1 | Introduction: **Adaptive performance in engineering in times of uncertainty and change**, conceptual backgrounds

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1 | Introduction: Adaptive performance in engineering in times of uncertainty and change, conceptual backgrounds

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ABSTRACT **This chapter provides conceptual backgrounds to the topic of adaptive performance in the context of engineering. It describes how engineers' adaptive performance develops and how this development can be supported in work- and learning contexts.**

Adaptive performance refers to the ability to solve new, complex problems in changing environments and new situations. On the one hand this demands domain related knowledge, skills, and attitudes of engineers.

On the other hand, it is the environment that can facilitate or restrict engineers' possibilities of showing adaptivity in their performance. Especially learning environments should allow for frequent experiences with complex tasks and wicked problems, interdisciplinary experience in different situations, and feedback and reflection on experiences.

This book refers to examples of learning approaches that match with these elements, such as challenge-based learning. This chapter aims to provide a conceptual discussion about adaptive performance in the professional domain of engineering. After an overarching conclusion the successive chapters in the book are laid out.

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In this chapter, we relate adaptive performance to three main topics. First, we address how the concept of adaptive performance can be embedded in the literature on engineering education. In this part, we connect the concept of adaptive performance to creativity and critical thinking as essential parts of adaptive task performance in engineering. Second, we explain how engineers' adaptive performance develops and emerges over time. Third, we briefly touch upon how engineers' adaptive performance can be stimulated in different contexts.

We conclude with an outline of the chapters of this book, including the contexts in engineering (education) they touch upon. The chapters are organised in answering the central research question of the book: What is adaptive performance in engineering and how can adaptive performance development be stimulated and formatively assessed in learning/work contexts?

Conceptualising adaptive performance

Engineers increasingly contribute to solving complex sustainability problems (Lönngren, 2019) as for instance captured in the Global Sustainable Development Goals of the United Nations (UN Desa, 2019). These problems are ill-structured, characterized by uncertainty, unpredictability, and change. Solving such complex problems requires efforts from different stakeholders and experts (Lönngren, 2019). Characteristics of these complex problems are (1) that they can be analysed at multiple levels of abstraction, (2) that they include uncertainty, and (3) that expertise and (transdisciplinary) collaboration are needed to come to feasible solutions.

In the domain of engineering education, the learning tasks of solving such problems are known as challenges (Johnson et al., 2009; Malmqvist et al., 2015). Challenges are perceived as self-directed work scenarios in which students engage (Johnson et al. 2009; Gaskins et al. 2015). Rather than solving the problem itself, the goal of these challenges is to learn to define and address the problem, and to learn what it takes to work towards a solution (Van den Beemt, et al., 2023a). However, the final deliverable can be a tangible solution or a proposal for a solution to the challenge (Membrillo-Hernández & García-García, 2020).

For example, a challenge could address dementia as a growing problem in healthcare. Not only because of human suffering, but also because it increases work pressure for health professionals. One question that can be derived from this challenge is: How are artificial intelligence-based solutions useful to address this problem? A solution then could be to develop a robot that supports professionals. Other questions that need to be answered during the process are: How to develop a robot that suits this context? What interactions should the robot be able to engage in with elderly? And how to make sure that the robot enables healthcare providers to relate to the data the robot gathers?

Challenge-based learning (CBL) is increasingly adopted in higher education institutions to educate students as change agents for sustainability problems (Gallagher & Savage, 2020; Malmqvist et al., 2015). In CBL, students work in interdisciplinary teams on authentic, complex challenges. CBL can be perceived as an educational concept (Van den Beemt et al., 2023a) capturing different educational practices and teaching methods. At the core, CBL is student-centred and has its focus on personal and professional development of students in the process of solving complex challenges (Maya et al., 2017; Membrillo-Hernández & García-García, 2020; Van den Beemt et al., 2023b).

Simply applying standard operating procedures are insufficient for such challenges, because they are characterized by uncertainty (Caratozzolo, et al., 2020). Navigating through this uncertainty is also known as adaptive performance. Adaptive performance refers to an elevated level of performance in unfamiliar situations based on an understanding of why certain actions are useful in certain situations (Chang et al., 2017). In the context of engineering education this approach to adaptive performance is closely related to the T-shaped professional model (Gardner, 2017), which combines in-depth disciplinary expertise with the ability to work with a broad range of people and situations (Gero, 2014). Adaptive performance is shown in the performance of an adaptive expert, which is triggered by a change in task or in the environment which is new for this expert (Pelgrim et al., 2022).

Adaptive experts can be distinguished from routine experts (Hatano & Inagaki, 1986). Both are experts, considering that they meet Ericsson's definition of experts as those who consistently perform better than others on tasks that are representative for the domain of expertise at hand (Ericsson et al., 2018). But where routine experts perform tasks at high levels of efficiency and effectivity in stable, predictable work environments, often working through protocols and established procedures, adaptive experts can successfully manage challenges and tasks that are new to them and that are new in their domain in a creative and flexible way. Adaptive experts have a good dose of resilience, self-regulation and self-insight (Bohle Carbonell et al., 2014; Ward et al., 2019; Pelgrim et al., 2022).

Also, the way in which adaptive experts' knowledge is organised differs from that of routine experts. The knowledge of adaptive experts is more abstract -or more declarative or conceptual- and therefore the link to a specific context is weaker. This makes it easier to use this knowledge to solve a new problem in a changed or new situation. Knowledge is not directly linked to performance, but knowledge guides the perception and interpretation of (new) situations and the subsequent decision-making process about performance (Blömeke et al., 2015). The process of perceiving, interpreting and, subsequently, decision making can be regarded as a form of reflection.

How deep reflection processes make adaptive engineers unique

Reflection is a cognitive and affective (emotional) process of creating meaning and understanding from experiences and content. It is often presented as a cyclical learning process that involves several stages, for example, from analysing specific experiences to the development of new knowledge about that experience, which can lead to alternative future actions.

Reflection can be divided in several levels (Kember et al., 2008; Wallman et al., 2008; Mezirow, 1991; Poldner et al. 2014). The lowest level is non-reflective and relates to awareness or perception of an experience or object. Next is 'content reflection', i.e., reflection in terms of questioning or making interpretations of own behaviour and drawing conclusions. The third level refers to 'process reflection.' This includes the creative consideration of alternatives and leads to a different starting point for future comparable situations. The highest level of reflection, 'premise reflection,' is also called 'critical reflection', because at this level one's own presuppositions and premises are the object of reflection, and 'possibility for transformation' (Mezirow, 1991).

Engineers who perform adaptively have deeper conceptual knowledge and show deeper levels of reflection. That is, they not only understand what central concepts underlying the complex problem are and how they work, but also why that is the case. In addition, they understand the relationships between concepts or parts of knowledge in a larger framework, i.e., how chunks of knowledge and skills can be meaningfully related to each other. This allows them to think more deeply and to associate and extrapolate between solutions of different complex problems and situations. Being able to alternately use the processes of divergent and convergent thinking makes them creative in their problem-solving process. Such experts draw their thinking on and analogous to earlier experienced complex problems (Bohle Carbonell et al., 2014).

The need for creative and critical thinking in adaptive performance

Innovation and creativity are considered important aspects for solving complex challenges (Gallagher & Savage, 2020). These aspects can be operationalised in creative thinking (Sternberg, 2003) and critical thinking (Bailin, 2002). Creativity can be defined as "The interaction among aptitude, process and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context." (Plucker et al., 2004, p. 90). In the context of engineering, creative thinking is an essential element of expertise because adequate task performance often involves finding a new and useful solution to a problem.

Devising creative solutions requires divergent thinking, that is, producing multiple or alternative answers from available information by "making unexpected combinations, recognizing connections among distant associations, transforming information into unexpected forms, and the like." (Cropley, 2006, p. 391). However, it also requires finding the best solution to the problem at hand. This requires logical thinking, validating and accuracy. The deeper a person's knowledge of a particular subject, the more opportunities that person has to come to creative expressions (Simonton, 2003).

So, creative thinking goes hand in hand with knowledge. This involves deep knowledge about certain topics that engineers can use flexibly, for instance to solve new problems or problems outside their own profession or specialism (thinking out of the box). Combined with not being stuck in rigid routines, engineers can produce original and useful solutions. Spiro et al. (2013) call this combination "cognitive flexibility". This flexibility allows adaptive performers to constantly restructure, reorganise and refine their knowledge for solving complex tasks in context (cf. Feltovich et al., 2006).

Critical thinking contextualises creative ideas, by examining what constellation of resources is needed in particular contexts in response to particular challenges, and what the range of application is for those resources (Bailin 2002). In engineering education, teachers in their role as coach guide students in formulating questions that explore these required resources, for example by clarifying what knowledge students need to develop. Engineering students with adaptive expertise bring critical thinking into new problems by asking many questions in new situations, identifying relevant content, and making connections (Froyd, 2011). They can choose to start from either content emphasis first, or process emphasis first. However, to address today's complex challenges, eventually a balance between content (product) and process needs to be found (Van den Beemt et al., 2023a).

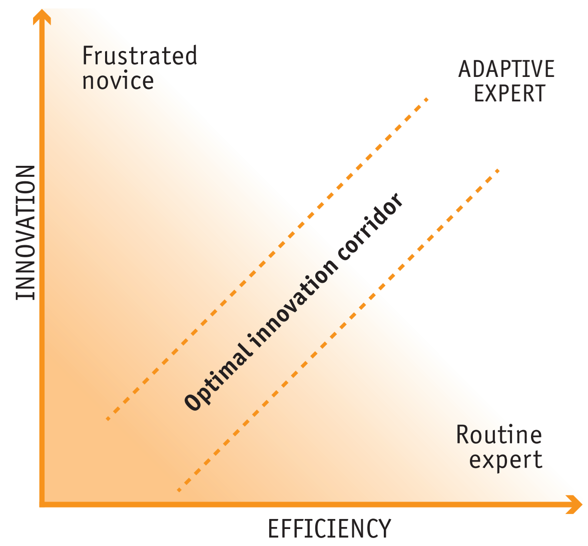
Development of engineers' adaptive performance

To develop engineers' adaptive performance, it is important to give them challenges that are just above the level of their abilities at that moment and that they can conduct with the support of a person who has more expertise, for example from a supervisor. This means that challenges should fit engineers' zone of proximal development to be effective for learning.

This zone of proximal development is also referred to as the 'adaptability corridor' (see Figure 1) (Bransford et al., 2005). Giving a beginner an innovative task that is above this corridor can lead to frustration, while giving tasks to a professional which he or she already masters can lead to higher levels of efficiency or routine, which in the long run may even become less effective if applied thoughtlessly (Choudhry et al., 2005).

The process of developing expertise can be sped up considerably by systematic efforts

FIGURE 1 ADAPTABILITY CORRIDOR (ADAPTED FROM BRANSFORD ET AL., 2005)



to improve task performance. Such a process is referred to as *deliberate performance* (Fadde & Klein, 2010; Van Tartwijk et al., 2023), a concept which was coined by Ericsson and colleagues as *deliberate practice* (Ericsson et al., 2013). This implies that in curricula aimed at the development of expertise, learners should be able to systematically improve tasks performance. This requires learning environments in which they learn to deal with constrains and use opportunities for optimal task performance. Typically, such learning environments are in realistic contexts that students work and learn in such as internships and learning trajectories in the workplace aimed at professional development.

Training principles that stimulate the development of adaptive performance within such learning environments are known as: frequent practice with feedback and active reflection on experiences and person; developing multidisciplinary experience through practice with different complex cases and in different situations and contexts; tailor-made support by a supervisor (Bohle Carbonell et al., 2014; Kua et al., 2021; Mylopoulos et al., 2018; Wallin et al., 2019; Ward et al., 2018). Two routes in training are known to stimulate cognitive flexibility.

First, to develop expertise by (assignments that stimulate) the use of multiple perspectives, different disciplines, or trying out several paths to solving complex problems. This stimulates openness to and getting acquainted with different perspectives. Second, by learning from mistakes. Unsuccessful attempts to complex problem solving give information that can be used as internal feedback that certain solutions do not work. This can trigger the search for alternatives and looking to the problem differently. In the case of complex tasks, this can lead to new original ideas. Weisberg, (2018) systematically elaborates on this principle for countless creative examples in history.

Stimulating the development of adaptive performance in learning and work contexts

Stimulating the development of engineers' adaptive performance always takes place in interaction, i.e., interaction between the engineer and the (work) environment and interaction with artifacts and others, such as machines and colleagues that are part of that environment.

This implies that the perception or sensemaking process of the environment by professionals is crucial and that it is guided by (a) existing knowledge and views (after all, you see what you think you see) and (b) sensory experience. Sensemaking is the effort to experience and understand events and is often triggered by unexpected circumstances that allow us to view situations consciously and through a new lens, and question and revise earlier interpretations (Ward et al., 2018). This process supports identifying problems and attaching meaning to findings.

Conclusion

This chapter provided conceptual backgrounds to adaptive performance as a way to navigate in uncertain tasks, environments and wicked problems in the domain of engineering.

Adaptive performance is based on being efficient and innovative toward changing tasks and environments. It is explained how adaptive performance demands domain knowledge, deep reflection, creativity, and critical thinking. To develop toward adaptive performance, it is important that the balance between innovation and efficiency needed for this navigation, fits the level of expertise of the person. This is also known as the adaptability corridor (Bransford et al., 2005).

The foundation for adaptive performance lies in the interaction between the organisational demands in workplace and learning environment and the characteristics, knowledge, skills, and attitudes of the professional. The interplay between the two, i.e., task/context and professional, contribute to engineers' sensemaking processes of environmental 'cues,' which is needed to identify problems and direct strategies for solution. Given the interplay between task environment and professional, challenges to develop adaptive performance lie also in institutional change and technological innovation.

Outline

With this book, we aim to contribute to the understanding of how adaptive performance develops, how learning/work environments can be designed to support this, and how the concept can be formatively assessed. The next chapters provide a wide variety of research and state-of-the-art developments in the topic of adaptive performance within engineering in different contexts and countries.

The contributions in this book stem from a shared urgency: the need to train professionals who are not only competent in their field but also agile, reflective, and creative in dealing with new, complex learning/work situations.

The chapters are organised in answering the central research question of the book: What is adaptive performance in engineering and how can adaptive performance development be stimulated and formatively assessed in a learning/work context?

The book is structured in three parts.

Part I regards the conceptual deepening and underlying mechanisms of adaptive performance in the context of workplace-based learning in engineering. This starts with chapter 2 in which Groenier and colleagues discuss three Dutch cases of innovative workplace-based learning environment that support adaptive expertise. In their study supporting working mechanisms, such as collaboration, self-regulation, and dealing with complexity, are identified. They also synthesize important design principles, particularly the interaction with others and working on open-ended tasks.

In three following chapters by Munneke & Ommering (chapter 3), Kaffka & Backhaus (chapter 4), and Gamborg & Jensen (chapter 5), conceptual backgrounds and underlying mechanisms of adaptive performance are deepened from different perspectives. The chapters elaborate on the concept of adaptive performance with cases and examples from contexts in three countries.

In chapter 3 Munneke and Ommering explain the meaning of epistemic agency as a driver for knowledge creation. They show how adaptive performance requires knowledge creation, not just knowledge reproduction and how epistemic agency develops through intentional engagement in context. They illustrate their chapter with examples from the context of Dutch higher education. Chapter 4 by Kaffka & Backhaus, describes agile methodologies, such as Lean, as a didactic approach to support workplace-based learning through an iterative process, perspective shifts, and metacognitive growth. A case from the German construction sector is included. Chapter 5 by Gamborg & Jensen take an embodied cognition perspective to describe the essence of bodily interaction with the environment as part of adaptive performance. In this Danish study, they illustrate how cognition is inseparable from motor actions and how adaptive performance is based on affordances in contexts. The chapter describes the shift in focus from purely mental processes to embodied knowledge and action in engineering.

Part II mainly concerns how adaptive performance can be stimulated in different contexts.

In Chapter 6, Van Bruggen and colleagues focus on the role of teachers and supervisors. They use the Q-sort methodology to stimulate teachers' reflection and awareness in adaptive performance, by making their challenges and beliefs explicit.

In chapter 7, Kaffka and colleagues describe how engineering students can develop adaptive performance through challenge-based learning (CBL). The authors use a cognitive sensemaking perspective. In their study they provide empirical insights into micro-level processes that explain how CBL support development of adaptive performance among students in higher education.

Part III regards formative assessment of adaptive performance. Chapter 8 by Pennings et al. describes the adaptation of a validated existing questionnaire (D-ADAPT) to measure adaptive performance. They provide a measurement tool to be used in learning/work environments.

In chapter 9, Baggen et al. introduce an innovative formative assessment method based on generative Artificial Intelligence (AI), using realistic scenarios for assessment. They discuss the development process and resulting instrument.

In the final chapter, Den Brok gives a conceptual synthesis and overarching conclusion. He describes overarching lessons learned in terms of directions for designing work/learning environments and he provides suggestions for further research and practice.

This book brings together insights from various international research projects focused on stimulating adaptive performance in workplace-based learning environments in engineering. The insights presented are relevant for instructional designers, educators, policymakers, and researchers involved in vocational education and the shaping of future-oriented learning environments.

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