2 | Complex work-based learning environments for adaptive expertise development in engineering education:

Lessons from three cases in Dutch higher education

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ABSTRACT

This chapter describes the working mechanisms of work-based learning (WBL) in adaptive expertise (AE) development. AE in engineering is needed because situations and environments are increasingly uncertain, unpredictable and changing quickly. Higher education institutions are challenged to educate for an uncertain future and WBL environments are especially suited to provide students with opportunities to develop AE.

We describe three initiatives in the Netherlands of innovative WBL environments designed to support AE development. Working mechanisms from these three case studies that are part of the Adapt at Work research project are shared. We highlight the need for careful design of WBL environments to support AE development, especially the interactions with others.

Characteristic for AE development in these cases is that students work on open-ended, ill-defined work-based assignments and/or in challenging workplace conditions. To thrive in these conditions, students need a safe learning environment and constructive and adequate support from educators and stakeholders who acknowledge the students as equal partners in a professional role. Room for students to make mistakes, reflect, and show a proactive attitude creates opportunities to explore and try out new ways of thinking and doing.

Implications of the lessons learned from these cases for designing WBL environments aimed at AE development in higher engineering education are discussed.

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Introduction

Engineering is characterised by complex systems with many interacting, interdependent factors that need to be adapted to continuously changing surroundings and unpredictable events. Engineers have to work in environments with multifaceted problems and the outcome of the problem-solving process is often unknown. An important aspect of successful problem-solving in this context is that engineers have "a willingness to deal with novel and challenging tasks in social interaction situations and to understand others' ideas and perspectives" (Lehtinen et al., 2014, p.212).

To be able to adapt to these novel and challenging tasks, engineers need routines and solid domain knowledge to build on and develop new solutions to current challenges (Chapter 1, this book) and find a balance between acquiring routines and innovating practice (Hatano & Inagaki, 1986). As engineering situations and environments are increasingly uncertain, unpredictable and changing quickly, engineers need (to develop) Adaptive Expertise (AE).

Adaptive expertise is the ability to develop new solutions to professional problems or new methods of problem-solving in changing circumstances (Hatano & Inagaki, 1986; Pelgrim et al., 2022; Bohle Carbonell et al., 2014). Adaptive performance is the visible expression of AE, and this is triggered by a changing task or environment (Pelgrim et al., 2022). This change refers to a change that is new for the professional or that is new for people in general (Pelgrim et al., 2022).

To prepare students for an uncertain future and help them develop AE requires the design of learning environments that rely on authentic, yet ill-defined, tasks that ask for new approaches. It requires a balancing act between innovation and efficiency, i.e., finding the optimal innovation corridor (Chapter 1, this book).

However, there is a lack of empirical studies showing how students can be supported in developing AE through WBL in higher education programmes, aimed at solving authentic, ill-defined or non-routine problems (Kua et al., 2021; Pelgrim et al., 2022). To improve the educational design of WBL for AE development, a deeper understanding is needed of the underlying processes, structures and dynamics, i.e., working mechanisms, that explain how specific educational methods, practices and interventions lead to specific outcomes.

Therefore, in the presenting chapter, we describe how three different learning environments support AE development of future engineers. Each learning environment has its own design characteristics and focuses on a specific group of students who work on engineering problems or bring an engineering perspective on societal problems.

Work-based learning and adaptive expertise development

To thrive in an uncertain future, engineering professionals need AE to be able to navigate successfully in altered situations and changing circumstances (Pelgrim et al., 2022; Kua et al., 2021). The understanding of such dynamic, complex situations is often biased by a reductive tendency to simplify: Feltovich et al. (2001) refer to the tendency to try to preserve misconceptions as knowledge shields. Overcoming these knowledge shields requires deliberate effort, and Ward et al. (2018) present a set of principles for designing learning environments to support AE development.

One of the central principles is not to reduce the complexity of the problem at hand but to preserve the complexity of important concepts and their relationships and help students grasp and deal with these. A study by Veltman et al. (2021) showed that students might cope with the tension of this complexity by avoiding risks and uncertainties and by limiting contact with others, thereby reducing learning potential. Work-based learning (WBL) environments can provide these challenging, ill-defined real-world problems in which the complexities of the problem at hand are preserved.

Such WBL learning environments, in addition to more traditional master-apprentice learning environments and theory-driven (tutorial) lectures, are likely to support the development of AE (Groenier et al., in press). WBL arrangements can vary greatly: from alignment models on the end of the spectrum, in which students switch from one context to another, to hybridization models at the other end, whereby both contexts are merged into one new learning environment (Bouw et al., 2019). Ideally, WBL in higher engineering education is designed based on an intricate interplay between the educational programme and practice requiring not only an effort from the educational institutions but also from the workplace.

Moreover, shifting from traditional engineering education to WBL arrangements for AE development suggests that the role of the educator also needs to shift from a more directing role towards a coaching role (Goldberg & Somerville, 2014; Groenier et al., in press; Veltman et al, 2022).

Currently, many higher education institutions are redesigning their curricula in the face of a changing world and are experimenting with integrative forms of education such as challenge-based education, case-based reasoning, interprofessional assignments and innovative work-learn environments (labs, hubs, apprenticeships). Bachelor and master education can be seen as the kick-off for lifelong learning trajectories, in which professionals have to develop from a novice status towards an expert status and have to adapt to unforeseen developments by learning and innovating. Professional practice is therefore increasingly involved as a partner in the design and implementation of the WBL arrangements, also in the Netherlands.

To explore how such environments and WBL arrangements contribute to AE development, the Adapt at Work project was launched in 2020.

The Adapt at Work project

Adapt at Work (www.adaptatwork.nl/en) was a practice-oriented research project in higher education (funded by NRO, the Netherlands Initiative for Education Research (40.5.19945.601)) on the development of AE in WBL contexts. A Dutch consortium of five research universities and six universities of applied sciences conducted research into WBL environments in bachelor's and master's programmes, aimed at the development of AE of (prospective) professionals.

Adapt at Work aimed to provide insight into effective learning mechanisms and working mechanisms for the development of AE. The Adapt at Work project covered WBL environments in a wide range of professional domains, including (para)medical, social, engineering, teachers and entrepreneurs. The core of the project consisted of comparative and thematic case studies using realist methodology, in which the operation of WBL in the development of AE is described and explained.

Realist research, initiated by Pawson and Tilly (1997), focuses on the context(s) and underlying mechanisms and tries to explain why a complex (educational) intervention works (or does not work). Important questions are what works, for whom, under what circumstances, why, and how? With a realist evaluation, researchers aim to answer these questions by formulating a programme theory, e.g., the set of assumptions why an intervention is thought to have an effect. For this purpose, so-called Context-Mechanism-Outcome-configurations (CMOs) are formulated.

A CMO does not serve (only) to describe a particular causal chain of reasoning but aims to explain how a specific action in a particular context leads to a certain outcome. Therefore, the focus of this type of research is not to find evidence for particular training interventions (does something work), but to offer a deeper understanding of underlying mechanisms (how/why does something work).

THREE ADAPT AT WORK ENGINEERING CASES

In this section, we highlight three initiatives from the Adapt at Work project. In these cases, innovative WBL environments were designed to support AE development in higher engineering education in the Netherlands. In these cases, the projects that students worked on ranged from alignment (Technical Medicine Case) to incorporation (Smart Solutions Semester, Digital Society Hub) and fully hybrid learning environments (Smart Solutions Semester, Digital Society Hub; see Bouw et al., 2019, for a description of the types of learning environments).

In-depth interviews with curriculum designers, educators, workplace supervisors and students were conducted as part of the Adapt at Work project to identify the working mechanisms of AE development in these specific WBL contexts. First, we describe the three cases, second, we discuss the working mechanisms identified in these cases.

Finally, we provide recommendations for the design of WBL environments based on these cases and the literature.

Technical Medicine: translating between engineering and medicine

Technical Physician (TP) is an emerging profession in healthcare. Technical developments follow each other rapidly, and technical knowledge is indispensable to use technology safely, efficiently and effectively (Groenier et al., 2017). In the Technical Medicine programme, students learn to apply the methodology of engineers to the medical domain which involves problem-solving thinking, analysing a clinical question and developing a treatment plan (see Groenier et al. (2017) for a more comprehensive curriculum description). This requires that students learn to position themselves as TPs in collaboration with other healthcare professionals, especially because many are unfamiliar with the TP profession.

Working on challenges at the intersection of patient care and technology and the positioning of TPs as independent healthcare practitioners requires AE. Internships are the prominent WBL environments in the second and third years of the master's programme.

Characteristics of the WBL environment

In the second year of their master's programme, students undertake four 10-week 15 ECTS internships, i.e., clinical placements in hospitals. Students primarily work on open-ended projects that address a specific technical-medical problem, e.g., how to monitor the harmful effects of mechanical ventilation and adjust this for a particular patient, and they practice clinical skills.

Students rotate internships between hospitals and departments within hospitals. Clinical activities, such as ward visits, outpatient clinic procedures, or assistance during surgery, are ideally integrated with the technical-medical project the student is working on and students are expected to progressively perform such activities independently.

Although students are expected to be able to work independently, this does not mean they work 'solo' or individually. On the contrary, students should demonstrate that they are able and willing to work in a collaborative relationship with other professionals.

Interactions with others

In the workplace, students are supervised by a clinical educator, usually a medical specialist. A technical educator from the university safeguards the level of technical innovation and the professional development (PD) educator from the university monitors students' professional development. The technical and clinical educators change per Technical Medicine internship, but students keep the same PD educator for two years.

During the internship year, students return to the university every other Friday for formal, on-site education. Guest lecturers teach about specific topics relevant to the internships, and there are guided peer-to-peer coaching moments with other students and the PD educator. Guided peer-to-peer coaching often has a set structure, where a group of students delves into a problem or question of one of the participants. In these sessions, the PD educators encourage a critically reflective work attitude so that students learn to act proactively.

The Smart Solutions Semester: The adaptive educator as a pivot in the development of adaptive expertise

Saxion University of Applied Sciences launched a new initiative in 2015 in which third- or fourth-year students from different bachelor programmes collaborate in interdisciplinary project teams of 6-8 students on ill-defined societal and professional challenges (25 ECTS in 5 months). Currently, almost 30 educational programmes are participating, from engineering disciplines mixed with social, economic, and health disciplines. In these programmes, the so-called 'Saxion Smart Solutions Semester' became a formal part of the curriculum.

Challenges (tasks) are provided by professional stakeholders or Saxion's professors and are usually open-ended. An educator team pre-formulates the challenges to ensure that these fit students' zones of proximal development and that learning outcomes can be realised within one semester. Whereas solution directions may be included in the description, it is up to students to determine the specific format, type of solution, and approach. Knowledge from different disciplines is needed to develop a good solution. An example of a project is the development of a flying robot for the physical maintenance of wind turbines. The topics are new for the students, and often, they also contain elements that are new to people in general.

Characteristics of the WBL environment

Student groups usually work in the Smart Solutions Semester environment at Saxion, where they can directly contact their educator or other student groups, but they do also have access to a place in the professional organisation, where they can meet their contact person or other professionals, depending on what the group has agreed upon at the start of the project. Educators were trained to specifically guide the collaboration process, independent of the project content. Because of the interdisciplinary nature of the assignments, these educators are not content experts themselves, even though they often do have some relevant content knowledge related to the project.

Interactions with others

Students meet each other on their own initiative and frequency. Furthermore, they meet weekly with a professional stakeholder and - separately - with their educator to discuss progress and their assessment. Depending on personal preferences (Visscher-Voerman & Van Harmelen, 2019), educators differ in how they guide the project teams, varying between supportive or directive behaviour (Assen et al. 2016).

Educators stimulate the exchange of inter-disciplinary knowledge among students as well as experiential knowledge among professionals, and help the project team set common goals, establish common ground and raise critical awareness (Boix-Mansilla, 2016). This regularly includes individual and group reflection on the different contributions of students and stakeholders to the project and on individual and group learning progress.

If groups decide that they lack certain knowledge to tackle the set task, they can consult other members of the Smart Solutions Semester community, educators or professionals.

Digital Society Hub: Adaptive expertise development in information technology

The Digital Society Hub is one of the many 'living labs' at Hanze University of Applied Sciences. Hanze initiated the Digital Society Hub in collaboration with the local government and multiple corporate enterprises, aiming to catalyse 'innovation in and with the help of IT', for example, on the topic of 'interconnectivity'. The province of Groningen is a rather rural area with limited infrastructure and a demographic decline concerning the number of inhabitants.

To match a specific question or challenge (task) from a company in the region to students from the Hanze, the Digital Society Hub has built a website for 'matchmaking' purposes. On this website, the different questions and commissioning companies are described, as well as a description of 'what expertise one is looking for'. This can be a single student coming from a specific discipline (e.g., electrical and electronic engineering, information technology, or law) or a – monodisciplinary or multidisciplinary - group of students. These specifications are derived from the question at hand. Students have to write a motivation letter and officially apply for the position as if it were an official job offer. In the Digital Society Hub case, we focus on the end-level students from the Network Security Engineering-track (NSE; one of three majors) from the Bachelor programme 'IT-training'. These students worked approximately 5 months on their graduation assignment of 30 ECTS, which is centred around the question from the commissioning company.

Characteristics of the WBL environment

The tasks students work on are usually open-ended. An example of a task is the development of a device that can spot ill potato plants while driving over a field of crops and communicating this to the farmer. In these assignments, there needs to be a project-based approach in which the 'solution direction' is undetermined or unfamiliar. Students are required to conduct a 'project-relevant' research, leading to further substantiation of the product (e.g., specification of requirements, performance testing, literature review). Also, the commissioning company is required to realise certain prerequisites to be able to function as a 'graduation assignment provider', such as having a professional stakeholder who acts as an educator with a certain higher-level educational background and tasks in the organisation.

Students can work on their assignment at the commissioning company, at the Digital Society Hub itself (a specific building on campus), and - frequently - partially remote (i.e., from the student's home). For students to finish their assignment, they have to demonstrate their ability in five learning outcomes; these learning outcomes are based on the nationally established IT-professional profile. The learning outcomes pertain to 1) analysis, 2) design, 3) realisation, 4) problem solution using a research-oriented approach and 5) interacting with others in a goal-oriented manner. Frequently, one finds prototypes, logs and reflections included in a graduation portfolio.

Interactions with others

Students are expected to encounter and collaborate with different professionals. One of the learning outcomes is interacting in a goal-oriented manner, which illustrates that the IT-training values and stimulates effective collaboration with relevant others and suitable communication, as well as the skill to take another person's perspective, which is embedded in the learning outcome 'problem solution using a research-oriented approach'.

Working mechanisms for adaptive expertise development through work-based learning

The working mechanisms we identified in the three cases based on the case studies illustrate how task characteristics, learner characteristics, reflective practice and characteristics of the learning environment were associated with AE development. In most cases, these working mechanisms interact with each other and should be viewed as interrelated factors contributing to AE development. While portraying them below, wherever possible, we include references to external literature that describe similar mechanisms or provide plausible reasoning.

Task characteristics: Challenging projects

An important characteristic of the projects that students work on in each of the three cases is that they are ill-defined, open-ended and require an innovative or interdisciplinary perspective on the task at hand. A project that is ill-defined and open-ended for everyone involved, i.e., student, educator and professional stakeholder, requires a 'thinking outside the box' mindset. This characteristic ensures that all participants are willing to step out of their comfort zone and are expected to collaborate and learn together during the process of working on the project. These challenging projects require risk-taking on behalf of the student and can thus provide opportunities to try out new approaches or refine existing approaches, i.e., develop AE (Groenier et al., 2023.; Mylopoulos et al., 2018).

Learner characteristics: Self-regulation, professional skills and attitude

Student characteristics identified in the three cases that contribute to AE development are proactivity, self-directed learning skills, critical reflection on their knowledge, skills and professional attitude, as well as having high levels of self-efficacy. These skills enable them to successfully adapt to new situations and try out new ways of thinking and working, i.e., develop AE (Technical Medicine, Smart Solutions Semester). In the context of challenging work conditions or projects, students need to be able to think outside the box and continue to adapt because, with each new step in the project, different expertise or approaches are needed (Digital Society Hub). This can lead to surprising events in the project, and for AE to develop, all those involved in the project need to be open to these learning surprises (Smart Solutions Semester; Gulikers & Oonk, 2019).

Reflective practice: Structuring and guiding reflection

Regular reflection on experiences with working on challenging projects, experimenting and making mistakes increases flexibility and a critically reflective work attitude which are important aspects of AE (Groenier et al., in press; Kawamura et al., 2020; Kua et al., 2021). Eva and Regehr (2008) argue that seeking out feedback on performance from others and reflecting on that feedback increases the quality of learning. In this process, the learner takes responsibility to explicitly seek feedback from others to direct their learning and performance; this is a habit of mind that learners can strengthen through practice (Eva & Regehr, 2008). Our cases illustrate how this support of guided reflection can take different forms.

In the Technical Medicine case, there are regular guided peer-to-peer coaching moments with the same professional development educator that stimulate Technical Medicine students' awareness of their own qualities, positioning and professional role. In these moments, students recognise similar struggles and dilemmas, have in-depth discussions about internship experiences and reflect critically on professional development, thereby promoting self-directed learning and reflection on professional development (Groenier et al., 2023; Kawamura et al., 2020; Kua et al., 2021).

From the Smart Solutions Semester case, we learn that equipping educators with the skills to support students' critical reflection is important. In the Smart Solutions Semester case, students are expected to formulate individual learning goals and steer their personal and professional development. Some students struggle with the uncertainty of such ill-defined challenges and expect their educators to structure the work that needs to be done. Educators should stimulate students' reflection on their experiences.

In this context, feedback from teachers or students can be powerful input for the reflection. Students should feel free to express and receive intensive feedback and use it to further enhance and structure their learning strategies. For teachers, it is important to provide feedback in such a way that it helps students to make sense of the situation and make further choices. This requires feedback literacy from both students (Carless & Boud, 2018) and educators (Carless & Winstone, 2023).

Learning environment characteristics: Psychological safety with room for experimenting and making mistakes

Psychological safety seems key to developing AE in all three cases. In psychologically safe environments, students can experience that there is room for experimentation and making mistakes (Smart Solutions Semester, Digital Society Hub). This stimulates the development of a critical stance and problem-solving skills, which are important aspects of AE (Fadde & Klein, 2010). Students should be encouraged to show a proactive attitude (Smart Solutions Semester). This requires a WBL environment in which educators serve as role models, modelling openness to surprising situations or insights (Gulikers & Oonk, 2019) and supporting students in this process (Digital Society Hub, Smart Solutions Semester).

Furthermore, treating students, stakeholders and educators as equal learning partners – while acknowledging differences in seniority, age, and expertise – was considered supportive of the AE development process (Digital Society Hub). When professionals in the workplace act as clients, dictating the outcome of the task or project, they hinder the AE development process (Technical Medicine, Smart Solutions Semester). Rather, activating the social network – being the professional stakeholder, educator and/or student – improves the quality of the solution or product (Digital Society Hub). This requires a certain level of adaptivity from all involved because, in different phases of a project, different expertise is needed and should be actively sought after in one's network. An open, learning attitude of all participants is essential (Visscher-Voerman & Van Harmelen, 2019) and in this way, a constructive and safe collaborative climate is established.

However, some WBL environments are experienced as less safe than others. In the Technical Medicine case, for example, students have to learn to position themselves during their internships in a conservative and hierarchical healthcare environment (Vanstone & Grierson, 2019) with few Technical Medicine practitioners as role models. This makes the WBL environment challenging and students stated that they need self-confidence to position themselves in the workplace (Groenier et al., 2023). The Technical Medicine case illustrates that creating a safe learning environment at the educational institution, away from the workplace, where students are supported in their professional development process by reflecting on their work stimulates students to position themselves in the workplace and thereby develop AE.

A psychologically safe learning environment should not be confused with a highly structured or predictable environment. Both relate to the context of work and what is acceptable practice in that domain. In some professions, such as firefighting, making errors could result in severe consequences. This impacts how much freedom and autonomy a learner may be given but also to what extent there are opportunities to explore and try out new ways of thinking and doing.

Different perspectives

Peers (Technical Medicine), educators (Smart Solutions Semester) or stakeholders who acknowledge the students as equal partners in a professional role (Digital Society Hub) can stimulate AE development in students by introducing different perspectives on a task, for example, in the case of interdisciplinary learning, and encouraging critical reflection on ways of working or thinking. Guiding students to view a task from different perspectives and cross boundaries is an important educational strategy for AE development (Boon et al., 2019; Bouw et al., 2019). The reframing of data and exploring different perspectives that facilitate AE development resonate with the working processes in engineering practices as described by Kaplan and Vinck (2013): 1) reusing pre-existing solutions, in combination with new designs (akin to reframing); 2) mobilizing a broad spectrum of academic disciplines (akin to different perspectives); 3) changing levels of aggregation.

This learning and AE development does not take place in isolation, but rather in a dynamic, social environment. From the Smart Solutions Semester case, where students work in interdisciplinary teams, we learn that students need to develop skills to open up to other perspectives. They usually tend to focus on their own knowledge, and therefore work side by side. In this sense, they do not work interdisciplinary, but multidisciplinary. Learning from each other and moving forward together needs to be explicitly encouraged and supported (e.g., Van Harmelen et al., 2021).

From the Smart Solutions Semester we learned that openness for interdisciplinary learning, this does not come easy. Working in interdisciplinary teams is still rather uncommon for students. Whereas some students may embrace the academic exchange of knowledge and theories, as they see the benefit of it, others have a primarily practical drive and just want to get to work. From their perspective, the time needed for exchanging disciplinary knowledge feels like a 'waste of time', since it keeps them away from working on the project. Guided reflection, as portrayed above, is likely beneficial in these situations to help students open up to different perspectives (Smart Solutions Semester) and to reframe the challenge, the data gathered, or the approach to be conducted.

Considerations for designing work-based learning environments

In the workplace, professionals navigate in a social environment where people work, collaborate and learn together. WBL environments need to be carefully designed to support AE development, taking into account the social environment, social interactions, and understanding others' perspectives and ideas (see also Billett et al., 2014; Groenier et al., in press; Goldberg & Somerville, 2014). We can derive several educational design considerations by integrating results from our project with findings from the literature to elicit the working mechanisms described above.

Task characteristics

Working on open-ended, authentic work-based assignments, sometimes in challenging workplace conditions, seems to stimulate AE development. Students need to reflect on what needs to be done, which steps to take and to (re)frame the task at hand to come up with adequate solutions. A question that remains is to what extent work-based assignments are challenging enough and truly allow for different ways of solving the problem and different solutions. Perhaps many domains and problems are complicated rather than complex. What is complicated or complex also depends on what the learner perceives as complex or challenging (Pelgrim et al., 2022).

According to the Cynefin framework (Snowden & Boone, 2007), assignments are complicated when a task requires refined judgment and expertise and when there are multiple right solutions, when they are in the realm of "the known unknowns" (p.3). The challenge of complicated problems is the problem-solving process because these types of problems often have a limited or known number of correct solutions (Snowden & Boone, 2007). In contrast, complex domains or problems are inherently uncertain and ambiguous, and factors and relationships in the environments continuously change. These complex problems are challenging because the very actions the problem solver performs change the task or context (Snowden & Boone, 2007). Complex problems cannot be reduced to a 'take-it-apart-and-see-how-it-works approach'.

A clear distinction between complicated and complex problems often cannot be made in advance. Although complex problems challenge learners to think critically, adapt quickly to changing circumstances and come up with innovative solutions, complicated problems help learners build a solid foundation of problem-solving skills and disciplinary knowledge. Balancing routine, complicated and complex problems or tasks in a curriculum is one of the challenges to finding the optimal innovation corridor to stimulate AE development (see also our introduction).

Collaboration and interdisciplinary learning

Working on ill-defined, complicated and complex problems call for more than a single disciplinary perspective, which is reflected in the interaction with others in the cases. Interactions with others stimulate AE development in terms of adapting current ways of working, developing new ideas about practice and developing AE competencies in general (Groenier et al.. in press). Stimulating boundary crossing learning mechanisms (identification, coordination, reflection and transformation, Akkerman and Bakker, 2011) might be an important educational strategy for engineering education in developing AE (Boon et al., 2019; Vereijken et al., 2023; Fortuin, et al., 2024). This boundary crossing can occur between school and work, between different practices, and also between different disciplines.

It is helpful that students work on open-ended challenges that necessitate an integrated interdisciplinary approach. An integrated interdisciplinary approach can be at odds with a programme that prioritises disciplinary learning outcomes, defining the conceptual knowledge that needs to be central in the WBL environment.

In disciplinary programmes with a focus on expert and routine knowledge, students are socialised by the knowledge, skills, routines, or habits in the particular discipline and they identify themselves with a particular job profile. Being rooted firmly in the discipline, they might find it difficult to be open to other perspectives, whereas curiosity and openness to other perspectives are necessary to learn and adapt (Pelgrim et al., 2022; Visscher-Voerman & Van Harmelen, 2023).

Differences in the qualifications of the assignments, required timeframes and assessment frameworks can hinder AE development through inter-disciplinary collaboration. For example, in the Digital Society Hub case, certain questions demanded a combination of disciplinary backgrounds but rather sequentially, and not simultaneously, which limited opportuni-ties for students to work together in interdisciplinary teams. To enable AE development through collaboration, educational programmes are recommended to include learning outcomes and ways of assessment aimed at interdisciplinary collaboration and learning, and to leave room for learning surprises, i.e., unexpected insights or shifts in understanding that emerge during the learning process and challenge prior assumptions. Therefore, in line with Veltman et al. (2021), programmes are encouraged to reconsider the learning outcomes and make the development of AE an explicit part of it.

Preparing students for future learning

We recommend to equip students with professional skills, such as communication, skills to work in interdisciplinary teams and reflection, throughout the curriculum to prepare students to further develop AE in WBL environments. They need these skills to effectively contribute to interdisciplinary teamwork (e.g., in the Smart Solutions Semester case) but also to create and maintain a larger network of stakeholders from different disciplines (e.g., in the Digital Society Hub case). Educators and stakeholders from the professional field expressed in our cases the importance of learner traits such as perseverance and proactive behaviour. Pelgrim et al.'s (2022) review of reviews also emphasised that certain personal characteristics are related to AE, such as cognitive flexibility and embracing complexity. It takes time to develop interdisciplinary skills and these learner traits. It is therefore helpful – if not necessary – to help students prepare by designing a learning line in which students learn to navigate in tasks or environments with increasing complexity. Students are likely to benefit from proper preparation in the first years of their education, e.g., experiencing what it is like to work for an external client, work in a project team, work with different disciplines and frame a problem themselves. Skills deficits are difficult to diminish during a single semester WBL for AE.

The role of educators

The role of educators is challenging because complex WBL contexts can place great demands on educators' guidance skills. Guiding students in project work asks for a fine balance between directive and supportive teaching strategies, whereas many educators feel most comfortable with more traditional, directive teaching behaviour (Assen et al, 2016). When aiming at the development of AE, it becomes more important for educators to create psychological safety, support reflection, provide relevant feedback and encourage students to have an open approach towards the task and others (Pelgrim et al., 2022).

Frequently, the ill-defined task requires a team of students with different disciplinary backgrounds, as was shown in the Digital Society Hub and the Smart Solutions Semester case. The variation between learners in interdisciplinary groups is large because they have different content expertise and identify with the customs and practices in their particular discipline. Educators should help students establish a common ground (e.g., search for commonalities in the different disciplines to handle the task), raise critical awareness towards their own and other disciplines, and integrate perspectives (Boix-Mansilla, 2016). When students from different disciplines do not share the same knowledge paradigm, it becomes more difficult to collaborate and understand each other and collaborate (e.g., Kolmos et al., 2024).

Variation in these interdisciplinary groups further increases when other stakeholder groups, such as professionals or citizens, learn and work together with students (see e.g., Visscher-Voerman et al., 2024). The larger the variety between learners, the more complex it becomes for educators to respond to the individual needs of the learners and to adapt their teaching behaviour, focusing on what individual students need. At the same time, this is important, as Veltman et al. (2022; 2024) show that students with different learning profiles and different competences in dealing with challenging problems and tasks need different teaching strategies in order to succeed. In addition, to utilize boundary crossing learning potential in developing AE, specific educational strategies are needed to foster boundary awareness and boundary work (Veltman et al., 2022).

Because the task is often ill-defined, this also calls for educator flexibility regarding the content. Some contexts or professional domains are more unpredictable than others or require major transitions in ways of working. Guiding students on AE development in the context of ill-defined tasks requires AE of the educators themselves to focus on what students need in their learning process (Visscher-Voerman & Van Harmelen, 2023).

Implications for research

Within the Adapt at Work project, we focused on researching working mechanisms during WBL for AE. The cases illustrated that working in complex work-based situations calls upon enormous demands on students and educators. This raises questions such as: how to recognise or develop assignments that call for adaptivity, but are within the zone of proximal development, how could educators be prepared for their new teaching roles and what workplace affordances could support AE development at the workplace? Being able to act in complex WBL settings also raises the question of how students could be guided throughout their curriculum towards becoming adaptive experts.

Is it necessary to first acquire a certain amount of basic knowledge and skills before students can work on ill-defined tasks? And how much, what knowledge, and what skills are needed? What are the underlying mechanisms of interdisciplinary learning and collaboration in AE development? These are examples of relevant questions that need to be addressed to deepen our understanding of AE development during WBL in higher education.

To answer these questions, we first and foremost need robust, validated measures of AE and AE development. Currently, most studies about AE or AE development rely on self-report and self-evaluation and the evidence of other methods, such as mixed methods instruments or design scenarios, for measuring AE or AE development is scarce (Hissink et al., 2025).

Furthermore, longitudinal designs are needed to not only adequately evaluate AE development while students are still in their educational programmes, but also to follow up their AE development at the workplace. Also, a deeper understanding of the conceptualisations of AE that educators have, how they perceive students' AE development and the required educator competencies to support this development is needed. Insight into the educators' perspectives aids in supporting educators in their new role and developing educators' professional development programmes aimed at AE development.

Conclusion

The current societal challenges in the world, e.g., environmental sustainability, responsible consumption and future-proof healthcare, call for engineers who can not only successfully adapt to continuous change but also initiate change to improve practice, i.e., who are adaptive experts. AE development does not happen automatically and many higher education institutions are currently experimenting with new types of learning environments to prepare students to adequately take on these challenges and become adaptive experts. Our cases show that WBL environments can be powerful environments to support AE development of engineering students since they lend themselves well to introducing authentic, ill-defined tasks. Encouraging students to step out of their comfort zone and be open to surprising events helps them to tackle these kinds of tasks. Furthermore, providing appropriate guidance in reflection and helping students reframe the task at hand and their professional role could further enhance the quality of learning from each other. From our cases, we also learned that acknowledging that all partners involved in these WBL environments are learning, and not just the students, contributes to creating a psychologically safe learning climate with room for making mistakes and learning from them.

The design of WBL environments asks for aligning learning outcomes, learning and teaching strategies, and assessment to AE development. A curriculum pathway with increasingly complex tasks helps students acquire and deepen professional skills, such as communication, inter-disciplinary teamwork, and reflection, as well as openness to uncertainty and different perspectives. Educators have a prominent role in creating psychological safety, and gearing the teaching strategies to the needs of the individual learners.

Ethical approval

Overall ethical approval was obtained from the ethical committee of HAN University of Applied Sciences, number 312.12/21.
Informed consent was obtained from all respondents.
All data were pseudonimised.

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