AN INTERDISCIPLINARY COMPETENCE PROFILE FOR AI IN ENGINEERING

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ABSTRACT

The use of Artificial Intelligence (AI) in engineering is on the rise and comes with the promise of cost reductions and efficiency gains. However, classical engineers often lack the necessary skills to implement data-driven solutions. At the same time, computer scientists lack the required understanding of engineering systems. Thus, we need to extend the current set of competencies of engineers across the boundaries of disciplines to include competencies of Artificial Intelligence as well as skills necessary for interdisciplinary work. In this paper, we propose a competence profile of a so-called AI Engineer that combines the expertise of AI systems in the context of engineering. Based on perspectives from literature and interviews with experts from industry and research, we highlight the most important set of competencies across the professional, methodological, social, and self-competencies. The contributions of our paper can act as a reference point for developing and advancing future engineering curricula. Furthermore, it serves as a guide for professional self-development.

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1 INTRODUCTION

1.1 Motivation

Artificial Intelligence (AI) is a powerful tool and is seen as enabling technology in many use cases. Hence, there is a growing interest in applying AI in engineering applications such as increasing energy efficiency, optimising processes, quality management, and predictive maintenance [1]. The rise of AI and digital tools also changes the competence profiles of the next generation of engineers. The value of digital innovation and data-driven processes lies in the intersection of disciplines. Thus, more than ever, strong interdisciplinary learning is required, integrating competencies across the boundaries of disciplines [2,3].

Recent studies have investigated changing competence requirements in the engineering discipline [2,3,4,5], competence requirements for developing and working with AI [6,7,8,9], and general future skills [10]. However, there is currently no work on which competencies are required across the boundaries of disciplines to work and develop solutions at the intersection of AI and engineering. Furthermore, established engineering competence profiles, such as the CDIO syllabus [11], ABET [12], and EUR-ACE [13], do not yet address the integration of AI competencies in engineering curricula. Thus, this paper aims to answer the question *which professional, methodical, social and self-competencies are needed in these future roles of AI in engineering.* We hypothesise that the next generation of engineers does not solely focus on one domain but needs an interdisciplinary skill set that includes digital and AI competencies. We refer to this generation of future engineers as *AI Engineers*.

We address the question by developing a competence profile of an AI Engineer that is based on perspectives from literature as well as interviews with experts from industry and research. Our work aims to be a reference point for further adoption of the engineering curricula in the future and a guiding point for engineers that want to upskill themselves.

The paper is structured as follows: The next subsection clarifies the used terminology and background. Section 2 describes the methodological approach. Section 3 gives an overview of the competence profile and the supporting literature and interviews. Last, we discuss the findings and limitations and conclude with an outlook.

1.2 Terminology and Background

In this paper, we use the term *competencies* as the ability to act in and cope with context-specific demands [14]. In the context of education, we emphasise the development of competencies to act within certain professional environments. Following [14], we can roughly distinguish four categories of competencies:

- *Professional competencies* describe the specific knowledge, skills and experience to carry out the professional function.
- *Methodological competencies* represent cognitive skills that can be applied across situations and are required for mastering complex tasks and problems.
- *Social competencies* characterise knowledge, skills and abilities to accomplish goals in social interactions.

- *Self-competencies* describe skills and behaviours that relate to the self-awareness and behaviour of a person and influence their working practice.

In the context of AI, different roles can be defined, for example, AI developer, AI user and AI observer [7]. Accordingly, when selecting relevant competencies, it is also necessary to define the applicable role. In the following, the focus lies in finding the relevant competencies for the developer role. Another important factor to keep in mind is that roles depend on multiple factors, for example, the industry and the size of a company lead to a focus and also a more broad or specialised profile.

2 METHODOLOGY

The research question was answered using a qualitative content analysis based on semi-structured expert interviews and an explorative literature review. To understand the developing occupational field of AI engineers, the aim was to combine scientific perspectives from literature with practical insights from the industry. In this context, recent literature studies and the reported experience of associations provide an overview of required competencies, whereas the experience of the experts supports and supplements these with practical insights.

For the expert interviews, we selected industry partners who work on the intersection of AI and engineering and come from different industries. These include manufacturers of logistic systems, engineering service providers in mechanical engineering and IT, pharma companies, automotive manufacturers, applied science, and IT consultancies. Next to the different industries, we considered that the interviewees come from small, medium and large companies and performed functions in a variety of areas (data science, strategic business development, IT strategy, software development, collaborative factory, business process management, consulting). More than two-thirds of the interviewees were in a leadership position. A total of eleven guided online interviews were conducted by one of the authors. The interview questions focused on the general understanding of AI, current and future use cases in the respective companies, challenges in the use of AI, and the question of professional and interdisciplinary competencies required in the field of AI. The interviews were recorded and transcribed for further analysis.

The literature was selected using various search terms such as "competence", "competency", "skill", "engineering", "artificial intelligence" and "machine learning". Scientific studies, as well as reports of associations, were considered and results from German-speaking as well as English-speaking countries were used. In total, nine different sources [2,3,4,5,6,7,8,9,10] were examined, which are also mostly based on literature surveys and qualitative interviews themselves.

Both the expert interviews and the sources from the literature were evaluated using qualitative content analysis. The competencies were filtered out and assigned to the competency areas of professional competencies, methodological competencies, social competencies and self-competencies. Last, subcategories were formed and the most mentioned competencies were selected and described as part of the competence profile.

3 COMPETENCE PROFILE OF AN AI ENGINEER

In the following section, we give an overview of the competencies and the supporting literature and interview extracts. Fig. 1 summarises the competencies across the different categories and gives a more detailed description of the individual competencies.

Fig. 1. List of competencies with their description in the four categories of professional, methodological, social and self-competencies.

Professional Competencies	
Data and AI Knowledge	Handling and understanding of the fundamentals of data and AI technologies, as well as the ability to employ tools and models to analyse them.
IT Competencies	Designing, building and programming applications (with intelligent functionalities) and the ability to deal with respective frameworks and platforms.
Interdisciplinary Domain Know-How	Understanding of the technical foundations, physical components, and technical and business processes in the application domain.
Methodological Competencies	
Process- and System Thinking	Structuring, analysing, describing, modelling and optimising (AI) processes and systems.
(AI) Problem Solving	Recognizing and dealing with complex problems and situations and having solution strategies for them (that can involve AI).
AI Reflection	Reflecting the impact of AI technologies, for example with respect to ethics, legal, safety and social aspects and understanding one's own role in it.
Social Competencies	
Interdisciplinary Communication and Cooperation	Communicating and cooperating in an interdisciplinary team setting, or with people of different cultures and experience levels. Ability to adapt the communication and working style to the respective environment and team.
Change Management	Managing and shaping change processes, supported by the ability to communicate value, listen, inspire, and resolve fears.
Leadership and Decision Making	Ability to organise, coordinate and manage teams, and the ability to make decisions within the boundaries of the current responsibilities.
Self-Competencies	
Learning and Curiosity	Ability to individually acquire contextual knowledge from different sources and the interest, curiosity and openness to learn new topics.
Creativity	Developing novel, innovative solutions and questioning the "status quo" of processes and ideas.

3.1 Professional Competencies

Data and AI Knowledge - As a central point, various authors highlight the handling and analysis of data, such as Data Analytics and Data Science [2,3,4,6,7,8,10]. Furthermore, some authors explicitly state the understanding of AI technologies, in particular Machine Learning (ML) [2,6,7,8]. In this context, it is important to understand the mathematical foundations, such as statistical knowledge, as well as the benefits and limitations of models [2,8]. Furthermore, understanding and using the currently available tools and libraries is mentioned [8].

Six of eleven interviewees mention the handling and understanding of data. Particularly, they refer to pre-processing, structuring and uniting data from different systems, as well as an assessment of data quality. On the topic of ML and AI, the interviewees point out the ability to build and deploy models. This includes understanding different types of models with their benefits and limitations. Moreover, few interviewees state the value of having a “building kit” of tools for various use cases and data types. Furthermore, the interviewees value an understanding of the mathematical foundations of ML and the model parameters.

IT Competencies - In the context of Information Technology (IT) competencies, an understanding of digital tools and technologies as well as computer science basics is found important [2,3,4,5,7]. More specifically, multiple papers point at the fluency of programming languages, design patterns, platforms, frameworks and libraries, next to an understanding of software engineering [2,5,6,8,10].

The IT competencies are supported through the expert interviews. Around two-thirds of the interviewees put forward the importance of an understanding of software engineering, the application development of intelligent functionalities, and how AI as a building block engages with other code elements. Furthermore, some interviewees state user-centric (application) development and agile software development.

Interdisciplinary Domain Know-How - One common theme in the literature is the integration of interdisciplinary skills and knowledge [3,4,5,8]. Accordingly, multiple authors put the focus on having a foundation in one core engineering discipline, especially when AI is integrated with a physical interface or hardware such as a robot [2,5,6,7].

The interviews are aligned with the importance of understanding the domain, especially the underlying business and technical processes, and the engineering basics. One interviewer refers to it as the most important skill, as the value of AI comes only from the combination of Data Science and domain know-how.

3.2 Methodological Competencies

Process- and System Thinking - Another group of competencies highlighted by literature are process- and system competencies, especially for processes controlled or enhanced by AI [5,6]. More generally, two papers mention system thinking [2,3] and Huang et al. [9] add logical and abstract thinking as high-level competencies.

The interviews emphasise the importance of understanding and contextualising business and technical processes. An example is the ability to analyse, structure and break down processes and systems. Moreover, around half of the interviewees

mention system and process thinking. This goes along the lines of understanding the boundary conditions in the domain, the drivers of the process and what data could be used to optimise it.

(AI) Problem Solving - Multiple studies mention problem solving competencies [3,5,6,8,10]. More generally in this category, Huang et al. [9] endorse observation skills and analysis skills, whereas Gottburgsen et al. [3] highlight the ability to deal with complexity.

The answers from the interview can be clustered around problem understanding and problem-solving with AI. Next to the importance of understanding and working from a real defined problem within a business context, it is important to have an idea of the boundary conditions, tools, and data available to decide if an added value can be derived from using AI.

AI Reflection - From the engineering perspective, the literature highlights the importance of assessing technology and its social, legal, and ethical impact on the development [3,6,7], capacity for judgement [10] as well as responsible action and the ability to reflect the effect of one's own actions [3,6,7]. Accordingly, the ability to judge, reason, analyse and draw conclusions is mentioned [9]. AI reflection is supported through knowledge of (digital) ethics and an understanding of the legal basis and norms, such as data protection [3,7,10].

One key cluster in the interviews is the understanding of the impact of using AI in the application context and the assessment of the usefulness of AI in this context. Moreover, two interviewees explicitly state the ability to develop explainable AI models to allow the translation of the AI models into understandable user language and gain trust in the model’s decisions.

3.3 Social Competencies

Interdisciplinary Communication and Cooperation - The literature mentions the ability to communicate, cooperate and work in teams with people from different disciplines, cultures and levels of experience [2,3,5,6,7,8,10]. Next to communication and cooperation between different stakeholders, two papers also highlight the importance of explaining AI behaviour to various user groups [5,7]. Moreover, competencies for dialogue, conflict management, and digital collaboration fall under this category [10]. The foundation of interdisciplinary communication and cooperation can be described in the ability to adapt communication and working styles [2,6,10].

These competencies are also supported by more than two-thirds of the interviews. Here, the interviewees emphasise adaptive communication and cooperation with different target groups, as working on AI systems is usually at the intersection of multiple divisions. Moreover, the communication aspect is seen as very important to gain acceptance with the final user and to understand the requirements of different stakeholders.

Change Management - Kirchherr et al. [10] state the development of strategies to execute transformation, especially with respect to group dynamics, group cultures, networks and systems. Similarly, André & Bauer [6] mention the communication of

potentials and limits of AI, and supporting the change process by removing fears and coordinating the expectations of various stakeholders.

More than half of the interviews support this competency and see it as one key competency. It is mentioned in various forms such as to inspire people, present added value, formulate success stories, address concerns, listen to people, manage expectations of different stakeholders, resolve resistance, convince and sell. The underlying message is that integrating AI in systems and processes requires a transformation of the existing processes (and sometimes even culture) which makes it necessary to also manage the change process next to the technological process.

Leadership and Decision Making - The literature mentions the ability to organise, coordinate and manage teams, and the ability to make decisions within the boundaries of the current responsibilities [5,6,8].

This group of competencies was not directly stated in the interviews.

3.4 Self-Competencies

Learning and Curiosity - The literature highlights the ability to learn and independently acquire contextual knowledge [2,3,5,9]. Furthermore, André & Bauer [6] emphasise the curiosity and willingness to learn how to work with ML and AI systems. In this context, two studies stress the need for openness to new experiences and technologies in the changing world [2,7]. Moreover, Kirchherr et al. [10] encourage digital learning such as processing digital information from different sources and using learning management systems.

Three interviewees stress the importance of self-learning and lifelong learning, especially in the context of the fast-moving field of AI. From their perspective, it is a key competency to know where and with what methods one can find help and stay on top of current technological developments. Moreover, the fascination and curiosity to discover new insights were brought up.

Creativity and Innovation - Multiple studies express the importance of creativity and innovation competencies, such as developing novel ideas and improvements through questioning the “status quo” and critical thinking [2,5,9,10]. From a company perspective, this also requires a failure culture [7].

This is also supported in a few interviews, mentioning the eagerness to systematically experiment, the resilience to failure, patience and drive in finding solutions to complex problems as well as thinking out of the box. Moreover, questioning existing processes is stated. One interviewee explicitly states the difficulty for engineers to think out of existing control loops.

4 DISCUSSION

The presented competence profile confirms the initial hypothesis that an interdisciplinary set of competencies is needed to integrate AI systems in engineering and highlights the most relevant competencies for the role of an *AI Engineer*. First, the professional competencies show that to develop AI systems for the engineering domain, a combination of Data and AI knowledge, IT competencies, and interdisciplinary domain know-how is needed. Second, the methodological

competencies indicate the importance of process and system thinking, problem solving as well as the ability to reflect on the implications of using AI. In the category of social competencies, interdisciplinary communication and cooperation gain more importance with more cross-disciplinary working teams. Furthermore, managing and leading people through accelerated change and transformations is essential. Last, self-competencies in themselves gain importance through the accelerated change among industries, above all the ability to learn and independently acquire knowledge. Some of the mentioned competencies are also of increasing importance in other subject areas and are already included in the scope of previous education of engineers or computer scientists. However, they need to be brought together into one novel profile of an *AI Engineer* that combines the expertise of AI systems in the context of engineering.

The trend towards interdisciplinary profiles and competencies also needs to be reflected in engineering education. This can be, for example, achieved through interdisciplinary and cross-disciplinary projects or the integration of topics from different industries in the engineering curricula. Furthermore, the importance of methodological, social and self-competencies needs to be further strengthened and incorporated into the technical subjects.

The significance of our findings is limited by two factors. First, *AI Engineer* is not yet an established role and can be found in different forms across company sizes and in literature. Depending on the envisioned role, different competencies might get assigned different importance. We try to overcome the limitation by selecting interview partners and literature from different perspectives, for example, literature on competencies for engineering in Industry 4.0 and AI literacy competencies. Second, our interview sample is relatively small and currently represents only German companies. Thus, there is a need for more investigation to what extent the proposed profile can be generalised.

5 CONCLUSION AND OUTLOOK

In this paper, we proposed a new interdisciplinary competence profile for AI in engineering, based on findings from the literature and interviews with industry experts. The competencies support the hypothesis that AI in engineering needs interdisciplinary access. Next to solid professional competencies in AI and the domain, our findings show a high relevance for interdisciplinary communication skills and strong methodological competencies, such as system- and process thinking.

Based on the initial competencies, further work involves a definition of required levels for different job profiles. Moreover, the competence profile can serve as a reference for competence-oriented study development and in designing a curriculum for people learning these competencies from scratch or people who want to upskill themselves. This can also include more research around the question of well-suited competence-oriented teaching methods in the engineering and AI field.

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