being able to do programming simply as a part of ‘being an engineer’, whereas those who primarily work within traditional mechanics raised a concern that traditional basic knowledge will be diminished or removed from the education as new content are introduced. To them, it is important that students continue to learn the basics, as ‘the same physical principles will always apply’.

One informant offered a future vision in which several engineering disciplines will need greater knowledge of cyber security, safety, and ethics. With more robotisation comes an even greater responsibility for safety when developing new innovations. Specifically, he argued that ‘... tomorrow these robots will be on the streets, in your home, and collaborating with humans. So you need to get safety … ’ (Swe 1).

5.1.4. Future digitalisation – energy engineering

In energy engineering, new digital tools are considered necessary for the development of new interdisciplinary subject areas. An example put forward is that big data can be collected from human habits, which opens up a range of applications (c.f. public health, online business, transport and communication). As in mechanical engineering, some points were made regarding the view that energy engineering should protect its core subjects and enable future students to acquire the basic knowledge needed to understand new energy challenges.

5.1.5. Future digitalisation – all disciplines

The majority of participants described a future where the knowledge to be able to programme and understand computational logic is very important. Although not every student will become a programmer, it is seen as important that engineers in different disciplines understand the ways in which digitalisation facilitates and develops new technologies. On the whole, applicable to all engineering disciplines, the participants claimed that there is a present and future need for students to practice more general skills, such as collaboration, teamwork, and systems thinking. These abilities are seen as something that is needed, even if the technical solutions change. The competence of just using digital tools as such, that is, becoming digitally literate, was also brought up by some of the participants as an important competence that may need more focus in education. Students of today need to be digitally literate to cope with both their personal and professional lives and to manage education, as pedagogical approaches are more likely to be computer based or online 10 years from now. Even the way students are supposed to do lab work has changed. Where they were previously doing much of the work in the lab environment, today most of the work is robotised.

5.2. Who may transmit what to whom? – Distribution rules for integrating digitalisation in engineering education

Who influences the education of our students? This section presents the actors our participants see as important in the development of education in terms of digital transformation. The term ‘the whom’ refers to the students (bachelor and master levels) in engineering programmes exposed to the teaching. In the model, the term ‘whom’ is a constant. Thus, Bernstein’s model does not include analyses of possible variations within the frames of this constant.
5.2.1. Society
The majority of the participants expressed the view that digital transformation is a process that is not only revolutionising engineering as a field but also the whole society. There seems to be agreement that society is in the midst of this revolution. The belief is that most of the development due to digitalisation is still ahead of us. Several participants expressed the view that digital change is present in ‘everything’. This is exemplified by one university teacher who described this as a two-step process, where we are now moving into the next step of digitalisation: ‘Up to now, we have mostly used computers to do what we could already do manually, but faster. But now we see innovations where computers bring about brand-new applications’ (Nor 1).

According to the participants, the digital transformation of society in general places pressure on education to be digitalised as well, both subject-wise and in terms of pedagogical approach (e.g. by digital tools). As the generational gap is obvious, the present faculty expects young people (today’s students) to be more digital literate than former generations. It is assumed that students want a more modern (i.e. digital) environment and that they are more aware than the faculty of what is needed for being successful in the future digital society.

5.2.2. Industry
Industry is a major actor in setting the rules for how content is or should be developed due to the digital transformation in engineering education. The participants expressed the view that the development in industry is much faster than the development in university education, which they said is somewhat behind. The participants stated that universities have fallen behind the industrial development or that the country in question has fallen behind other countries that are further developed in terms of Industry 4.0. Most of the university teachers testified to a huge demand for graduates who are better equipped with digital and programming skills. One university teacher claimed that students who participate in internships without having programming skills often complain to the teacher that they lack such skills, whereas students who have these skills typically feel that they have a great experience when in internships. The industrial sector was perceived as a strong driving force when it comes to the need for programming/data knowledge in today’s work life.

Some participants, closely linked to production, where software development is crucial, claimed that digital transformation has led to a real Golden Age in industry and for engineering education.

Internet of Things or automated driving, or artificial intelligence, billion after billion has been invested and companies are looking for prospective future markets. There’s an extreme technology push for new markets. And then there’s an extreme push for getting hold of the right competence. (Swe 1)

The fact that programming skills are so coveted that these university teachers cannot see the limit of how many engineers are needed with these skills is seen as a particularly strong motivating factor for educational change.

5.2.3. Universities
The universities are seen as important actors that influence if and how education changes. When it comes to digitalisation, the university teachers described the difficult process of integrating new content into an existing programme without affecting the established content in a negative way. Educational development was described as a balancing act, where the university management has the final control over how fast the development proceeds. It is a process that normally also takes long time. One informant argued as follows:

It is a moving target, it means … in a world where we don’t know what we need in 5 or 10 years, that’s a miracle, or it’s a little bit mystical. Usually, a faculty dean or a president, have to decide such matters. And to steer a university is like an oil tanker. You cannot put it left or right, it’s five years. (Den 4)

Some of the participants from Finland suggested a new structure, where students have much more impact than previously on what courses to take within a given engineering programme. They...
claimed that students were better suited to select what education they want/need than the university.

When looking at the actors who govern the academy, the scientific community and the state, participants from the most research-oriented universities (Fin, Swe) claimed that the current policy does not adequately promote the development of education. Research merits rather than educational merits are encouraged, which makes it difficult for researchers to take the time to work with educational change, and, because merits are often attributed to well-cited scientific publications, working close to applied educational research and education development may not be the easiest way to achieve higher legitimacy in academia.

5.3. Transformation of legitimate knowledge – re-contextualisation rules for integrating digital transformation in engineering education

Most participants expressed a view that digital competence is and will be required for their engineering graduates and therefore needs to be included in the learning outcomes for engineering education programmes. Digital competence was often described as the ability to programme or to understand the logic behind computational processes. In line with Bernstein’s model, the participants presented different approaches that have been (could be) followed when including digital transformation in their main discipline (the classification and framing of digitalisation as a new learning object in engineering education).

5.3.1. Introduction in already existing courses

Although most participants agreed that engineering students will need to be able to relate to specific cutting-edge competences (e.g. managing big data and AI), they expressed a belief that digital transformation is better viewed as something that is affecting everyone, everywhere, and therefore digital competence should be integrated within already existing courses. Another reason for integrating digital knowledge within existing courses is the educational and administrative challenges related to removing existing courses and replacing them with new ones in already dense educational programmes. Having to add additional courses may also lead to less opportunities for students to absorb the scientific core given in the existing programme. Specifically, one participant claimed:

> Of course, they need all parts of it (digitalisation) but I’m also seeing the risk that if we try to make too much of different things in the education, then we lose depth. And I think this is a real risk … a way to go with this could probably be to try to combine the new things with the more traditional things, to bring them closer together, having them more integrated. (Swe 4)

Another participant drew attention to a problem that occurred when integrating digital transformation in an already existing project-based course in the later years of their engineering programme. In this course, digitalisation was introduced as a practical activity using specific software, relevant for later work life. This activity was well received but was judged to be difficult due to the complexity of setting the learning outcomes so that they could be easily assessed within the course.

Several of the participants reported that even though programming, AI or big data had previously been a part of the educational programme, it had been removed during recent programme revisions. This has resulted in a complete lack of opportunity to obtain this knowledge in the programmes offered today, something one saw a strong need to change. This fact leads a dilemma when this knowledge is not treated as academically important.

5.3.2. Content introduced as a new course(s)

Some participants expressed that digital competence has been introduced as a separate field of knowledge. In such cases, new courses have been developed, sometimes managed via other
disciplines at the university, such as programming, statistics, or ethics courses. Other participants mentioned that digital transformation is covered in new courses created by teachers within the discipline.

One course was mentioned as being very successful. It was developed and applied so that the students themselves ‘can visit different industries with the aim of seeing what digital tools are used’ (Fin 3). Another example mentioned was an ‘add-on course’ in which teachers and students collected knowledge together on how digital transformation has affected their engineering discipline.

Yet another strategy that was mentioned is adding on a whole set of courses aiming at providing digital competence for use in later years. This was the case in some of the biotechnology programmes, where the use of big data has become such an obvious part of the discipline. This has led to reconsideration of the content of the whole programme, and courses in statistics and programming have been added as modules in the first-year curriculum.

5.3.3. Content introduced as new disciplines or in new programmes

According to the participants, new digital-related disciplines were formed due to the digital transformation as early as the 1980s. Then, bioinformatics was formed as a discipline in between biotechnology and IT, and mechatronics in between mechanics and electronics. According to the participants, this has not been a clear success. Although these sub-disciplines have survived and been successfully formed in some universities, they are still somewhat in the shadows of the original disciplines, something that could be improved. Characteristically, one participant argued that:

The problem might be that, according to my knowledge, most of those programmes are rather small in head count. And maybe this latest type about Industrial Revolution 4.0 and digitalisation etc. is underlining there the importance of taking all this a little bit more seriously and not just having those fancy elitist small study programmes here and there. (Fin 4)

Reykjavik University has chosen to form educational programmes where students obtain a double degree, one in a traditional engineering discipline and one in computer science, after finishing a five-year programme (which is the normal pace for getting a master’s degree). At the time of the interviews, this type of programme had just recently started and was expected to be very attractive since industry demands engineers with computer skills. These programmes can be seen as an attempt to integrate digital transformation, as a strong part, with another engineering discipline. However, this could also be interpreted as an attempt to only add digital transformation on to an engineering programme without really integrating the knowledge areas, treating the engineering discipline and computer science as two separate disciplines that must be combined later, to create a whole, within the students’ minds.

5.3.4. T-shaped or I-shaped engineers?

When the participants were asked to predict the future, they offered a picture of a future labour market in which many more engineers with interdisciplinary knowledge are needed. That is, according to the participants, future engineers not only need to have knowledge in one disciplinary area. A competence profile where one discipline dominates, and other areas functions as complementary regions will be required. The knowledge needed reflects a reality where the disciplinary boundaries have been blurred or look somewhat different. Specifically, a teacher said, ‘I mean there are a lot of courses and staff members that are kind of between departments of computer science and engineering … we are getting more and more … or the subjects are getting more and more interdisciplinary’ (Ice 2).

The participants indicated that the universities need to consider how they can not only train I-shaped engineers with deep knowledge in a single discipline. Future society needs T-shaped engineers, that is, engineers who have relatively deep knowledge in a traditional engineering discipline but who also have had the opportunity to add a broad cross-competence (c.f. digitalisation or
social sciences, ethics or sustainability) (Bierema 2019; Neeley and Steffensen 2018). Such cross-competences could include knowledge areas that are not directly part of mechanical engineering but rather disciplinary knowledge from a different discipline that engineers must consider when designing new products.

The vision of the participants was not that education to produce T-shaped engineers would be the sole solution for the future, rather than an increased number of engineers will need to be T-shaped. According to the participants, there will be room for I-shaped engineers as well as generalist engineers, who are multidisciplinary, albeit to a lesser extent.

...Where I see the true change is that this amount of people who still are strong in something but who have this or who have that who has those connections, understanding, respect, and better capabilities for co-working with other experts from other fields, this is the one that must change. (Fin 3)

The different approaches regarding the introduction of digitalisation that the participants have used (or want to use) in their respective main discipline are summarised in Figure 2. Here it can be noted that T-shaped engineers is something that is only discussed by participants originating from mechanical engineering.

5.4. Transformation of pedagogic discourse into pedagogical practice – rules of evaluation

Below we present the participants’ views regarding two aspects of the transformation of curriculum into teaching-learning activities. First, findings regarding the participants’ views on who has the legitimacy to teach about digitalisation are presented. This is followed by their views on the development of pedagogical approaches that are/will be used to create the best possible conditions for students to acquire knowledge.

![Figure 2](image-url)

Figure 2. Overview of the findings regarding strategies to include digitalisation in education. The diagram shows the number of participants (y-axis) who talked about either strategy (x-axis); both discussions on present status and future expected development are counted.
5.4.1. Teaching practice – who is qualified to teach?

The participants pointed out the problem of qualifications. Who is in fact qualified to teach about digital competences? Our data reveal some tensions when it comes to this issue. The older generation of faculty tend to rely on the younger ones. Often, PhD students or new graduates are hired for teaching the content related to digitalisation and the digital transformation.

And that is a challenge for the supervisors because we cannot do it. None of us can handle the data. But my PhD-students can, and my post docs can do it. So, they can be coaches in the projects at all levels. (Nor 2)

Some of the participants raised the question of more collaboration with already existing engineering disciplines that are more experienced when it comes to digitalisation processes. Specifically, one professor said, ‘… this is something that has been done in the discipline of computer engineering for decades, they should be able to help us others out...’ (Den 3).

Others have experienced less successful examples of mixing computer science students and engineering students as well as faculty from computer science and the engineering field. Based on those experiences, considerable effort is required for the two disciplines to understand each other’s needs. Nevertheless, a continued desire was articulated for developing successful collaboration between those engineering disciplines in the future. A third way of solving the question of who is going to teach digital competence is to hire staff from other countries, where they have developed competence combining digital competence with the engineering discipline of interest.

5.4.2 Teaching practice – pedagogical approaches

Time constraints were often mentioned as a barrier to shifting pedagogical approaches as well as a lack of focus on educational issues within the academic system. It takes effort to bring about change in organisations in which the focus is not on education and students but rather on research. This fact makes it is difficult for the organisation or the individual teacher to prioritise taking the time needed for achieving pedagogical change in the classroom.

- Traditional lectures … perhaps with a digital dispute

There appeared to be a common understanding among the participants that the ‘old-fashioned way’ using mainly lectures and tests at the end of the course is not the most efficient way of teaching, even though it is still a common way to teach in today’s engineering programmes. A wish for developing teaching strategies that allow spending more quality time with the students in the future was often expressed, independent of discipline. The professors valued discussions with the students. Online methods, predominantly video-recorded lectures that students can watch before class, were mentioned as a tool for increasing the face-to-face time with students in teaching what Bernstein describes as ‘strong classified’ disciplinary knowledge.

Overall, digitalisation was seen as something that will provide important tools for future pedagogical approaches. An increase of digital experiments, including making models and using simulations, was predicted in the coming 10-year period.

- Future teaching practice – project/challenge-based learning

According to the participants, different project-based learning approaches, sometimes referred to challenge-based learning, will probably become more popular in the next 10 years. This pedagogical approach has been the cornerstone for education in some universities (especially at Aalborg University), while for others it is a newer concept. However, most of the participants seemed to agree that this trend serves as a future model for education.

Many of the participants said that the main purpose of project courses is to give students the chance to work in close relationship with industry. More specifically, one argued that ‘… it gives them a really good integration with the industry that has demanded this project course, and it’s a
really great learning process and they learn the most advanced and modern tools you can get in this topic …’ (Den 1).

The participants also expressed that project work is linked to weaker classified disciplinary knowledge, such as collaboration with companies, system thinking, or training their interpersonal skills. One informant stated, ‘… I mean, with that comes the emphasis on the soft skills obviously. And you have this nice experience of starting something and sort of following it through to the end’ (Ice 4).

The participants also predicted that project courses can serve as the place where different disciplines meet in trans-disciplinary projects. This is important, as future engineers are believed to need more interdisciplinary competence. Characteristically, one participant stated that ‘You need to talk to a lot more people in a lot more different disciplines to be project leader in multi-disciplinary, multicultural even, projects’ (Swe 3).

Other participants noted that it takes a lot of time to manage a good project course. Some criticism was also levied at the vast number of projects in education, as one of the participants claimed that ‘the learning outcomes for project work could be much better defined’ (Swe 4).

The participants wanted their project work to be more linked to weaker classified disciplinary knowledge, such as the link to reality and collaboration with companies, systems thinking and the possibility to use the factual knowledge that students have learnt and to train their interpersonal skills. It was also predicted that project courses could serve as the place where different disciplines meet in trans-disciplinary projects:

I hope it increases (interdisciplinary courses). It may not be in every course … It may be a housing project or another, but when one thinks of heat exchanger and solar energy, then one thinks of another social sustainability, and rent setting and availability and inclusion. (Swe 3)

6. Discussion

Next, an overall reflection is presented on how engineering education, according to the participants in the study, is developing in terms of digital transformation. In the chapter, we also identify issues of interest to those who want to be involved and influence the development path that prevails.

6.1. How is digitalisation described?

Generally, the knowledge area of digitalisation was most often described as the ability to programme or the ability to understand the logic behind digital tools. Our participants also described that knowledge about disruptive technologies was important to keep up with the digital transformation. Altogether, almost every one of the most prominent future key technologies described by Bongomin et al. (2020) were mentioned as important to be included in various engineering education programmes. However, the participants mentioned different technologies representing different engineering disciplines, which suggests that engineering education cannot be seen as a single entity but rather as different disciplines that are different when it comes to how content linked to the digital transformation is described. The ‘what’ is described for each engineering discipline in more detail below (6.3). The results agree with the literature in that our participants emphasised the need for tomorrow’s engineers to have the skills to use digital tools so they will be employable (Suarta and Suwintana 2021). The majority of our participants claimed that the digital transformation is a process that not only revolutionises engineering as a field but also the whole society. Hence, they generally shared a strong desire to include digital competences in engineering education.

However, the trajectory from digital knowledge being acknowledged as an important new subject area to its integration into engineering education practice is neither simple nor straight. Decisions on educational issues are made at different levels, and each analysis in this process depends on and is limited by the perspective from which the analysis is based. Bernstein’s theoretical
model of pedagogical device was used in the analysis process, where data were consistently organised around the three predefined sequences of the model (distribution rules, re-contextualising rules and rules of evaluation). Our participants’ statements were made from a close-to-practice perspective. This perspective is also the starting point for our discussion, resulting in a reverse-order presentation in relation to Bernstein’s model. We start by reflecting on how digitalisation affects teaching approaches (6.2), then move on to how the digital transformation has been framed in engineering education (6.3). Finally, we reflect on how power relations and legitimacy affect the future development of engineering education (6.4). Throughout the discussion, the authors’ foresight is based on the stories given by the participants.

6.2. The impact of digitalisation on teaching–learning practice

Several of the participants testified to the importance of extending various forms of project-based learning when a development toward more ill-defined projects was seen. This is not a development that is unique to the subject area of digital transformation; rather, it is a sign that engineering education is shifting toward more society-challenge-oriented than industry-problem-based education (Rådberg et al. 2020), the hybrid mode.

According to the participants, digital tools (e.g. streaming lectures) will be a significant part of teaching in a few years’ time. Hence, digitalisation is expected to affect teaching methods, regardless of whether the teaching is about content related to the digital transformation or other subject areas (Eriksmo and Sundberg 2016).

This answer would probably have been even clearer if the question was asked during or after the COVID-19 pandemic, when virtually all teachers have been forced to switch to online teaching methods. There is reason to assume that both faculty and students perceive positive and negative experiences. On the one hand the challenges to adapt to online education, the lack of interaction, technical issues, data privacy, and security concerned. On the other hand, low costs, convenience, and flexibility could be seen as positive aspects. The sudden transition to digital distance teaching and learning needs special study.

It is notable that our pre-Covid 19 interviews yielded few reflections regarding new teaching methods, developed due to the digital transformation, even though there are literature present on how i.e. learning analysis using big data can improve teaching (Leitner, Khalil, and Ebner 2017). The pedagogical development has obviously not reached phase three, the digital transformation in this study, and most likely this phase has not been reached even during the pandemic. It appears, both directly and indirectly, that the status and perceived merit of engaging in pedagogical development work are low and hence, digital transformation when it comes to educational practice is not in focus for the future.

A challenge unique to digitalisation, addressed by several of the participants, is the difficulty for senior faculty to keep up with the emerging digital transformation. Several of the stories provide evidence that the older ones trust the younger ones, as digital competences including digital technologies are taught by doctoral students rather than by the senior university teachers themselves. This development can be seen as both positive and negative. It is positive with regard to the mutual dependence among different age groups, which may lead to less hierarchical structures in academia. It is negative since one could assume that if the experienced and knowledgeable university teachers do not have sufficient knowledge to teach about the new technologies, in a longer perspective, it may even affect the research output when new innovations are to be developed.

6.3. Framing digitalisation as a new learning object in engineering education

Once a decision has been made that digital competence should be included in engineering education, the question remains as to how the subject area should be designed and delimited. The strongest academic classification described by Bernstein occurs when a knowledge area is treated
as a singular discipline. For areas developed because of the digital transformation, strong classification would obviously be the case within IT/computer science education. When the content is considered to be academically strong but still not treated as singular, (i.e. not only representing a skill needed for professional life but also considered to be a tool needed to understand the development of the discipline as such), the content can be accommodated in an engineering programme by being represented as a region of knowledge. An area of knowledge is most often defined either as an entirely new course or as several courses that form modules of knowledge about digitalisation.

In this present study, we explored the views of university teachers who represent an engineering subject other than IT/computer science. In our case, the highest degree of academic classification should probably be represented by the possible introduction of new sub-disciplines in which digitalisation is treated equal to the discipline our participants represent; that is, a discipline where the courses and learning objectives consider both digital competence and the other discipline in question.

Based on the analysis, the digital transformation has had different impacts on different engineering subject areas. The university teachers who work in close relation to industries in which digitalisation has more or less been a prerequisite for current development handle digital transformation as a stronger classified part of the subject. In mechanical engineering (or rather in the part that is developed close to digitalisation: mechatronics) and biotechnology, there is a strong need for graduates to have digital competencies (e.g. programming) and understand the effects of digital transformation.

Mechanical engineering programmes that lean towards computer-aided techniques seems to be the engineering discipline that sees the greatest need for change due to digital transformation, which in some cases has led to or is expected to lead to new educational programmes with a higher degree of interdisciplinarity. Several of the interviewed university teachers emphasised that mechanical engineers of the future, to a larger extent than today, will need to be T-shaped instead of I-shaped. In other words, trained engineers should not only have deep knowledge in one engineering discipline but also good knowledge in another area. In the literature (Euro-CASE 2020) pi-shaped engineers are presented as engineers who have deep knowledge in two disciplines. Furthermore, the literature indicates (Euro-CASE 2020) that the development of T-shaped and pi-shaped engineers is necessary to create engineers who are flexible, efficient and have a global view, which is in line with the participants’ belief in the need for interdisciplinarity.

When it comes to biotechnology, the digital transformation has affected this engineering discipline for many years in several ways, and access to big data has been one of the key steps in the development of the discipline. According to Bongomin et al. (2020), biotechnology itself can be seen as one of the new disruptive technologies that are part of the industry 4.0 development. In biotechnology, there is a call for developing courses aimed at teaching students to use digital tools. However, in addition to this, the participants also argued that students need a stable knowledge base within the area of digitalisation to be able to learn biotechnology in later years. This means that digitalisation is viewed as a knowledge area in between weak and strong disciplinary knowledge, where knowledge is communicated to students through modules, not as a new programme but as several progressive courses. We see that the knowledge needed to move through phases one, digitisation, and two, digitalisation, is now seen as basic knowledge to enable later development in phase three, the digital transformation. Several informants (representing mechanical engineering [not closely linked to industries equally reliant on digital development as in the previous example], energy engineering, civil engineering) expressed the need for integrating digitalisation-related content into existing courses. The primary rationale behind this suggestion is that digital transformation is still largely perceived as a vital skill essential for professional life. Another reason is that having to add additional courses might lead to less opportunities to absorb the scientific core provided in the existing programme. Here we see that digitalisation is characterised as important but as rather weak classified knowledge. The same seem to be true for civil engineering even though the participants stated they are aware that digitalisation is about to revolutionise their
subject area. Examples were given of how courses are developed together with industry, as the universities want to learn how industry works with digital tools. These findings prompt the question of whether the knowledge areas associated with digital transformation are categorised based on the stage of digital transformation within a specific discipline. It could be that mechanical engineering and biotechnology have long been exposed to digital development and have already entered phase three of digital transformation, while civil engineering is to a larger extent entering phase two, and this is why digital transformation is framed differently in these disciplines.

6.4. Legitimacy of knowledge and power relations between involved actors

Through the interviews, three actors were identified as important for the way in which engineering education develops in the Nordic countries: the universities themselves, industry, and society at large. The extensive influence of actors outside the university must be highlighted in this development process. Our participants pointed to industry and the requirements for students to acquire both general and specific digital skills. The industry was seen as an important player in establishing rules for how content should be developed due to the digital transformation in the field of engineering. The considerable influence of industry on educational development likely explains the observed similarities among engineering disciplines. This influence appears to be more pronounced than any commonalities in how universities or the respective countries approach digitisation.

The interviews did not reveal exactly how and by whom a change in education takes place, but most of the participants agreed that potential changes occur at the programme or course level rather than through the strategic will of the university management. An exception is the university in Iceland, where management has decided to introduce several double-degree programmes in which computer science is one discipline and a traditional engineering subject is the other. A requirement for such a development to take place may be that this is a smaller university where industry and teachers have more direct contact with the university management.

Several of the participants experienced inertia in the system of which they are part, and the university and the way in which it is managed (i.e. from the governmental point of view) were perceived as not favouring the rapid change in the content of education that is needed. Several societal actors claimed that this is a problem. In Euro-CASE (2020), it is argued that engineering education is far too important for society to be conducted only by the university. This raises the question of whether other more fast-paced educational actors need to complement the universities in order to achieve flexibility and a shift of knowledge competence in society.

7. Concluding remarks

The stories of the participants in this study present a picture of what digital transformation means for their respective educational disciplines. A variety of trajectories of development are described, and the differences tend to depend on which engineering discipline each informant represents rather than which university/country the informant comes from. Although the Nordic context represents a relatively limited geographical part of the world and we make no claims that these results can be generalised to the rest of the world, we find it as highly likely that the fact that the results are discipline-dependent means that the results discussed here are relevant for comparisons between engineering disciplines also for other countries, especially in Europe where a majority of countries are part of the Bologna process where the educational structure is similar.

Based on an analysis of the interviews using Bernstein’s model of pedagogical device, three main areas emerged that deserve extraordinary consideration when further developing engineering education:

- Views on digital transformation
According to our data new knowledge is introduced into education in different ways depending on how this knowledge is viewed by those involved in educational development. In this study, we found the whole range, where some of the participants viewed digital competence as a skill graduates need to have to be able to practice their profession, while others viewed digital competence from a relatively strong academic perspective, where digitalisation and digital transformation was one of two disciplines in a given programme. We believe that it is important that those responsible for education reflect on the purpose of integrating content related to the digitalisation. Such reflection would facilitate the understanding of the impact of the digital transformation by the university teachers involved and might also clarify when and how it is appropriate to include various elements in the curricula.

- **Need of teacher training**

Based on the results, universities should investigate whether continuous training should be offered to senior teachers related to the digital transformation. This was mentioned as a critical issue in the Euro-CASE report (2020). One could also argue that it is worth developing the positive side of the crucial collaboration across age groups and different positions in academia. At least in Sweden, the law requires that students are included in all decisions concerning education. This is most often fulfilled by inviting students to participate in programme committees and advisory boards. It may be that students/doctoral students should be invited to take an even more active part in the development of courses and programmes to capture their digital expertise.

- **Universities in the ‘back seat’**

Upon closer reflection on how Nordic universities are handling the grand challenge of digital transformation, it seems that the universities are taking on a reactive rather than a proactive role. Several of the participants described a need to develop education to keep up with the developments in society and industry. Few of the participants viewed universities as the driving force for digital innovation. If we want the universities to be in the driver’s seat through their education (and research) when it comes to digital development, most universities need to provide better conditions for their teachers, such as an increased focus on and dedicated time for educational development.

- **Looking back to see forward**

The data collection for this study was done in 2019, i.e. just before the global Covid pandemic broke out at the turn of the year 2019–2020. The study thus provides a contemporary historical perspective on the digitalisation of engineering education. The results can be analysed on the basis not only on the reported results but also on the basis of today’s ‘answer key’. In 2024, the developments within e.g. AI has developed rapidly. The question of whether the digitalisation of engineering education has developed just as quickly has probably more than one answer. However, knowledge of how actors and factors collaborate and counteract with each other in the introduction and implementation of new elements in the engineering programmes should, provide good conditions for being successful in this work.

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