

Competencies in the Digitalized Working Environment: A Concept for Engineering Education in Higher Education Institutions

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Abstract

In the contemporary working environment, Industry 4.0 concepts and technologies offer a multitude of possibilities to increase productivity and, therefore, the long-term success of industrial companies and small and medium-sized enterprises, as well. In this context, the systematic development of digital competencies is a major success factor of modern industrial engineering education in higher education institutions. Therefore, this paper reflects the theoretical concept of competencies within modern educational approaches, e.g., 'Education 4.0' in Europe, with a special emphasis on digital competencies. Moreover, the authors present the design of the course 'logistics system engineering and material flow management' to illustrate the implementation and application of digital technologies in university teaching. The module-based concept should further be used as a reference for the realignment of engineering lectures in higher education institutions to contribute to the professionalization of industrial engineering education.

1 Introduction

In today's transformation society, the teaching of relevant and up-to-date skills is indispensable and represents a central element of the European Pillar of Social Rights (EPS, 2020). Thus, high-quality education should be made available to all people, so that they can actively and self-confidently make a significant contribution as citizens regarding further development and ongoing innovation. The European Competence Agenda of the European Commission (2016) makes it clear that Europe has a lot of catching up to do in this respect since around 70 million people are neither able to read and write properly, nor do arithmetic, nor do they have digital skills and are, therefore, at risk of poverty, unemployment or social exclusion. The demand here lies in fundamental reforms of education systems and their orientation toward future-oriented knowledge, skills, and competencies 'adapted to the digital age' (EUCO14/17, 2017). Since technological progress (keywords: artificial intelligence, robotics, IoT, etc.) is developing rapidly, a lifelong investment in key skills and, above all, digital skills is required. The tertiary sector is particularly forced to push sustainable reforms in terms of skills development and labor market trends to ensure that the next generation of professionals is available. Practical experience, new learning instruments, and materials, the use of digital technologies, and a lifeworld orientation must be incorporated into modern curricula (European Commission, 2018). This paper aims to respond to this demand. In the first step, the concept of competencies will be examined in more detail. Moreover, the authors focus on the concept of digital competencies by considering current studies in the context of learning and teaching approaches in industrial engineering education (Dallasega et al., 2019; 2020; Woschank and Pacher, 2020). In the final chapter, the course 'logistics system engineering and material flow management' will be used to illustrate the usage and implementation of digital technologies in university teaching.

2 The concept of competencies

“Those who do not want to be left behind in the discourse about our future must not be left behind in the trend towards competence(s)” (Geißler and Orthey, 2002). A much-cited definition of competence by Franz Weinert describes the term as “the cognitive abilities and skills available to individuals or learnable by them to solve certain problems, as well as the associated motivational, volitional and social willingness and ability to successfully and responsibly use problem-solving techniques in variable situations” (Weinert, 2001).

For further discussion, a relevant definition of the fashionable term ‘competence’ is required. Roth (1976) examined the question of what abilities and skills a person should possess to ‘be of age’. In this context, maturity is understood as “competence for responsible action competence” (Roth, 1976). The author defines this pedagogical maturity based on the following three levels of competence:

- 1) Self-competence - dealing with oneself: To be able to deal with oneself and one's life, i.e., to be able to shape one's own life and take responsibility for it. Qualifications: Determination, self-control, concentration, reliability, sense of responsibility, open-mindedness, criticism/judgment, creativity, and decision-making ability.
- 2) Professional competence - dealing with the professional world: Coping with the demands of work, politics, etc. Qualifications: Cross-professional knowledge and skills, handling of new technologies, learning techniques, willingness to learn, and problem-solving abilities.
- 3) Social competence - dealing with other people: Coping with social life (e.g., in family, school, kindergarten, and the circle of friends) the necessity of cooperation, communication, and conflict resolution. Qualifications: Communicative skills, willingness to make contacts, ability to cooperate, empathy, patience, openness, helpfulness, co-responsibility, honesty/sincerity, solidarity, tolerance, and assertiveness (Hobmair, 2002).

The term ‘maturity’ thus refers to certain abilities that aim to achieve better, higher quality, and more appropriate action (Geißler and Orthey, 2002). According to Roth, this theory of action combines the personal and situational aspects of actions. For the competence assessment, it seems to be essential to measure and consider both personal and situational factors as pedagogical guidance of action (Kaufhold, 2006). Competence is derived from the Latin ‘competencia’ and means ‘meeting’. The adjective ‘competent’ can be interpreted as ‘appropriate’. Competence is manifested when situational requirements and the individual's available potential of knowledge, skills, and abilities meet. “Competence is demonstrated when the meeting of situational requirements and the individually available potential of knowledge, skills, etc. can be acted upon appropriately” (Gnahs, 2007). Thus, competence appears to be something that enables one to act appropriately in specific situations due to the meeting of requirements and individual abilities and skills (Gnahs, 2010; Treptow, 2014). Siebert (2003) defines competence as follows: “Competencies are life-historically, acquired profiles of emotion and cognition, of experience and knowledge acquisition, of thinking, wanting, and acting.” Competencies are largely acquired ‘en passant’ during life, they are hardly taught and learned in seminars - even though seminars can be a training ground for competencies. Accordingly, competence is described as the ability to learn to be able to act adequately in certain situations (North et al., 2013). To be able to differentiate between the various aspects of competence, it is necessary to analyze the meta-concept of ‘competence’ and to distinguish between the basic types of competence.

Table 1 displays a generalized categorization of competencies.

Table 1. Competence types (based on Strauch et al., 2009; Gnahs, 2010).

Competence types			
Specialist competencies/ special competencies	Interdisciplinary competencies		
	<i>Social competence</i>	<i>Methodological competence</i>	<i>Personal competence</i>
	Ability to work in a team	Problem solving techniques	Time management
	Conflict ability	Presentation skills	Organization ability
	Communication ability		Resilience
			Independence

Specialized competences comprise the first competence class. This type of competence refers to special subject areas (Erpenbeck and von Rosenstiel, 2007). As the name suggests, the ‘interdisciplinary competences’ are “relevant in principle in all situations”, not just for a specific ‘subject’ (Gnahs, 2007). The term ‘interdisciplinary competence’ is often equated with the term ‘key competence’.

Also, the European Parliament defines further so-called key competences that are essential for an active, self-determined lifestyle.

These competences include (European Parliament 2006):

- Mother tongue competence
- Foreign language competence
- Mathematical competence and basic scientific and technical competence
- Digital competence
- Learning competence
- Social competence
- Personal initiative and entrepreneurial competence
- Cultural awareness

As it already includes Treptow (2014), competence describes the connection “between wanting, knowing, being able, being allowed, and proving.”. As has been made clear in previous attempts at definition, the term competence encompasses various elements such as abilities and skills, knowledge, dispositions, values as well as motives and motivations. Competence manifests itself in the successful interaction of the respective elements. This manifestation is generally referred to as ‘performance’.

Moreover, the discussed aspects can be graphically summarized in the following Figure 1.

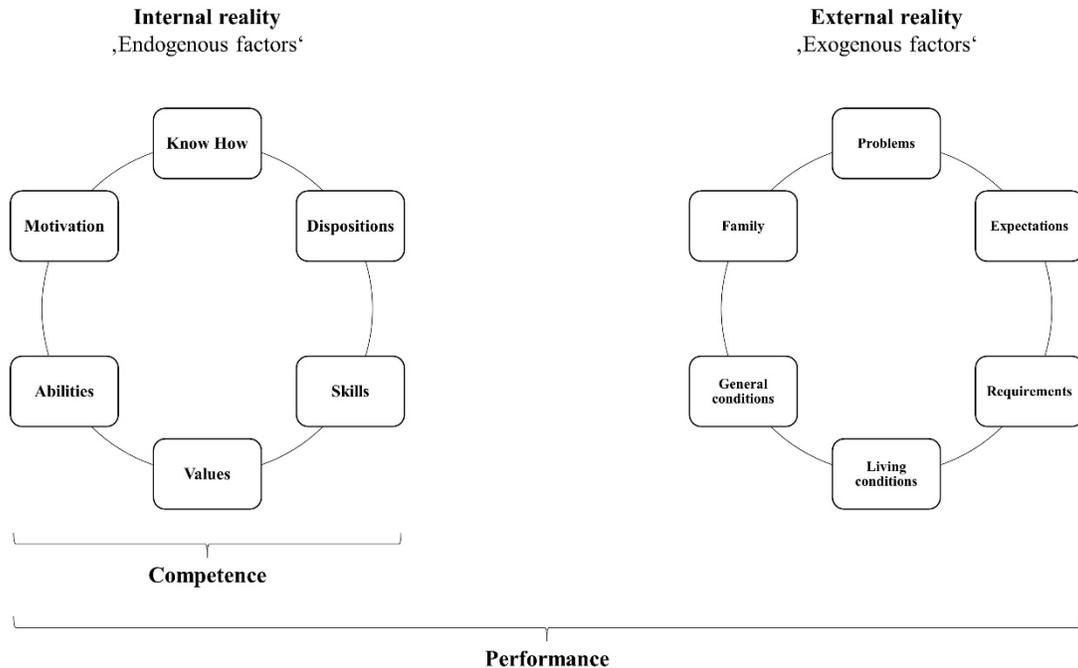


Figure 1. Competence types (based on Gnahs 2007).

If one looks at the inner reality of a person, it becomes clear that many elements of competence are in the respective subjects.

Knowledge comprises one essential competence element. Knowledge is generated through the mental processing of information and this forms the foundation for coping with situations. According to Luhmann (1987), knowledge can, therefore, be understood as the result of a learning process as well as a personal option for action. This knowledge stock can be accessed if necessary. There are different forms of knowledge. Kaufhold further refers in her explanations to different differentiation possibilities. The classical distinction between explicit - conscious knowledge - and implicit knowledge - experiential knowledge, which is not always conscious of the subject - is sufficient for further discussions (Kaufhold, 2006).

According to Gnahs, **motives/motivations** are 'emotional driving forces and interests' which require action (Gnahs, 2007). A person's specific actions are determined in the respective situation by reference to the subjective emotional situation(s). Motives are latent dispositions and influence how situations are perceived and evaluated and are, therefore, relevant for further competence assessment (Kaufhold, 2006).

Dispositions are personality traits as well as attitudes of a person. These dispositions are acquired during life and form the inner basis for subjective action (Kirchhöfer, 2004; Gnahs 2007). Gnahs (2007) further identifies five dimensions of a person's overall personality:

1. Neuroticism
2. Extraversion
3. Compatibility
4. Conscientiousness
5. Openness to new experiences.

Like **dispositions**, **values** develop throughout a lifetime. The difference lies in the fact that values are generated by external influences and are conveyed, adopted, and internalized during socialization. The following Figure 2 illustrates this process.

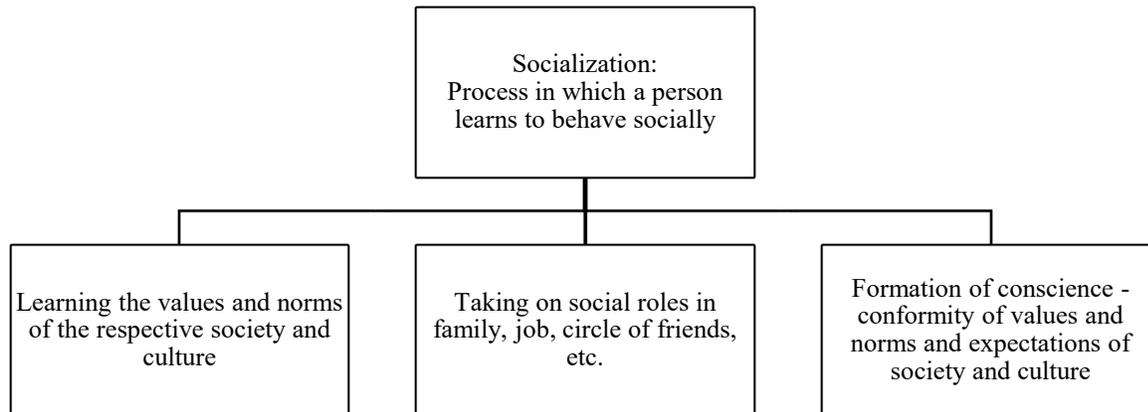


Figure 2. Socialization process (Pacher 2019 based on Hobmair, 2002).

As a supplement to this, Erpenbeck (2010) argues that values must be “transformed into one's own emotions and motivations” if they are to achieve a certain effect. Political, ethical, enjoyment, and utility values are defined as basic values in the literature.

Skills can - analogous to the remarks of the European Parliament in the Qualifications Framework - be differentiated in terms of cognitive and practical skills. Logical, creative, and intuitive thinking are called cognitive skills. In contrast, practical skills include dexterity or the use of different materials, methods, or instruments (European Parliament and Council of the European Union, 2008). Kirchhöfer (2004) defines skill as “a largely automated and stabilized manual, technical or mental form of action that is trained and available through practice and use.” The term most frequently used in combination - and sometimes even as a synonym - with the concept of competence is ability. Gnahs (2007) outlines this term as “something like the generic term of knowledge and skills”. In the European Qualifications Framework, competence is used as ‘proven ability’ (European Parliament and Council of the European Union, 2008). According to this, skills are the prerequisite for ‘carrying out actions’ (Kaufhold, 2006). Skills are very versatile, such as motor, intellectual, cognitive, emotional, but also communication, problem-solving, or learning skills. Abilities can be differentiated in terms of the degree of development or type. Within the framework of these two characteristics, further subdivisions can be made. As in the above-mentioned explanations, a person acquires competences in different situations through different learning paths. According to Gnahs (2007), the essential learning processes include:

- Formal learning
- Non-formal learning
- Informal learning
- Socialization
- Learning ‘en passant’

The recording and measurement of competencies are as versatile as the ways of acquiring them. If competences are to be recorded and measured as ‘outcomes of learning processes’ and subsequently recognized as equivalent, regardless of how, why and by what means, then reliable instruments must be implemented. As the literature and research in recent years have shown, instruments for the recognition, validation, and certification of non-organized learning processes are being developed (Gnahs, 2007).

In the discussion about competence recording, the statements of Kaufhold (2006) can be referred to: "The recording of competence must always be considered in connection with the underlying goals and purposes as well as the interests involved." Also, systems theory - for example, Luhmann (1987) - distinguishes between the following reference fields for competence assessment:

1) Person: By recording the competencies of a person, the subjective competencies can be presented transparently. This, in turn, can lead to the retention of employment or to the admission to further training opportunities. Further essential characteristics are the (further) development of reflection and (more conscious) perception of strengths and development potential.

2) Organization: In organizations, the main interest in competence assessment lies in the selection of personnel. Relevant here is the recording of competencies for the entire personnel management from recruitment, assessment, and further development to the optimization of personnel deployment.

3) Society: The focus of competence assessment is on social and political interests (Kaufhold, 2006).

3 Digital competencies

Under the postulate 'Industry 4.0', the permanently and rapidly developing digitalization of the working world through the penetration of new technologies such as augmented reality, virtual reality, internet of things, digital twins, etc., requires the implementation of new methodological-didactic teaching and learning settings, 'Education 4.0' so to speak.

The European Commission's action plan for digital education formulates measures for the implementation of innovative teaching formats. Table 2 displays the main priorities and measures generated based on the action plan for digital literacy from the European Commission (European Commission, 2008).

Table 2. Action plan for digital literacy (European Commission, 2008).

Priority	Action
Better use of digital technologies in teaching and learning	Providing tools for teachers and trainers to make better use of new technologies, including better Internet connectivity
Development of relevant digital skills and competencies for digital change	Targeted measures to develop relevant digital skills
Better education through meaningful data analysis and forecasts	Increased and new efforts to improve education through meaningful data and analysis

Following the demand for targeted instruments and teaching materials for the use of digital technologies, the next chapter will deal in more detail with the implementation of digital technologies in university teaching and the course 'logistics system engineering and material flow management'.

4 Course concept for the incorporation of digital technologies

In general, the course ‘logistics system design and material flow management’ aims to teach the application of methods for factory planning to solve company-relevant questions in the context of logistics system design and material flow optimization. Therefore, the lecture will be divided into 2 parts: 1) Module 1: Theoretical Part and Module 2: Practical Part.

4.1. Module 1: Theoretical Part

Module 1 introduces the students to basic and advanced topics of logistics system design, factory planning, and material flow design and optimization. Therefore, we use face-to-face lectures and group discussions as the primary teaching and learning methods. The advanced lectures are conducted online by using a Moodle-based e-learning approach and an online communication tool (e.g., Zoom, WebEx, Microsoft Teams, etc.) for lectures and group works (e.g., group discussions, breakout sessions, etc.). Table 3 summarizes the concept of the first module of the course ‘logistics system design and material flow management’.

Table 3. Module 1: Theoretical Part.

Module 1: Theoretical Part		Timeframe: 2 hours per week	
Topic(s): Introduction to the fundamentals and principles of logistics system design (1); introduction to the fundamentals and principles of factory planning (2); introduction to the fundamentals and principles regarding the design of material flows in logistics systems (3); basics of factory planning, manufacturing layouts, product, and process-based layouts, design of workstations, group technology, and cell design, computer-aided layout planning (4); material and information flow in logistics, activities of material flow management, material flow control, conveyor and storage systems, control of automated material flow systems, material flow accounting, approach to material flow planning (5).			
Objective(s): Knowing the most important principles and methods of logistics systems design, factory planning, and material flow optimization. Understand the advantages of new toolsets and supporting digitalization technologies.			
Content:	Methods:	Materials:	Duration:
(1)	Face-to-face lectures and group discussions	Handouts, videos	
(2)	Face-to-face lectures and group discussions	Handouts, videos	
(3)	Face-to-face lectures and group discussions	Handouts, videos	
(4)	Online lectures and Moodle-based e-learning	Handouts, videos, online tutorials	
(5)	Online lectures and Moodle-based e-learning	Handouts, videos, online tutorials	
Remarks:			

4.2. Module 2: Practical Part

Based on the theoretical framework from module 1, the students will have to work on a set of interactive case studies on the topics of logistics system design, factory planning, and material flow design and optimization. The case studies will be supported by online sessions and augmented reality demonstrations (e.g., 3D layout planning, building information modeling, etc.). Moreover, the students will use state-of-the-art discrete event simulation tools (e.g., Plant Simulation, etc.) for the modeling of material flows in logistics systems. Table 4 summarizes the concept of the first module of the course ‘logistics system design and material flow management’.

Table 4. Module 2: Practical Part.

Module 2: Practical Part		Timeframe: 2 hours per week	
Topic(s): Case studies on logistics system design (1), case studies on factory planning (2), case studies for the design of material flows in logistics systems (3)			
Objective(s): Knowing the most important principles and methods of logistics systems design, factory planning, and material flow optimization. Understand the advantages of new toolsets and supporting digitalization technologies.			
Content:	Methods:	Materials:	Duration:
(1)	Interactive case study, online sessions, and augmented reality demonstrations	Handouts, videos	
(2)	Interactive case study, online sessions, and augmented reality demonstrations	Handouts, videos	
(3)	Interactive case study, online sessions, and simulation tools.	Handouts, videos	
Remarks:			

5 Conclusion

In this paper, the authors identified modern industrial engineering education in higher education institutions as a major success factor within the framework of Industry 4.0 concepts and approaches. Thereby, a special focus should be placed on the systematic development of digital competencies to ensure an ongoing professionalization of the industrial engineering profession.

Based on recent theories of competencies and competence development, this paper has introduced a module-based concept for the course of ‘logistics system design and material flow management’ by using a set of online and offline teaching and learning methods combined with interactive case studies, online sessions, augmented reality demonstrations, and discrete event simulation tools.

In this context, future research should focus on the investigation of holistic competence-profiles in the context of industrial engineering education in higher education institutions for the engineers of tomorrow. New teaching and learning methods are needed to enable students to acquire the necessary transversal skills for the post-industrialized world. Higher education must provide future experts with future-oriented knowledge, skills, and competencies for maintaining competitiveness and strengthening the European economy. For all students, especially those in STEM (science, technology, engineering, and mathematics) subjects, the acquisition of extensive cross-sectional and key-competencies is a major success factor.

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8 Biographies

Corina Pacher is an Education Project Manager at the Resources Innovation Center in Leoben. She studied pedagogical and educational science at the University of Klagenfurt with a specialization on social and inclusive education as well as on professional education. During and after her studies, she gained work experience, e.g., as the head of educational programs and in different social public service enterprises as social education worker. Currently, she is mainly focusing on raising the awareness for a resource-orientated handling of raw materials by connecting research, education, and society, e.g., by building and expanding skills and competencies of students through training initiatives.

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