IDENTIFYING INDUSTRY NEEDS FOR INNOVATION SKILLS IN ENGINEERING EDUCATION: A THEMATIC ANALYSIS OF CASES FROM DANISH INDUSTRY

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ABSTRACT

Providing students with knowledge, skills, and competencies in innovation has become a central focus in engineering education. However, there is limited knowledge on which innovation skills need to be supported and how well engineering education meets current knowledge gaps in the industry. As a first step towards addressing this research question, our paper presents findings from examining 49 innovation cases provided by Danish industries for the Applied Innovation in Engineering (AIE) course at Aarhus University. A thematic analysis was conducted to identify dominant trends from the case descriptions and to assess areas of interest and demands from different industry sectors. Results identify areas of interest from the cases that correspond to desired innovation skills in three primary aspects (i) technology/product, (ii) digitalization, and (ii) sustainability, and five secondary aspects: (a) future trends, (b) customer behaviour, (c) business, (d) regulations, and (e) training. This study provides valuable insights on needs from the Danish industry and the areas of interest to which innovation skills are required, therefore supporting EE in integrating industry-oriented competencies for engineering students.

1 INTRODUCTION

Today's engineers are required to cope with the demands of a multifaceted professional world marked by rapid changes, associate information and computer technologies to traditional practices, consider ethical- and sustainability-related implications of their decisions, and address complex multidisciplinary issues. Moueddene et al. (2019) emphasize the need for improving university education among the priorities on policies for the future of the labor market [1]. Thus, higher education institutes (HEIs) have the responsibility of providing students with the necessary means to develop such knowledge and skills before they enter the job market. In order to do so, HEIs need to go beyond standard engineering curricula by bringing industry actors closer to their education setup and further understanding market needs [2].

Understanding the knowledge, skills, and competencies required from future engineers has become an important focus in engineering education (EE) research [3]. The diversification in required competencies has led to an increase in the number (and type) of courses and educational activities offered in engineering curricula. New interest areas such as sustainability, ethics, digitalization, and innovation have become integral to several engineering programs. Such courses can provide students with innovation skills that help engineering students contextualize their technical skills, and solve multi-faceted challenges and needs faced by industry. In this paper, innovation skills are considered as technical or professional skills that are complementary to primary technical skills. For example, assessing relevant sustainability regulations and recognizing the potential for digitalization, are innovation skills that complement primary technical skills in engineering education. However, there is limited knowledge on what innovation skills should be emphasized to meet current industry needs.

This study evaluates **the areas of interest demanded by local industry** and **the need for innovation skills to be reflected in EE.** To identify the need for innovation skills, we analyze the contents of case descriptions proposed by a range of Danish companies to students in an MSc. course at Aarhus University. The industry cases expose the needs of the involved companies for future engineering practices. Furthermore, the cases reveal local industry needs and trends to be considered in EE for better preparing students for upcoming industry demands. Based on our results, we provide a broad set of recommendations to help engineering educators better align curricula with innovation skills demanded by industry.

2 METHODOLOGY

The methodological approach of this study aims to analyze industry-provided cases to evaluate demands from Danish industry and further propose insights in relation to industry trends and required engineers' innovation skills. An open call for cases was announced to both large firms and small & medium enterprises (SMEs) in Denmark for the Fall 2020 semester of the Applied Innovation in Engineering (AIE) course at Aarhus University. A total of 23 companies from different sectors answered this call.

The sample of 23 companies included five sectors: (i) computer programming & information technology, (ii) engineering & construction, (iii) manufacturing, (iv) public sector & foundations, and (v) other (research, wholesale, geology, and food). Furthermore, the selection also accounts for a broad spectrum of company sizes as illustrated in Table 1.

Table 1. Sample of companies involved in this study

Company Size	Nr. of Companies	Nr. of cases	Generic Category
Micro (<10 employees)	3	7	
Small (<50 employees)	6	10	SMEs =12
Medium-sized (<250 employees)	3	12	
Large Enterprises (<5.000 employees)	9	17	Large = 11
Corporations (>5.000 employees)	2	3	
Total	**23**	**49**	

The companies involved provided a total of 49 cases. The cases had a primary technical focus since it was oriented to a diverse group of engineering students. Each case was composed of two blocks of text: (i) a case description, and (i) a challenge, which we analysed together. Figure 1 illustrates an industry-case analysed in this paper.

Case Description	The Challenge
Unnecessary consumption of electricity, heating, water and gas in buildings leads to high recurring costs and unnecessary CO2 emissions. Municipalities own and rent several thousand square meters of buildings and have an energy management team who are focused on analyzing and maintaining the energy consumption. Their analysis is time-consuming and does not always result in optimal reductions, since local technical staff are required to manually adjust equipment/infrastructure and the users of the building must change their behavior. A method or equipment to analyze or automate building infrastructure and change the consumption behavior of the users of the building if necessary.	We want to provide a way for municipalities to effectively reduce their spend on energy and CO2. The tool also should help the energy management team to communicate actionable data to the local technical staff and convey the importance of changing their behaviour to the users.

Fig. 1. Example of an industry case (description and challenge)

A thematic analysis was carried out based on the description and challenge specified in each case. The analysis followed an iterative coding process between three authors (2 senior & 1 junior researchers). The qualitative data from each case were systematically analysed via inductive coding and iterative coding cycles, until a final set of codes had been developed [4]. Finally, these codes were further refined into dominant themes to identify areas of interest for the innovation skills. The areas of interest convey current industry demands identified in the descriptions from the assessed cases. In our analysis, innovation skills are defined as the understanding and use of engineering knowledge to create new ways of thinking in order to develop solutions to new industry needs, and to create new products/services [5]. The qualitative data was further evaluated using NodeXL, an open-source plug-in for MS Excel 2010[1]. We used network analysis for illustrating the relations between the themes, companies, and areas of interest [6].

3 RESULTS AND DISCUSSION

The analysis of the 49 industry cases reveal three main areas of interest: (i) technology/product, (ii) digitalization, and (ii) sustainability, along with five secondary aspects: (a) future trends, (b) customer behaviour, (c) business, (d) regulations, and (e) training. Figure 2 presents the distribution of these areas of interest against the individual cases (C01-C49).

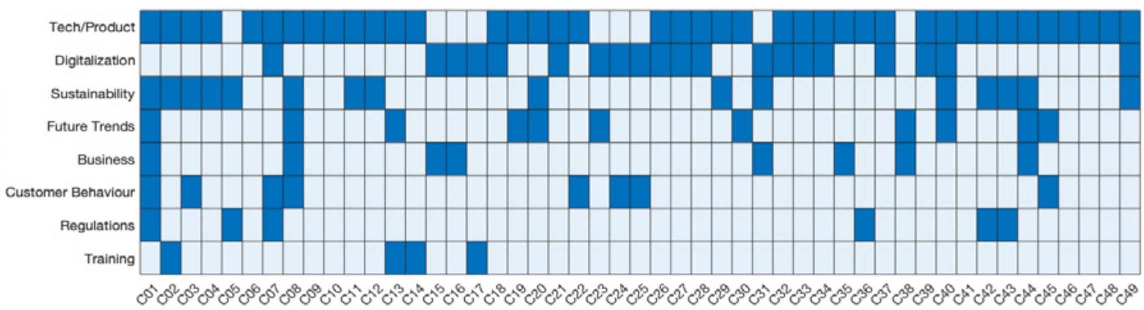
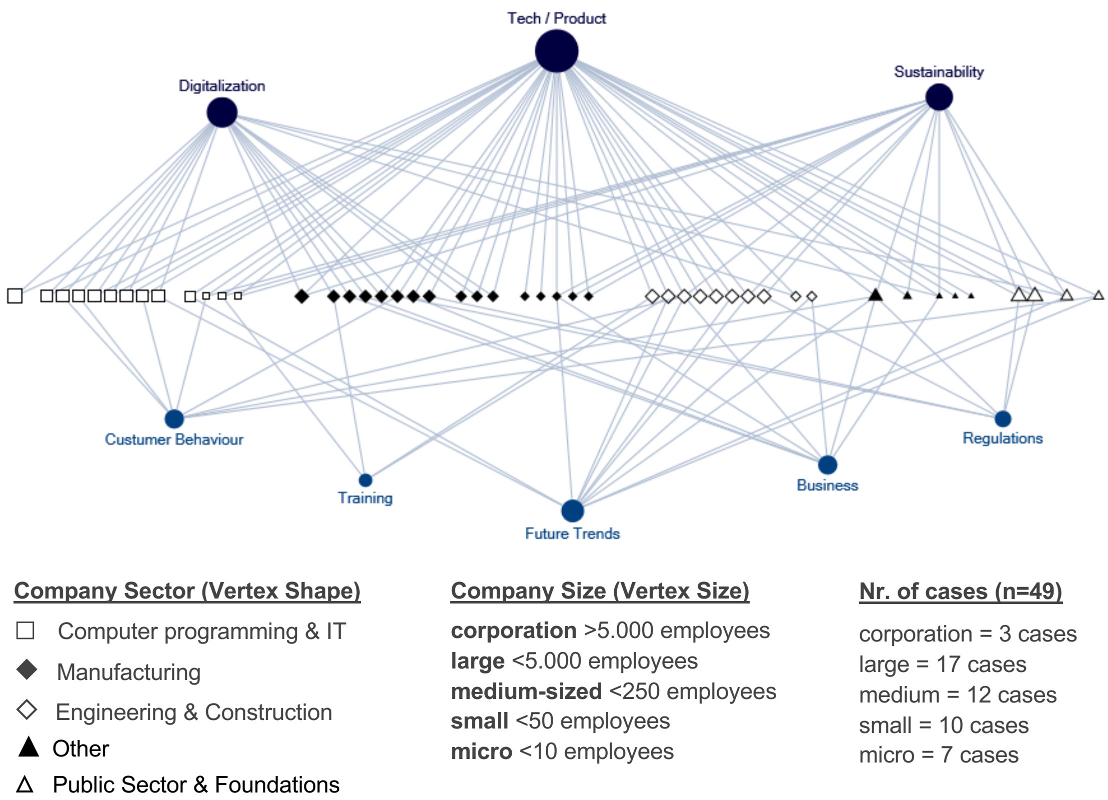


Fig. 2. Distribution of expressed areas of interest per case



[1] https://nodexl.com/

Fig. 3. Network analysis of company cases by areas of interest and industry clusters

Figure 3 illustrates results from the network analysis. The three main areas of interest are shown at the top and the secondary aspects are at the bottom. The cases are arranged horizontally in clusters determined by the industry sector (vertex shape) of the proponent company, and ordered by company size (vertex size) ranging from the largest to the smallest (left-to-right). The following section expands on the areas of interest identified from the above analyses.

[a] 3.1 Areas of Interest for Innovation Skills

Tech / Product refers to the explicit interest of new technology or product development assigned to the proposed challenge. This is the primary area of interest for the companies enrolled in this exercise. This area of interest is explicit in 82% of the cases (n=40) and is well distributed along companies of all sectors and sizes. This results from an increasing demand for creating new products and services that differentiate a company from their competitors.

Digitalization refers to the integration of digital solutions to existing practices or the need for developing digital tools and artifacts. Cases that requested use/development of sensors, data collection, LiDAR, VR/AR, simulations, digital twins, mobile applications, digital platforms, and data processing technologies are included in this category. This is also a primary area of interest for the companies and is present in 41% (n=20) of the cases. While digitalization was seen as an important aspect by all sectors, it was more predominant in large and medium-sized companies. Additionally, this aspect was commonly observed in relation to optimizing business strategy or product development.

Sustainability refers to the explicit aim for solutions that can help minimize environmental impact such as CO_2 emission reduction, use of resources, issues related to air and water pollution, and so on. This is the third primary area of interest accounting for 33% (n=16) cases from all companies. However, within our sample this aspect is mainly present in cases from the public sector and in cases from micro or small companies.

Expressed concerns of adequacy or need for preparedness in relation to **Future Trends** are observed in 22% (n=11) of the cases, primarily in large companies in the engineering & construction sector, and are nearly absent in the manufacturing sector. These concerns are mainly related to the potential long-term impact of a developed solution and ensuring the positioning of these companies in the market.

Business and **Customer Behaviour** areas are each observed in 16% (n=8) of the cases. The first interest area mainly indicates the need for business strategies in relation to market penetration, time to market, or market positioning, and is more common in cases from large companies in the manufacturing and engineering sectors. The second mainly relates to nudging and understanding customer behaviour which is notably represented in the computer programming & information technology sectors as well as large companies from other sectors.

Concerns related to upcoming **Regulations** and compliance is observed in 12% (n=6) of the cases exclusively provided by large companies. The most common factors influencing the case challenges are in product category certifications, General Data Protection Regulation (GDPR), safety and privacy, and legal environmental compliance.

Finally, aspects related to **Training** were noted in 8% (n=4) of the challenges and specifically address the need for optimizing training and employee performance, and the need for behavioural change within industries. Case descriptions tap into the need for increasing knowledge transfer in multidisciplinary firms and across international operations. The cases highlight aspects related to educating or training citizens for behavioural change, and new methods for training employees in relation to both machinery and product simulations. In addition, companies are seeking digital solutions to support their workers with machinery maintenance.

[b] 3.2 Lessons learned and recommendations to engineering education

The above results reveal the areas of interest from Danish industry and point to avenues for improving the teaching of innovation skills in EE. Emphasizing such innovation skills throughout the curriculum can help students better apply their engineering knowledge towards solving real-world challenges [5]. Therefore, a broad set of recommendations are suggested in Table 2 for integrating results from Section 3.1 as innovation skills into EE.

Table 2. Innovations Skills and Recommendations to EE

Areas of Interest from Industry	Innovations Skills and Recommendations to EE
Tech / Product	Future engineers must be able to assess and develop new technologies and products. Therefore, EE curricula must reflect this need by providing students' with a dedicated space for practical learning [7]. This recommendation can be achieved by incorporating active learning and case-oriented pedagogical approaches into the best practices of EE, and by increasing collaboration between HEIs and innovation-oriented technology and product companies.
Digitalization	Future engineering practices will require a broad understanding of digital technologies in relation to both the development and implementation. EE should consider integrating digitalization aspects across all engineering disciplines, which can be implemented by using a variety of educational components such as new study modules in the curriculum, hands-on laboratory work, and extracurricular activities [2].
Sustainability	The development of an instrumental understanding of sustainability and the capability for implementation of its concepts into engineering practices is acknowledged due to the increasing demands from the job market. However, Lönngren (2017) observed that there is still a lack of integration of overall sustainability knowledge in foundational engineering courses [8]. Ramanujan et al. (2019) explores guided discovery learning as an approach to teach environmental sustainability in undergraduate engineering courses, and highlights the benefits of promoting students' understanding of complex relationships between domain-specific design parameters and environmental sustainability [9]. Sustainability aspects should be presented very early in the

	engineering curriculum for supporting students with learning opportunities and internalization time that along with personal commitment facilitate a long-term sustainable mindset that guides impact-driving engineering practices [10].
Future Trends	Engineers should be able to use tools that help to foresee market trends that can promote or hinder the development or implementation of technologies, products and services. Prior research shows that methods such as a trend analysis can be easily integrated as part of innovation courses in EE, and that it requires a rigorous step-wise process where the choice of tools and techniques is given in relation to the characteristics of a case [11].
Business	Future engineers are expected to hold a broader range of capabilities that allows them to understand concurrent aspects of technology and product development such as business strategies and market assessment. These areas of knowledge are traditionally disconnected from the technical aspects of EE and require a different approach to problem-solving. According to Lönngren (2017), engineering students are less likely to be able to adequately address wicked problems - such as those occurring in socially complex contexts [12], without operationalized innovation skills provided by extensive training [8]. This aspect of cognition development requires greater attention from HEIs to develop professionals that are able to also tackle non-engineering problems.
Customer Behaviour	Future engineers must be able to relate technical solutions to customer behavior. In EE such skills are discussed under human centered design (HCD). HCD is viewed as an essential engineering skill but prior research shows that students have significant misconceptions about the process and the terminology of HCD [13]. EE should increase the emphasis on HCD and its relationship to innovation and help future engineers become more competent at leveraging technology to address unmet customer needs.
Regulations	De Graaff and Ravesteijn (2010) outline the knowledge and skills in the field of “science, technology and society” as a broader category of competences with high relevance to engineering education [14]. In such a skill set, working with regulations and rules are to be considered as part of the job as an engineer. It provides the ability to make decisions and balance the pros and cons from a standards and normative perspective.
Training	Operator training is a significant concern for industry as insufficient training can result in damages and injury to both machinery and staff, impacting operational efficiency and costs [15]. Traditionally, engineering students had a limited perspective on the implications of the technologies they developed on operator training. A significant barrier for this was the time and expenses entailed for conducting such studies. The recent rise of digital technologies such as virtual reality (VR) have the potential to reduce these barriers [16] and they should be further used in the context of EE.

4 DISCUSSIONS & CONCLUSIONS

Technological developments lead to new industry demands that creates a need for EE to adapt its pedagogical approaches and redefine engineering curricula [1,2]. Today’s newly trained engineers are required to develop a number of innovation skills that support their technical practices, become socially and culturally aware, as well as entrepreneurial [7]. Therefore, there is a need for future interventions in EE to consolidate these capabilities demanded from industry.

This paper analysed 49 industry-provided innovation cases expressing the challenges and concerns of 23 Danish companies across five industry sectors. A qualitative analysis was conducted to identify dominant trends from the case descriptions. As a first step, our analysis identified the areas of interest for which innovation skills are required in the Danish industry based on the exposed needs and problems from the representative companies in the study. The analysis also provided insights into the synergy between the industry sectors and EE. We plan to conduct further studies that assess the degree to which current EE approaches enable students to acquire the required innovation skills, and identify innovation skills developed in the current setting that are not recognized by industry as yet.

In the innovation process taught in the current AIE course, we encourage engineering students to work with strategic and technological foresight across their cases, and to systematically look for opportunities into the future. In this way, we aim to equip students with the necessary skills for the job market by advancing their understanding of innovation, new product development, and business processes as a holistic approach related to the companies' contexts. Results from this study will help us focus the pedagogical practices and curriculum in the AIE course with respect to the needs expressed by Danish industries.

The results from our study are limited to the context of one university and the cases provided by selected Danish companies that volunteered for this study. Companies which opted out, or that were out of the scope of our study, could potentially provide different insights. Therefore, further work is required to generalize the findings from this study.

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[c] REFERENCES

[2] Moueddene, K.; Coppola, M.; Wauters, P.; Ivanova, M.; Paquette, J.; and Ansaloni, V. (2019). Expected skills needed for the future of work: Understanding the expectations of the European workforce. Deloitte Insights. Accessed May 02, 2021 https://www2.deloitte.com/be/en/pages/public-sector/articles/upskilling-the-workforce-in-european-union-for-the-future-of-work.html

[3] Coşkun, Selim; Kayıkcı, Yaşanur; Gençay, Eray. (2019). "Adapting Engineering Education to Industry 4.0 Vision" Technologies 7, no. 1: 10.

[4] Mohd-Yusof et al. (2015). Future Directions in Engineering Education: Educating Engineers of the 21st Century. ASEAN Journal of Engineering Education, 2(1), 8-13

[5] Miles, M. and Huberman, A.M. (2014), An Expanded Sourcebook: Qualitative Data Analysis (3rd Edition), Sage Publications.

[6] Beers, S. (2011). 21st century skills: Preparing students for their future. Accessed May 02, 2021 https://cosee.umaine.edu/files/coseeos/21st_century_skills.pdf

[7] Jaspersen, LJ and Stein, C (2019) Beyond the Matrix: Visual Methods for Qualitative Network Research. British Journal of Management, 30 (3). pp. 748-763.

[8] Liebenberg, L., & Mathews, E. H. (2012). Integrating innovation skills in an introductory engineering design-build course. International Journal of Technology and Design Education, 22(1), 93-113.

[9] Lönngren, J. (2017). Wicked problems in engineering education: preparing future engineers to work for sustainability. Ph.D. thesis, Chalmers University of Technology.

[10] Ramanujan, D., Zhou, N., & Ramani, K. (2019). Integrating environmental sustainability in undergraduate mechanical engineering courses using guided discovery instruction. Journal of Cleaner Production, 207, 190-203.

[11] Kunrath, K., & Ramanujan, D. (2021). FOSTERING SUSTAINABLE MINDSETS IN ENGINEERING EDUCATION. Proceedings of the Design Society, 1, 1597-1606.

[12] Magruk, Andrzej. Innovative Classification of Technology Foresight Methods. Technological and economic development of economy 17.4 (2011): 700–715.

[13] Camillus, J. C. (2008). Strategy as a wicked problem. Harvard business review, 86(5), 98.

[14] Zoltowski, C. B., Oakes, W. C., & Cardella, M. E. (2012). Students' ways of experiencing human-centered design. Journal of Engineering Education, 101(1), 28-59.

[15] De Graaff, E., & Ravesteijn, W. (2001). Training complete engineers: global enterprise and engineering education. European Journal of Engineering Education, 26(4), 419-427.

[16] Tam, E. K., Badra, F., Marceau, R. J., Marin, M. A., & Malowany, A. S. (1999). A Web-based virtual environment for operator training [for power systems]. IEEE Transactions on Power Systems, 14(3), 802-808.

[17] Ostrander, J. K., Tucker, C. S., Simpson, T. W., & Meisel, N. A. (2020). Evaluating the Use of Virtual Reality to Teach Introductory Concepts of Additive Manufacturing. Journal of Mechanical Design, 142(5).