7 | Building engineering students' adaptive performance through challenge-based learning: A sensemaking perspective

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ABSTRACT This study seeks to provide insights into micro-level processes which help explain how challenge-based learning (CBL) supports development of adaptive performance among students in higher education. Based on empirical data and using the sensemaking perspective, we analyse how educational design of CBL enables and develops adaptive performance among engineering students.

We show that, in addition to task- and curriculum-related factors, there are important contextual factors in education design supportive of adaptive performance development. Specifically, a safe learning environment and informal interaction with teaching staff contribute to this.

We found that such an environment allows students to engage in (negative) feedback loops using sensegiving, sensedemanding, and sensebreaking. These sensemaking skills constitute collaborative discourse relevant for development of adaptive performance in higher education.

Our findings indicate that practice of sensegiving, sensedemanding, and sensebreaking during CBL helps to develop students' adaptive performance. Namely, by enabling students' use of questions as well as their engagement with (negative) feedback within and outside the classroom, such as with a challenge-owner or relevant stakeholders.

Furthermore, we argue that sensegiving, sensedemanding, and sensebreaking can serve as empirical indicators for assessment of adaptive performance development among students in higher education and beyond.

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Introduction

Adaptive performance describes professionals' task achievement under conditions of novelty or uncertainty (Pelgrim et al., 2022). Because firms seek such adaptive professionals (Nandini, Gustomo, & Sushandoyo, 2022), the development of adaptive performance in higher education has received interest from academic research (Kua et al., 2021).

Scholars have identified diverse elements of educational design which can help to build students' adaptive performance in higher education (Streveler et al., 2008; Carbonell et al., 2014; Kua et al., 2021). In recent years, challenge-based learning has gained traction in higher education (Leijon et al., 2022). Challenge-based learning (CBL) is an educational strategy which combines content learning with interdisciplinarity, stakeholder engagement, and real-life, non-routine problem-solving tasks (Membrillo-Hernandez, 2019; Van den Beemt et al., 2023; Doulougeri et al., 2024).

Challenge-based learning is associated with the development of adaptive performance in education (Carbonell et al., 2014; Kua et al., 2021), also among engineering students in higher education (Van den Beemt et al., 2023). Meanwhile, there is a lack of detailed qualitative methodologies to study micro-level mechanisms by which adaptive performance development in higher education occurs (Gallagher & Savage, 2023). This is problematic as it impedes optimal design of educational interventions, such as CBL, which are aimed at training adaptive performance in higher education. Hence, clarifying the micro-level mechanisms by which CBL affects development of adaptive performance among higher education students merits closer attention.

In this chapter, we examine how educational design of CBL enables and develops adaptive performance among engineering students in higher education. This yields the following research question: *How does challenge-based learning support engineering students' adaptive performance (development) in higher education?*

We carried out a qualitative, explorative study among students participating in an educational programme which uses CBL at a technical university in the Netherlands. To answer our research question, we examined how challenge-based learning design enables students' use of sensegiving, sensebreaking, and sensedemanding. Various studies show that these three sensemaking processes are associated with adaptive performance of professionals (Randall et al., 2011; Sparr et al., 2022; Kaffka et al., 2024). We propose that they facilitate conceptualisation and micro-level analysis of how CBL design enables and develops adaptive performance.

We start this chapter with an introduction of adaptive performance, its development in higher education, as well as a description of challenge-based learning. Then we present the sensemaking perspective and zoom in on the processes of sensegiving, sensedemanding, and sensebreaking. We demonstrate how these three sensemaking processes function as mechanisms which enable and develop adaptive performance in CBL in engineering education. We then present the key findings of our analysis, discuss their contributions to the literature, practical implications, and end with a short conclusion.

Adaptive performance

Adaptive performance describes professionals' ability to handle work stress, solve problems creatively, possess, have superior interpersonal adaptability skills, and a learning orientation (Pulakos et al., 2000; Charbonnier-Voirin & Roussel 2012; Pelgrim et al., 2022). For example, adaptive performance occurs when professionals make more effective use of resources or invent new procedures to support learning and problem solving in practice (Mypolous et al., 2018).

Adaptive performance and conceptual knowledge

Conceptual knowledge goes beyond content knowledge which describes declarative ('what') and procedural ('how to') knowledge (Hatano & Inagaki, 1984). Conceptual knowledge is a person's understanding of when and why to transfer domain-related declarative and procedural knowledge (Streveler et al., 2008; Baard et al., 2014). Conceptual knowledge refers to knowing why a concept or skill works in novel or uncertain situations. It forms the base for professionals' adaptive performance (Myopoulos et al., 2017).

Traditionally, engineering faculties transfer declarative ('what') and procedural ('how to') knowledge to their students. Declarative and procedural knowledge yield students with speed and accuracy in domain-relevant tasks, described as routine or content mastery (Clegg & Diller, 2019). This focus on context expertise in engineering education has been criticised, as it might come at the detriment of developing students' conceptual knowledge base (Hicks et al., 2014).

Development of adaptive performance

Extant work shows that there are design elements which relate to context, curriculum, or task (learning activity), which facilitate development of conceptual knowledge among higher education students. Below, we elaborate on their role in adaptive performance development in higher education.

Design of educational context

In their research on adaptive performance in relation to higher education, Kua et al (2021) noted that social and physical context play an important role for development of adaptive performance. Other authors agree that safe learning environments have a general effect on preparedness to innovate and be creative, which form crucial dimensions of adaptive performance (Gube & Lajoe, 2020). A socially and physically safe context yields an environment suitable for collaborative discourse, meaning student-centred discourse which elicits students' engagement and reflection by means of questions (Bowers et al., 2020).

A positive error condition relates to educational design, which allows for experimentation, negative feedback, or failure. Research shows that a positive error condition helps to build adaptive performance among students. A study showed that it is important to build a space where students are safe to experiment and to engage in (negative) feedback (Charbonnier-Voirin & Roussel, 2012). Similarly, Gube & Lajoie (2020) describe educational design which contributes to adaptive performance as being supportive of productive failure, as it encourages creative thinking and supports mastery of goals.

Design of curriculum

Adaptive performance can be developed with active learning activities which promote a learning orientation (Bransford & Schwarz, 1999). To build adaptive performance, scholars have advocated that higher education should (1) emphasise understanding rather than performance, (2) offer opportunities for struggle, risk taking, and failure, and (3) be coupled with opportunities for meaningful variation around conceptual or procedural knowledge (Bransford & Schwarz, 1999; Myopolous et al., 2017).

Exposing students to struggle, risk taking, and failure by means of guided discovery (Kua et al., 2021) is known to support development of conceptual knowledge (Myopolous et al., 2017). The concept of guided discovery describes supportive information in the form of feedback as well as reflection on how things are organised and how tasks are best approached, i.e. cognitive strategies (Bohle Carbonell & Van Merriënboer, 2019).

Guided discovery enables students to critically reflect on the quality of both personal problem-solving processes, which is relevant for development of adaptive performance (Carbonell et al., 2014). Giving students a certain degree of freedom in task selection and letting them explore possible solutions and relationships between solutions and goals that can be reached with them, as well as making errors in an environment where it's safe to make them, all contribute to developing students' adaptive performance (Carbonell et al., 2014).

Design of learning tasks

Task variety and task complexity are crucial for building adaptive performance among students (Van der Schaaf et al., 2020; Kua et al., 2021). Bohle Carbonell et al. (2014) also suggest that using open learning tasks and simulated task environments develops adaptive performance in higher education.

To support students' learning optimally, scholars recommend guided discovery, the use of flexibility-focused feedback related to methods to acquire knowledge, including the use of mentoring, to stretch students' skills (Ward et al., 2018). These feedback methods, which put an emphasis on learning, require students' reflection as well as their engagement in different perspectives while critically examining and identifying and articulating their own perspective and learning process.

Notably, reflection and engagement in different perspectives have been identified as relevant for building students' adaptive performance (Fisher & Peterson, 2001).

Challenge-based learning

A CBL-based curriculum involves innovative strategies on how to apply the students' technical knowledge (Clegg & Diller, 2019). CBL is characterised by inter- or multi-disciplinarity, stakeholder interaction, and an open, flexible, learner-centred pedagogical strategy (Membrillo-Hernández et al., 2019; Van den Beemt et al., 2023; Gallagher & Savage, 2023; Doulougeri et al., 2024).

Like other active learning experiences, challenge-based learning emphasises students' agency and self-directed learning (Doulougeri et al., 2024). CBL revolves around a challenge, often societal (for example, concerning issues of sustainability, energy, or public safety), and always involving a challenge-owner. A challenge-owner is crucial in CBL as this vouches for students' learning from a real-life issue Membrillo-Hernández et al., 2019). CBL is regarded as one of the most engaging and personal growth-oriented active learning approaches at present (Irani, 2015). For example, Clegg & Diller (2019) found that students identified challenge-based pedagogies as their preferred methods of classroom instruction.

Research shows that CBL facilitates learning in several ways. Benefits of CBL for students are identified as the application of skills in a real-world environment, such as training in multidisciplinary teamwork, conflict resolution, and communication, problem solving and innovative thinking, as well as technical skills, and achieving a deeper understanding of knowledge (Membrillo-Hernández et al., 2019; Gallagher & Savage, 2023).

We know that CBL can support skills development relevant for adaptive performance, such as collaborative and innovative skills (Gallagher & Savage, 2023) which are essential for adaptive performance of professionals.
Extant work points to the usefulness of CBL in the context of engineering students (Doulougeri et al., 2024). However, we know little about the micro-level processes which help explain how CBL enables and develops adaptive performance among students in higher education. To study development of adaptive performance during CBL on the micro-level of individual students, we draw on the sensemaking perspective.

Sensemaking perspective

Sensemaking relates to processes of meaning-making in situational or task uncertainty and/or novelty, serving purposes of both interpretation and action (Weick 1995). It encompasses individuals' cognitive efforts in detecting, labelling, and categorising information (Weick et al., 2005). Sensemaking plays a key role in the cognition of adaptive performance of professionals (Klein et al., 2007; Ward et al., 2018).

Notably, research shows that (shared) sensemaking plays an important role in a team's adaptive performance (Randall et al., 2011; Sparr et al., 2022). The literature distinguishes between different sensemaking processes which enable adaptive performance in shared, i.e. collaborative, task achievement. Namely, sensegiving, sensedemanding and sensebreaking.

These three socially situated sensemaking processes function as mechanisms which allow professionals to engage with others in successful task achievement under conditions of novelty and uncertainty (Kaffka et al, 2021; Kaffka et al., 2024). We briefly describe each of these three mechanisms.

Sensegiving

Sensegiving describes all effort directed towards achieving shared meaning (Hill & Levenhagen, 1995; Weick, 2005). Sensegiving is the most common sensemaking process by individuals to reduce equivocality and ambiguity of a situation. It consists of *"offering descriptions and explanations, providing signals, constructing credible and consistent narratives, and projecting images through stories, slogans, metaphors, and artifacts"* (Vlaar et al., 2008: p. 240). Studies show that sensegiving, such as narrative framing, enables shared meaning-making under conditions of uncertainty or novelty of task or context by use of symbols and shared meaning (Zott & Huy, 2007; Cornelissen, Clarke, & Cienki, 2012; Day, Balugon & Mayer, 2023).

Sensedemanding

Sensedemanding relates to all efforts made by individuals to acquire and process novel information. Like sensegiving, sensedemanding aims to establish 'a manageable level of uncertainty', in terms of reducing the equivocality or ambiguity of a situation or task by improving the quality of information upon which someone can base their decisions (Vlaar et al., 2008). Sensedemanding involves the asking of questions, performing inquiries, and cross-checking one's own perceptions and interpretations with other individuals, including participants of other organisations (Vlaar et al., 2008; Kaffka & Krueger, 2018).

Sensebreaking

Sensebreaking interrupts someone's understanding by different or even contradictory evidence or information provided by others in the process of sensemaking (Pratt, 2000). By means of sensebreaking, stakeholders and other parties can provide negative or critical feedback to an individual (Kaffka et al, 2021). Sensebreaking can take the form of questioning one's existing understandings, redirecting which relates to diverging *"attention [...] for solutions"*, or reframing which challenges existing assumptions "of previously held conceptions" (Vlaar et al., 2008: 241). Sensebreaking contributes to reducing equivocality by providing interruption to currently held notions, namely 'atypical cues' in the form of negative or critical feedback.

Conceptual framework

To answer our initial research question of the role of CBL in facilitating the development of adaptive performance among engineering students, we drew on the concepts of socially situated sensemaking mechanisms. To systematise the analysis further, we also used the educational design elements for structured visualisation of results (see Table 1, p.108).

Methods

To analyse how CBL provides exercise in the three mechanisms sense-giving, sensedemanding, and sensebreaking, we study educational design elements in CBL in an empirical context.

Research design

A qualitative research design facilitates exploratory analysis of (shared) meaning-making processes, i.e. use of socially situated sensemaking mechanisms by students during CBL. The study took place at a technical university located in a medium-sized Dutch town. We approached teachers of an (elective) CBL-based course in an engineering graduate programme of that university and obtained permission to carry out research on this course. The course had 25 participants. Most students were graduate students from tracks of computer science, data science and artificial intelligence, and embedded systems. The course was mandatory for students in a specific master-level programme, followed by students from the tracks mentioned. As it was open to master's students from other faculties of the university, there was a small number of students graduating in the fields of industrial design, biomedical engineering, and chemical engineering.

Data collection

Data collection was part of a larger postdoctoral research project carried out by the first author on cognitive factors in students' expertise development in higher education. Data collection included real-time observations as well as retrospective data from interviews with the teaching staff. Permission of an ethical committee for this study was sought and received.

The real-time observational data collection took place by means of field observations carried out by the principal investigator, in following two student teams (each team consisting of five students). The field observations of student teams focused on students' use of sensegiving, sensedemanding, and sensebreaking during solving the challenge, i.e. under conditions of uncertainty and novelty.

In addition, we collected data in the form of two interviews with the teaching staff, using open-ended questions. The interviews with the teaching staff helped to get a better understanding of the vision behind educational design of CBL used in this course. Recently, scholars (Van den Beemt et al., 2023) have argued that vision as an essential element of CBL design. The interviews were used to provide insights into the vision, i.e. aims and objectives, of the course, with data recorded and transcribed.

Data coding and analysis

The central analytical concepts of this study are sensedemanding, sensebreaking and sense-giving. Using content analysis, we carried out first-level coding by identifying data containing reference to the three socially situated sensemaking mechanisms of sensegiving, sensedemanding, and sensebreaking. The distinctive empirical qualities of these three concepts facilitated their empirical analysis. Also, prior research has operationalised the central concepts (sensebreaking, sensegiving and sensedemanding) into empirical indicators which have been validated in empirical research (Kaffka et al., 2021).

A codebook was used to identify relevant discourse of students for analysis. Table 1 contains the codebook. It translates the central analytical concepts of sensegiving, sensedemanding and sensebreaking into empirical indicators to allow for a transparent coding process during the analysis and to ensure the validity and reliability of the findings. The codebook does so with signal words, which helped to reliably identify and categorise entrepreneurs' discourse from the interviews.

In first-order coding, discourse transcribed from the observations was coded into (one or several) of the sensemaking-related mechanisms: sensedemanding, sensebreaking, and sensegiving. It must be noted that just as the latter can occur in association with either of the former three, the three mechanisms can also appear intertwined with each other in respondents' discourse.

In second-level coding, data were categorised according to the relationship with context, curriculum, and task-related factors of educational design. Researcher triangulation, coding of the data by different researchers, was used to ensure interrater reliability.

Findings

Table 1 (p.108) displays the key findings of the analysis. They are presented in more detail below, in terms of context-, curriculum-, and task-related factors of educational design of CBL.

Context design

The course takes place in a centrally located venue on the campus. In the same building yet another part the university hosts its 3D printers and some other larger equipment for prototyping. The course room has an open floor plan and consists of a large, high-ceiling, open space setting on the first floor of a two-story campus building. The area designated as teaching space for this course was equipped with square, sturdy and spacious worktables. The long side of the course floor space was formed by high windows. There were many electricity outlets at the worktables (hanging from the ceiling) and there were a few work benches (equipped with drilling etc. facilities) at the lower end of the course space.

There was no mandatory presence. Neither was there a door to enter the location of the course, or walls surrounding it, as the course space was part of an open floor plan of the entire building's floor, except for a few meeting rooms in the middle of the vast space. Instead, mid-raise high shelves formed boundaries to different groups who occupied the space. In addition to the students' course space, which covered one entire half of the building's floor plan, there were office desks and meeting rooms as well as an open space area with several tables and a general helpdesk (for office

TABLE 1 CONCEPTUAL FRAMEWORK DEPICTING SOCIALLY SITUATED SENSEMAKING MECHANISMS (RELEVANT FOR ADAPTIVE PERFORMANCE) OBSERVED IN CBL

Sensemaking-related mechanisms	Challenge-based learning educational design elements		
	Context	**Curriculum**	**Task**
Sensegiving	■ Socially and physically safe environment for collaborative discourse	■ Use active learning activities ■ Presentation of abstract materials early in the training ■ Facilitate integration of conceptual ideas with existing knowledge ■ Meaningful variation around conceptual or procedural knowledge (emphasising understanding)	■ (Increasing) task variability and complexity (case-proficiency scaling) ■ Reflection and flexibility-focused feedback ■ Guided discovery
Sensedemanding	■ Exploration	■ Exploration ■ Hypothesis testing	■ Exploration ■ Hypothesis testing ■ Using questions
Sensebreaking	■ Encourages productive failure	■ Inclusion of opportunities for struggle, risk-taking, and failure ■ Creating a positive error condition	■ Positive error condition ■ Using framing errors as guideposts

materials, print paper, etc.). The open floor plan of the building made it impossible to have visual control of students. But this did not appear to worry the teachers. In the interviews, the teaching staff confirmed this observation. They reported that their students were expected to come in on Wednesday between 1 and 3 pm to work on their challenge, but there was no timekeeping of any kind, and they had no intention of refusing students from wandering in and out of the area in which the teachers were seated.

All worktables were designed to sit at least four to six people. There was no teacher's desk for the teaching staff. It made the educational staff literally equal to students, in the sense of belonging to the room. Material resources could be accessed easily (and used readily) in the form of small electronic and construction tools and related equipment, which were within hand reach. Also, students were allowed to get hot beverages with the teacher's coffee card, which contributed to the teacher-student bond, or freely grab various materials and instruments.

By demonstrating accessibility and benevolence (the available equipment and free coffee) in an informal, high-trust context (i.e. no formal attendance taking), teachers instilled trust in students and created the basis for engaging in reflective dialogue with them. Such an informal context facilitates collaborative discourse, which is known to develop adaptive performance among students (Kua et al., 2021).

We observed that the more time teams spent in the course area, the more they used various materials and equipment present (cutting and drilling tools). They not only used these tools to express their ideas to each other, engage in feedback, or in shared novel meaning-making processes. They also played with materials or would simply throw ball-shaped objects to each other.

For student teams which sought to tackle (the complexities of) their challenge, the context provided literally and figuratively space for experimental try-outs, debates, disagreement, and failure. In this way, students were embedded in a context which explicitly treated errors as positive ('error-friendly'). In that way, the physical and social context of CBL provided students with a safe environment offering opportunities for and enabling (productive) failures – and learning – in a condition where it was safe to struggle, take risks, and fail. We observed that this stimulated students' explorative activities.

We observed a 'positive error condition' in CBL, which provided students with opportunities to exercise their sensegiving, sensedemanding, and sensebreaking skills. This occurred during deliberation about ideas, design and testing of an idea, or using a certain tool or mechanism to make a prototype. The communication involved required students to use the three socially situated sensemaking mechanisms (with their team members, their peers, the teaching staff, or the challenge-owner), constituting so-called collaborative discourse conducive to the development of adaptive performance (Kua et al., 2021). Collaborative discourse describes student-centred discourse which elicits students' engagement and reflection by means of questions (Bowers et al., 2020).

Our findings show how the context of CBL educational design provides a stimulating and resource-rich context for exploration and failure for students. This context offered students opportunities to not only engage in sensegiving, but also in sensedemanding and sensebreaking, during performance adaptation.

Curriculum Design

The course followed phases typical for CBL: 1) identification of a challenge, 2) generation of ideas, 3) consideration of multiple perspectives, 4) research and revision, 5) testing, and 6) going public. This corresponds closely with active learning approaches which are used for development of adaptive performance in higher education (Gallagher & Savage, 2023). The teaching staff acted mainly as mentors for the students, treating the students in a very informal, open way. In addition, we observed that there was one student assistant. The latter was himself a student about to graduate from the same university.

During the different phases of this CBL course, the teacher-student interaction followed a guided discovery process. Guided discovery describes that supportive information occurs in the form of feedback as well as reflection on how things are organised and how tasks are best approached (Bohle, Carbonell, & Van Merriënboer, 2019). This CBL course integrated summative with formative assessment, the latter consisting of regular feedback and reflection moments aimed at supporting students in their learning tasks.

We noted a very informal relationship between teaching staff and students (mentorship). For example, students were allowed to grab coffee (using the teacher's coffee card). The two teachers who co-taught this course – one with substantial prior industrial experience – encouraged exploration and experimentation by students. In the interviews, teaching staff explicitly emphasised the importance of (stimulating) students' feedback-seeking and processing.

During the first weeks of the course, the learning task of students was to understand their challenge – from other perspectives. During the course, student teams made noticeable use of the teachers' and student assistants' knowledge and support. This occurred very informally during the course. Occasionally, an alumni of the course would also drop by to give teams informal feedback on the teams' definition and solving their challenge.

The learning environment created by the curriculum extended the safe learning environment created by the context by emphasising autonomy, exploration, and room for struggle and failure. Guided discovery and engagement in feedback encouraged critical reflection along students' use of sensedemanding in exploration of the challenge including seeking other perspectives.

We give an example. A situation was observed in which a student signalled to the teacher that his team was stuck with the development of a solution for the challenge. The student expressed his inability to identify the right solution that his team should pursue.

> *Student: "We don't know what sensors work.."*
> *Teacher: "..I agree with that. And that is why I said you need to work closely with the problem owner. To know exactly what they need. And also, to know how they look at it and use it."*

We observed that this teacher invited the student to seek other perspectives, by encouraging him to find out from i.e. engage in sensedemanding with the challenge-owner, regarding the challenge-owner's perspective on the (potential) solution currently ideated by the student team. The communication between teacher and student illustrates how the teacher sought to engage the student in reflection on how to achieve the task and why.

We know from research that reflection on task performance builds conceptual knowledge (Ward et al., 2018). We observed that the teacher used the framing error of the student as a guidepost, as he redirected the students' attention from domain-related expertise (knowing the workings of sensors) to the importance of customer orientation (seeking information from the challenge-owner) to achieve the task. The instructional methods used in this situation - guided discovery, using framing errors as guideposts, and seeking to teach cognitive strategies to support students' learning - have all been associated with building adaptive performance among students (Bohle Carbonell et al., 2014).

Task design

In this course, student teams were connected to a challenge owner (a business or organisation) who presented an open learning task. This was in the form of a challenge in the field of applied technology. With (consideration of) the challenge-owner, the student teams identified a concrete problem related to the challenge. Then, always taking the challenge-owner's perspective, the teams must ideate a technology-based solution for (parts of) the challenge, design a technology serving to implement the solution (in the form of a working prototype), and identify a product/market fit for it.

Tasks in this CBL-based course had a high variability, as achievement depended on iterative co-creation with a challenge-owner and possibly other relevant stakeholders, through interaction. We observed that students had to incorporate an increasing amount of 'details' into solving of the challenge. In that way, students' tasks also showed a high degree of coordinative and dynamic complexity.

The ambiguity of the challenge and potential solutions associated with this challenge played a role, as well as considering the (differing) perspectives of each team member on the tasks to be performed. The inherently ambiguous tasks required students to use various skills associated with adaptive performance, managing expectations of and relationships with others (i.e. with team members, challenge-owner, or teaching staff) in task achievement. As teams were interdisciplinary teams, they had to communicate and negotiate with each other about the understanding and carrying out of activities involved in task achievement.

We give an example. In one situation, students were under time pressure to finish their task (a mid-term presentation). Two team members were working on the same presentation in the same file simultaneously. Both were visibly stressed and busy finishing a PowerPoint presentation, which was due to be presented by them in a few minutes. The two students were evidently not agreeing on the layout of the slides. They were looking down on their respective screens from opposite sides of the table, intent and time-pressed to finish the task at hand. They did so by asking questions about each other's changes in layout (sensedemanding), by rebutting the other's change verbally (sensebreaking), and trying to establish shared meaning by means of persuasive rhetoric and humour, seeking to reconcile their different perspectives about a specific layout of a slide (sensegiving). This made for frequent, sped-up use sensegiving, sensedemanding, and sensebreaking, which aided the students to achieve the task in time.

We observed that fast, frequent, and simultaneous use of sensegiving, sensedemanding, and sensebreaking facilitated students' achieving the task at hand, namely finishing the PowerPoint presentation in time for the presentation. In a process of a few minutes, the two students managed to articulate, signal, analyse, and reconcile their differences, reaching consensus on the design of each slide, and finishing with the layout of it just in time.

Two main findings emerged from the analysis which help answer our initial research question. One, the educational design of CBL contributes to the development of adaptive performance by exercising relevant sensemaking skills. Notably, high frequency of socially situated sensemaking mechanisms helped students to adapt their performance to achieve the task. Two, the three socially situated sensemaking mechanisms help explain how educational design elements of CBL facilitate the provision of indicators for empirical assessment of adaptive performance (development) among students in higher (engineering) education.

A sensemaking perspective on adaptive performance development in CBL

The physical setting of the CBL course, namely in a prototyping facility, offered an abundance of resources to ideate and prototype. Also, the teachers guided students informally through the course, making the latter noticeably feel at ease and free to experiment. We found that this educational context affected students' communicative engagement.

Our findings confirm prior research, namely that a safe environment is a key condition for development of adaptive performance in higher education, by having a general effect on preparedness to innovate and be creative (Kua et al., 2021; Gube & Lajoe, 2020). A study by Kuismin et al. (2024) showed that discursive and affective reconfiguration of space aids the enactment of ambiguity in task achievement under conditions of uncertainty and novelty.

And so-called 'in-between spaces' facilitate organisational and professional learning (Bailey, Winchester, and Ellies 2023). Such spaces are characterised by an informal, open environment which enables the fusion of technology and work in organisations (Orlikowski & Scott, 2008). The physical and social setting of CBL education, i.e. the resources which students could *literally play* with and the informality of the teaching staff, represent an 'in-between' space and helps to explains how students' learning is enabled.

Our findings provide an account of the micro-level mechanisms which enable collaborative discourse, namely: sensegiving, sensedemanding, and sensebreaking. Used together, these socially situated sensemaking mechanisms exercise students in collaborative discourse. While sense-giving aims at creating shared understanding, both sensedemanding and sensebreaking constitute more inquisitive and critical cognitive processes (Kaffka & Krueger, 2018; Kaffka et al., 2021; Kaffka et al., 2024).

Sensebreaking played an important role in collaborative discourse of students because it helps them to identify (and subsequently address) differing and contradictory perspectives or information. Recognising so-called 'atypical signals', or cues from the environment, is essential in adaptive performance of professionals (Klein et al., 2007).

Sensedemanding manifested in teaching staff asking questions and seeking new or alternative information. We observed that open questions by teaching staff helped to 'grease' the feedback for students. This corroborates research which underlines the role that use of questions plays in developing adaptive performance in higher education (Charbonnier & Voirin, & Roussel, 2012).

It has been argued that "students need a knowledge of the meta-linguistic features of argumentation (claims, reasons, evidence, and counterargument) to identify the essential elements of their own and others' arguments" (Osborne, 2010: p. 466). We observed that collaborative discourse, and in particular (negative) feedback loops in which students used sensedemanding and sensebreaking, provided students with exercise in challenging claims, using counter-argumentation, and perspective-taking.

This exercise in using socially situated sensemaking mechanisms practised sensemaking skills of students essential in collaborative discourse (Kua et al., 2021) and which contributes to the development of adaptive performance among students (Fisher & Peterson, 2001).

Assessing adaptive performance development

In this study, we explored the role of socially situated sensemaking mechanisms associated with collaborative discourse. We found that CBL offers ample exercise in sensemaking mechanisms. The three mechanisms are empirically distinctive phenomena, hence representing quantifiable indicators for assessment of collaborative discourse in higher education.

The three mechanisms also have not yet been recognised for their value in assessing (meta)cognitive development of engineering students, although such development supports that of adaptive performance among professionals (Kaffka et al., 2024). Specifically, integration of sense-breaking is an important enabler of developing adaptive performance.

We see that CBL echoes this in context, curriculum, and task-related elements in the form of a positive error condition and incorporating struggle.

Extant works suggest that CBL might encourage building adaptive performance by enabling students to learn via so-called collaborative discourse (Kua et al., 2021). Collaborative discourse describes student-centred discourse which elicits students' engagement and reflection through questions (Bowers et al., 2020).

We know that practising a skill contributes to its development. Along these lines, we argue that students' use of sensebreaking and sensedemanding during collaborative discourse - yields practice in sensemaking skills relevant for adaptive performance. This offers an explanation of how CBL enables collaborative discourse and the development of adaptive performance among engineering students.

Practical implications

Results of our study show that students who practice sensemaking skills during engagement in complex and novel task performance build adaptive performance. The three socially situated sensemaking mechanisms offer empirically grounded indicators for students' pro-active, intentional engagement in collaborative discourse aimed at task achievement under conditions of novelty or uncertainty. Hence, we posit that the assessment of when, how, and why students use the three sensemaking-related mechanisms can help understand differences in adaptive performance as well as how micro-level practices shape the development of adaptive performance.

Assessment of students' use of sensegiving, sensedemanding and sensebreaking – in their proper teams, with their peers, the teaching staff, or the challenge-owner - can help gauge the development of adaptive performance-related cognition, among higher education students as well as in continuing education. Inarguably, to be effective such a learning environment must be a safe setting, i.e. socially and physically functional and protective.

As shown in extant work, a safe environment contributes to building adaptive performance (Kua et al., 2021). We propose that students' engagement in sensedemanding and sensebreaking, i.e. negative feedback loops can be indicative of the way students perceive their learning environment. Extant work shows that sensedemanding and sensebreaking are indispensable in adaptive performance development of professionals (Kaffka et al., 2024) as well as in the development of entrepreneurial ventures (Kaffka & Krueger, 2018).

We suggest that educational interventions aimed at adaptive performance development should stimulate and monitor students' use of questions (more) as well as their engagement with (negative) feedback within and outside the classroom, such as with a challenge-owner or relevant stakeholders.

Training in socially situated sensemaking mechanisms goes beyond higher education. Today's managers seek to make their organisations more flexible and responsive (Mergel, Ganapati & Whitford, 2021). Intentional use of them can help professionals become more adaptive at work (Kaffka et al., 2024). We suggest their training contributes to building young engineering professionals' sensemaking skills relevant for adaptive performance. In that sense, skilled use of these socially situated sensemaking mechanisms presents a valuable lifelong learning asset.

Conclusion

This study showed that in addition to curriculum- and task-related elements, context-related factors of CBL design are crucial for exercising students' sensemaking processes relevant for development of their adaptive performance. We propose that sensegiving, sensedemanding, and sensebreaking clarify conceptually how social interactive context matters in adaptive performance and its development. Also, these three concepts represent analytical tools suitable for empirical research on adaptive performance and its development in higher education.

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