Developing professional expertise for safety: a learning design framework

Sarah Holdsworth1 · Jan Hayes1 · Orana Sandri1 · Sarah Maslen2

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Abstract
Continuing professional development recognises that changes in the contemporary world demand that engineering professionals continuously learn. Today’s professional landscape requires the provision for ongoing learning relevant to evolving workplace requirements. This is particularly the case for engineers working in hazardous industries who make decisions every day with significant consequences. Despite this, the safety literature has paid little attention to best practice in professional learning. There is a large literature regarding lessons to be learned from accidents. Other published studies focus on training methods such as simulation. Educator-focused approaches such as these separate learning from real day-to-day workplace contexts and the learning needs of professionals. It is increasingly recognised that professionals learn, in a way that shapes their practice, from a diverse range of activities. Learning must therefore be active, social, and situated within the sphere of professional responsibilities, contexts, and groups. This paper presents a learner-centred framework that can be used to develop professional learning for safety that is grounded in day-to-day work practices and professional context needs. The framework aims to move away from the limitations that have been found with the current professional development approaches to enhance learner-centred professional learning. The framework was developed and used in the context of engineering practices regarding safety, but, because the framework encourages learning to be designed based on workplace contexts, it is applicable across a range of training needs and professions.

Keywords Professional learning · Professional development · Knowledge · Competence · Capability

1 Introduction

High-quality professional engineering practice that evolves with societal expectations regarding public safety requires ongoing professional learning. Engineers who work in hazardous industry make decisions every day that can impact safety outcomes. Over the past two decades, continuous learning has become increasingly important to safe practice due to the ongoing shifts in labour markets, subsequent changes to everyday work tasks, and increased complexity and demanding requirements placed on professionals, all of which can impact the best safety choices. As such, ongoing learning has become an essential part of a professional’s working life (Billett and Harteis 2014; Collin et al. 2012; Webster-Wright 2009).

In the safety context, learning from past accidents and incidents has formed a key part of individual professional learning. Despite engineers’ strong interest in past disasters (Maslen and Hayes 2020a, b), the disaster record is replete with cases where engineers have made poor professional choices. While such cases are seen as valuable for learning to the point where they are sometimes referred to as ‘the gift of failure’ (Carroll and Fahlbruch 2011), there is significant room for improvement when it comes to learning from accidents, and other types of learning linked to safety outcomes. More structured approaches to professional safety training are therefore relevant, rather than the current (over) reliance on individuals to seek out lessons themselves.

Traditional approaches to workplace professional training are not the answer as research has shown that such training, managed and organized by typical organisational learning and development functions, is not meeting organisational needs. Training is often disconnected from real-life work
contexts and the return on investment regarding learning outcomes achieved is poor (Corrigan et al. 2015). Consistent with this general finding, our review of professional development (PD) in the safety literature shows little engagement with the underpinning educational philosophy, and a lack of reflection on the andragogy (i.e., theory of adult learning) that informs and justifies the selection of professional development and training approaches, methods, and learning outcomes.

In the education literature, research on professional and practice-based learning is emerging as a crucial topic whose findings require broad consideration and wide dissemination to support individuals in their employability across lengthening professional lives. This literature can provide insights for the safety training of professionals in high-hazard industries. Overall, the safety literature supports the importance of professional learning, but the discussion is absent regarding a learner-centred andragogy supporting ongoing professional learning grounded in the learning contexts and needs of professionals to support excellence in safety decision-making. Drawing on the education literature and applying it to the professional engineering context, we address the following question:

How can professional learning about safety best be constructed to support excellence in engineering professional practice?

We begin with an exploration of the existing trends in safety literature regarding ongoing learning followed by an overview of professional learning processes and outcomes that are desirable for achieving safety outcomes. We then present and explore a learning framework that can be used to inform the development of formal learner-centred professional learning opportunities, concluding with how it relates to the pipeline engineering context we address in our own work.

2 Professional learning for the best safety outcomes

2.1 Professional learning in the safety literature

Learning is a popular topic in the safety literature, but when it comes to learning for engineers, there are significant weaknesses in the way learning is treated. First, there is a large literature about learning from incidents of various kinds including both workplace incidents (Lukic et al. 2012; Vastveit et al. 2015) and learning from disaster cases (Eburn and Dovers 2015; Quinlan 2020). Various authors have highlighted the extent to which lessons from accidents are not being learned (Filho et al. 2021; Hopkins 2008; Quinlan 2014). From the resilience engineering theorists, Hollnagel (2014) emphasises the need to extend learning about safety to include things that go right, as well as times when things go wrong. While this is an important insight, we are no closer to seeing how such learning might be supported. Learning, here, is principally being addressed at the organisational scale of analysis. As disasters have organisational causes, it is often acknowledged that we need to understand and address these failings at the organisational level, and so, lessons should be embedded in the organisational fabric (Reason 1997).

When it comes to individual learning, a common management assumption is that all errors made by individuals are the result of lack of knowledge which can be remedied by better training and more detailed procedures (Pelegrin 2013). As a result, talk about prevention of human error is often about compliance (Fucks and Dien 2013) and learning is framed as something that individuals need to do. This consideration of learning among practitioners is important, given expertise among individual practitioners is a factor that allows complex technologies to be managed safely (Roe and Schulman 2008). Conversely, it is found to be missing where things go wrong (Hopkins 2012; Snook 2000).

However, there is disagreement over the character of this learning. In a compliance model, the assumption is that actions are driven by knowledge in the form of generalised principles about how to perform specific tasks in specific ways. This is what might be commonly known as ‘book learning’ with a focus on matters such as using the correct equation or specifying the best material. Consistent with this, much engineering education focuses on competency, typically defined as the ability to consistently apply knowledge and skills to a defined standard (Australian Skills Quality Authority 2019). Where formal training with a competency focus is provided, it tends to be based on a transmissive mode of learning that separates learning from the workplace (Collin et al. 2012).

Whilst competency is critical for many engineering tasks, effective engineering practice requires other skills that support engineers to make the most informed decisions in dynamic, uncertain, and complex situations (Hayes et al. 2021). Safe outcomes are also a matter of professional judgment in uncertain circumstances, and so, a ‘safety imagination’—an ability to link one’s actions to the potential consequences—is required to ensure the best result (Pidgeon and O’Leary 2000). By this definition, therefore, professional learning to improve safety is not only a question of competence. We want professional engineers to be able to do much more than to apply highly technical principles to well-defined technical problems. They need the skills to make the best choices in situations of uncertainty. Such skills extend beyond technical knowledge and are collectively known as capabilities (Mulder 2014).
When it comes to learning about safety, there has been some focus on training requirements, specifically for safety professionals (Pryor 2016; Wybo and van Wassenhove 2016). Some researchers have delivered and evaluated professional training driven by specific skills, e.g., resilience (Hermelin et al. 2020) or how to improve error management skills (Naikar and Saunders 2003). Many papers focus on training methods or training content, with little reference to the underlying andragogy. Examples include Aneziris et al.’s recent paper regarding training for LNG storage and bunkering at ports which focuses on the content to be delivered, rather than the specific learning needs of the different professional groups that they aim to engage (Aneziris et al. 2021), Leder et al.’s study comparing the effectiveness of virtual reality versus lecture-based styles of teaching (Leder et al. 2019), and a study of the relative effectiveness of a serious game, a paper-based game and lectures in an engineering context which found that the serious game was most effective (Din and Gibson 2019).

Following the focus on virtual reality and games is a developing literature on simulator training including studies of health (Guerlain et al. 2008; Koutantji et al. 2008), forklift drivers (Lehtonen et al. 2020), vessel traffic service operators (Song et al. 2022), train drivers (Tichon 2007), construction workers (Tichon and Diver 2010), rail flow operators (Vanderhaegen 2021), and maritime officers (Wahl 2020) amongst other frontline workers. Simulations are most relevant in that context where action selection drives short-term outcomes, and so, skills can be developed. Another limitation of this literature is a disconnect between the training carried out and the defined training objectives with a particular need for a better andragogical model. In one of few exceptions, Crichton (2017) proposes five principles for improving safety training in the form of simulator exercises, but application is limited to training in skills for frontline workers with short-term feedback.

For professionals such as engineers, feedback on decisions made is often much longer term with the consequences of choices made often far removed both temporally and geographically from daily practice and so different training considerations arise. In these conditions, learning is not simply the ‘acquisition’ and ‘transference’ of knowledge, and it requires participation, construction and becoming (Hager and Hodkinson 2009; Smith et al. 2009). Along these lines, some researchers have focused on the possibilities of case-based learning approaches, in which learners imagine themselves in specific past accident situations and thereby reflect on the strengths and weaknesses of their own professional practice (Rae 2016). Similarly, others have pointed to the importance of mentoring and working alongside more experienced others (Maslen 2014). These studies are more grounded in engineering learning needs, but still lack a formal andragogical framework.

Overall, we know that the actions of engineers drive safety outcomes and yet a theoretical framework or andragogy for ongoing learning has not been significantly addressed in the safety literature. A trend towards safety training that fails to focus on the needs of those being trained and has little consideration of andragogical pedagogies (Loosemore and Malouf 2019) or to connect objectives to evaluation (Aronsson et al. 2021) has been noted. Studies of learning in the safety context rarely cover the full learning cycle from needs to evaluation. Any theory regarding adult learning, i.e., andragogy, is largely absent. In addition, studies of safety-related training and learning tend to focus on front-line workers, rather than largely office-based knowledge workers such as engineers whose decisions may have much longer term consequences.

### 2.2 Developing capabilities

The education literature provides for a more robust appreciation of professional capabilities and the andragogy of how to develop them. First, we find that the education literature makes a distinction between capabilities and competencies, and discusses the limitations that a competency-based system introduces when it comes to PD. Stephenson (1998, p. 3) argues that workplace training has evolved into a system characterised as ‘effective in the delivery of current services based on standards’ that reflect those identified by industry to meet the needs of employers as determined by past performance. Competency models as applied to PD are used to determine business needs through the identification of knowledge, skills, and personal characteristics required for successful performance in a job; in behavioural terms, they are what people need to do to produce the results that the organisation desires and thereby are used to inform subsequent PD programs (Noe and Winkler 2009).

Such an approach might seem appropriate in the context of safety, since organisations usually want to prevent accidents, but this approach to PD pays little heed to professional practice issues. Competency alone does not capture the need for a combination of specialist expertise developed from reflection in, and experience of, practice leading to efficient and appropriate action and results in line with organisational goals, such as continuing safe operation of complex systems. The ability to explain and justify oneself and one’s action in the context of practice and the application of expert knowledge results from confidence in the application of expertise within both known and unknown contexts, not just the possession of knowledge. Competence coupled with confidence, self-efficacy, and professional identity results in capability (Mulder 2014).

Capability encapsulates the development of the competencies, knowledge, and skills required to explore the assumptions, biases, and the limitations of existing...
practice. As Sadler (2013) argues, capability can be considered as an integrated and large-scale characteristic. When the whole is judged to be more than the sum of its parts, the ‘something more’ that makes up capability includes any extra qualities or properties, of whatever kind, that were not initially identified and named at all. It also includes the ability to ‘read’ a complex situation, which is not precisely like any seen before and also how to call on the various competencies productively, adaptively, confidently, safely, and wisely (Sadler 2013).

A person with capability would be expected to develop a critically reflexive approach to both personal and new forms of professional practice—an epistemology of practice ‘knowing in practice’ (Markauskaite and Goodyear 2014, p. 87) beyond that of mimesis of specific proceduralised know how (Lambert et al. 2012). Capable people ‘not only know about their specialisms; they also have the confidence to apply their knowledge and skills within varied and changing situations’ (Stephenson 1998, p. 3). Capability is broader in meaning and application than competence where a capable individual can not only perform effectively but also is forward-looking and able to participate in their own development.

A PD approach based on capabilities, therefore, has the potential to improve professional learning regarding safety expertise. Unfortunately, the education literature demonstrates that the current reality is very different. Formal PD activities of most organisations have failed to address capability development. In contrast, PD has been critiqued as (a) simply the development of competencies required for a changing professional context to ensure organisational advancement and advantage (Stephenson 1998) and (b) delivered as learning transferred in a discrete package separate from the workplace and absent of practical situations (Webster-Wright 2009).

The predominant model is PD delivered as learning transferred in a discrete package of prescribed competencies, bounded and led by professional bodies or in-house activities. This will not result in improvement in practice toward competent or even ‘accomplished’ practice, no matter how flexible or well designed. PD delivered in such a way limits ‘the potential for making the most of professional learning opportunities within organisations, particularly when considering everyday work’ (Rooney, Reich, Willey, Gardner, and Boud 2012, p. 2). PD in its dominant form is underpinned by an ‘objectivist epistemology and dualist ontology’ (Webster-Wright 2009, p. 714) based on the assumption that professionals are ‘deficient and in need of developing and directing’ (Webster-Wright 2009, p. 712). The skills to be ‘developed’ are typically delivered by a top–down, one size fits all approaches where objectified knowledge is understood to be acquired through cognitive transference between instructor and learner in formal educational programs separate from the sociocultural context in which it is used (Webster-Wright 2009).

The focus is on the deliverer and delivery of competence required for organisational task-led practice rather than the learner needs and their praxis.

In light of evidence about how professionals learn as described above, to be effective PD must evolve to learning about practice conceptualised as ‘learning as participation,’ ‘learning as construction’, and ‘learning as becoming’ (Rooney et al. 2012, p. 118). Situated learning within the workplace can engage individuals in actively working with others on genuine problems within their professional practice. Within the educational research community, it is understood that effective PD is based on a notion of learning as continuing, active, social, and related to practice (Garet et al. 2001; Wilson and Berne 1999), and yet, this approach seems rarely to have been adopted in practice. In contrast, learning should be conceptualised as the outcome of an enabled active, intentional interactional engagement in experience and thinking. In Wenger’s words, at its best, ‘education is not merely formative—it is transformative’ (Wenger 1998, p. 263).

The workplace presents ‘a major learning challenge in its own right’ (Eraut 2010, p. 51), and an individual must extract relevant information from their previous learning environment and reconceptualize it, such that this information can be understood in a new situation, identifying the relevant knowledge and skills and repositioning them to fit in the new context while integrating them within the existing knowledge and skills for future application. Therefore, separating formal learning from day-to-day work practice learning is not helpful, and formal and informal learning is best integrated to enhance continuing professional development.

Work itself is at the centre of effective PD which bridges the binaries of formal and informal learning providing a ‘common currency’ and means to ‘navigate the set of orthodoxies that permeate education, training, and development’ (McCormack 2000, p. 398). Effective PD reflects the social, material, and situated nature of learning and the evolving recognition of workplace learning opportunities, challenging how professional learning is understood and evaluated (Boud and Hager 2012; Fenwick 2009; Hager and Hodkinson 2009).

2.3 A framework to guide the development of professional learning experiences

Drawing together learning needs of engineering professionals in a hazardous industry, the demonstrated gap in the safety literature, and criticisms of current PD practice from the education literature, we have demonstrated the value of a professional learning development framework that meets four key requirements:
• Grounded in the learning needs of professionals.
• Linked directly to professional practice.
• Focused on capabilities.
• Includes a workplace-focused evaluation approach.

In best practice educational design, a method that includes the steps or procedures to develop the approach to professional learning and the subsequent professional learning module is first established. This systematic process to the design of a professional learning module is important for first establishing the professional learning needs the module seeks to address and then aligning the delivery approach and methods to fulfil these needs. This method, in educational terms, is called a ‘learning design framework’. This framework is important as it informs deliberate choices about why, what, when, where, and how to teach, and the associated learning objectives and outcomes. Using the framework, the focus is on learning as the outcome, rather than instruction as the approach (Wasson and Kirschner 2020) thereby encouraging consideration of any experience that is designed to facilitate learning (Neelen and Kirschner 2020). Depending on the needs identified by the steps in the framework, such learning experiences could include formal learning modules or other activities that are situated in work practice needs and contexts.

3 The framework

In good practice education, it is important that learning needs, capabilities, educational approaches, learning activities, and assessment align to meet the professional needs of the learner cohort (Biggs and Tang 2011; Holdsworth and Hegarty 2016). The Professional Learning Design (PLD) Framework presented in Fig. 1 promotes such an alignment. It provides a systematic process to design learning experiences by first establishing the learning needs the educational experience seeks to address and then aligning the delivery approach and methods to fulfilling these needs drawing on the four key requirements listed above.

The process begins in Stage 1 by identifying the professional gaps in knowledge/capability/competence/skill or the aspect of professional practice that needs to be supported or enhanced. The identified learning needs inform the development of learning objectives to address gaps or enhance existing professional practices in Stage 2. Stage 3 involves identifying professional capabilities that can help address gaps in, or enhance, professional practice (Lambert et al. 2012). Following from this, appropriate educational approaches are identified in Stage 4. In Stage 5, learning activities and content for the training are designed, ensuring alignment with the learning objectives and supporting the development of identified capabilities. Stage 6 of the learning design framework is the development of an evaluation approach to determine if the intended learning objectives have been met by the training. It is important to note that this step-by-step process is likely to be iterative, rather than

Fig. 1 Professional learning design framework (PLD framework)
linear. The following sections describe each stage of the framework in further detail.

### 3.1 Stage 1: needs identification

The first stage in the PLD Framework draws on the existing research and professional evidence to determine the needs of the professional and the associated capability (including associated competence and skills) to be nurtured and/or enhanced in relation to practice. This stage of the framework forms the foundation of any learning experience which grounds the professional learning in the workplace contexts, professional practices, and needs of participants to ensure that they perform their work safely. It is at this stage that the framework provides the opportunities to address key issues raised by Havnes and Smeby (2014), Webster-Wright (2009), and Rooney et al. (2012) by integrating learning into professional practices, thus supporting a move away from traditional professional development approaches focused on content, into structured professional learning experiences based on learner needs. This stage of the framework helps to ‘understand professionals’ experiences of learning in a way that respects and retains the complexity and diversity of these experiences, with the aim of developing insights into better ways to support professionals’ (Webster-Wright 2009, p. 714). This stage of the PLD framework design includes the identification of the learners, an understanding of who they are in relation to the identified professional objectives, and their organisational outcomes and operation. To address the need for, and type of, PL to be developed, drawing on both the literature and professional knowledge, the following reflective questions can be explored:

1. What is the objective(s) of the profession?
2. What is the justification/rationale for that objective? What evidence is it based on?
3. Who has a ‘stake’ in this field/conversation? How have we captured that key perspective?
4. What does the evidence (literature, professional practice, lived experience) tell us?

### 3.2 Stage 2: learning objectives and outcomes development

The second stage in designing a professional learning experience requires the developers to reflect on the industry’s professional needs and use these to inform the development of associated learning objectives and outcomes. The learning objective reflects a learning purpose in the context of professional practice and seeks to fill a knowledge and/or capabilities gap in current professional practice. Learning outcomes describe what participants will be able to do upon completion of the professional learning module to meet the learning objective. At these initial stages of the PLD process, it is important to also consider learning evaluation. Evaluation occurs at the end of the learning experience or after, and yet the needs analysis and identification of learning objectives and outcomes are essential to systemic professional learning evaluation. This approach aligns with Kirkpatrick’s Training Evaluation Model, a widely used training evaluation framework that includes identifying the organisational requirements specific to the training module as a key step in determining the effectiveness of training. Therefore, it is imperative that professional learning modules are designed to achieve learning outcomes situated in professional needs. Kirkpatrick’s Training Model (Kirkpatrick and Kirkpatrick 2016) grounds professional training or learning in these workplace needs and training objectives. For effective evaluation, the Kirkpatrick Model requires organisations, along with training providers, to identify training requirements based on their organisational context. These requirements include:

2A. Development of a statement of results (undertaken in conjunction with the training participants’ organisation) which informs and reflects the purpose of the training (and desired organisational outcomes) with the developed learning outcomes of the training program (undertaken by the training developers).

2B. Identification of critical behaviours that the primary group will have to consistently perform on the job to bring about the identified outcomes.

2C. Identification of leading indicators (that assess the workplace behaviours that reflect the desired organisational outcomes) and bridge the gap between individual initiatives in the workplace post-training and desired organisational results.

This then allows for the learning experience to reflect these needs and supports the evaluation of the effectiveness of professional learning against these organisational needs. This further reinforces the importance of undertaking an organisational needs analysis and establishing the professional learning objectives at the beginning of the PLD process.

### 3.3 Stage 3: professional capability identification

The foundation of any professional learning module must include the identification of the capabilities, competencies, skills, and knowledge that the program aims to develop or enhance. As already established, developing capability is an essential component of professional learning and the associated development of the professional learning module. As such, it is recommended that a capability framework is developed to inform the professional learning module’s...
objective and to promote the development of shared skills, behaviours, and competences required within the profession. The identification of capabilities and their alignment to the organisational requirements specific to the learning module is a key step in determining the effectiveness of the learning and aligns with Kirkpatrick’s Training Evaluation Model. Therefore, it is imperative that learning modules are designed to achieve learning outcomes situated in professional needs.

### 3.4 Stage 4: identification of educational approach

Stage 4 focuses on the educational foundation that informs the development of the professional learning module. This includes reflecting on the most appropriate methodological and philosophical orientation of the education process in an adult education context, i.e., andragogy, which informs subsequent learning and teaching activities, appropriate curriculum/content, and assessment methods.

This stage of the module’s development requires reflection on the andragogy informing the session. Andragogy also informs what education should do, and for whom, and why (what problems education does, and should, address). On a broad level, andragogy shapes the relationship between learners and instructors/teachers. A simple example of the influence of andragogy on the education module is the role of the instructor in the education process. In a teacher or instructor led andragogy (the more traditional approach), the teacher acts in the familiar role of instructor in the classroom, providing information to learners who passively receive it. In a learner-centred andragogy, the teacher acts as mentor or facilitator as students adopt a more involved and interactive role in their own learning. The former approach is underpinned by the assumption that learners are ‘empty vessels’ which can be passively filled with information. The latter approach assumes that learners bring their own experience, values, and skills to the learning process and are active in the creation of their own learning experiences. The learner-centred approach sits best with professional learning, which by its title, draws on and develops from, existing professional experiences and practices. This orientation is essential to re-conceptualise didactical transmission-oriented professional development approaches to professional learning, situated in social practice, institutional cultures, and structures in which learning revolves around work (Havnes and Smeby 2014).

### 3.5 Stage 5: identification of appropriate activities and content material

The fifth stage of the PLD Framework involves identifying the learning experiences suitable for developing the identified capabilities, learning objectives, and outcomes, along with content materials to support the learning process. These activities are situated in the educational approach taken, and therefore in the context of supporting professional learning. The emphasis must be on situating learning in the professional practices of participants to enhance the development of professional competence as capability. For example, a teacher-centred approach lends itself to activities that present learners with information and ask them to memorise and repeat. A learner-centred approach lends itself to activities that invite learners to express their views, share experiences, and develop understandings. As a result, learner-centred activities are more transformative and enable the development of capabilities rather than just memorising content information. Therefore, this distinction in the educational approach is important. There are many learner-centred activities. However, widely used activities include experiential case-based learning, problem-based learning, and scenario-based learning that explore learner perspectives, develop capabilities, and transform perspectives through exploratory tasks designed around existing professional cases, problems, or scenarios. Whatever the choice of learning experience and delivery, it must be informed by the evidence base developed in Stage 1 and subsequent learning outcomes, objectives, and capabilities that have been developed from this.

### 3.6 Stage 6: evaluation strategy

A critical aspect of workplace learning is its evaluation, which identifies the impact of learning on professional performance and behaviour. This is essential to understand, given that by using this framework, professional learning is designed to address an identified need that is required in an organisation (Topno 2012). Sound professional learning begins with an organisational needs analysis and evaluates the resultant deliverable (Gopal 2008). As such, evaluation is best understood as a systematic process to determine the learning value against a developed criterion of comparison. Importantly, evaluation should not only determine whether participants have developed new or evolved knowledge and skills, but also whether they can implement this learning within their respective workplace post-completion (Boulemetis and Dutwin 2000; Philips 1996).

Evaluating professional learning is difficult, given the subjective nature of learning and change. It is often hard to set measurable objectives and even harder to collect the information on the results, or decide on the level at which the evaluation should be made (Nagar 2009). To gauge the effectiveness of the learning module, it is important to evaluate and assess the module both, while it is being developed, and after it has been delivered. Assessment and evaluation can and should be both formative (carried out during the course) and summative (carried out following the course). Given professional learning occurs through both formal and
informal learning (Webster-Wright 2009), evaluation should consider the learning outcomes not just immediately after completion of the module or activity but the learning outcomes over time seen in professional practice. The Kirkpatrick Training Evaluation Model suggests four levels at which assessment and evaluation may occur. Both Level 1 and 2 evaluation strategies focus on assessing and evaluating the participants’ experience of the professional learning experience. Kirkpatrick’s evaluation Level 3 and 4 focus on assessment of knowledge in the workplace and more broadly evaluate the success of the learning experience.

- **Level 1** assesses and evaluates the reaction of the participants to the learning module. This level provides an assessment of the degree to which participants were satisfied with the education they experienced. This is often collected through satisfaction surveys drawing on open or closed questions.
- **Level 2** assesses and evaluates the learning outcomes of the participants. Learning is defined by Kirkpatrick and Kirkpatrick (2016, p. 23) as ‘the degree to which participants acquire the intended knowledge, skills, attitude, confidence and commitment based on their participation in the learning event.’ Kirkpatrick’s learning components are defined as:
  - Knowledge: ‘I know it.’
  - Skills: ‘I can do it right now.’
  - Attitude: ‘I believe this will be worthwhile to do on the job.’
  - Confidence: ‘I think I can do it on the job.’
  - Commitment: ‘I will do it on the job.’

- Assessing and evaluating knowledge and skill at this level require the incorporation of activities into a professional learning module. These may take the form of formative or summative methods and these may be interspersed throughout the course or left to the final stages of the session. Evaluation methods selected should reflect the educator’s andragogy and the designed learning outcomes and identified critical behaviours. In the case of evaluating the participant’s attitude towards the task, this may be determined by the educator by observation of the participant throughout the education module. In addition, a more formal assessment of attitude may be undertaken.
- **Level 3** focuses on the assessment and evaluation of learner behaviour post-completion of the learning module. Specifically, this level of evaluation focuses on the degree to which participants apply the knowledge and skills gained in the module to their workplace activities. This level requires not just the assessment of the learners’ actions but also the degree to which the workplace supports such behaviours.
- **Level 4** focuses on the evaluation of the module and determines whether or not the targeted outcomes or primary goal of the program has been achieved. It seeks to evaluate the success of the program from a whole organisation perspective. Commonly measured by measuring factors such as lowered spending, higher returns on investments, improved quality of products, fewer accidents in the workplace, more efficient production times, and a higher quantity of sales. Leading indicators may be used to assess workplace performance over a period of time post the training experience.

### 4 Implications for professional learning for safety

In 2009, Webster-Wright (2009) undertook a strategic review of the existing literature on PD and concluded that the dominant approach focused on the transmission of content with ‘learning defined as “filling up” a reservoir of knowledge in a professional’s mind that will run dry if left too long’ (Webster-Wright 2009, p. 712). Despite the adequate initial preparation for professional practice as met by university qualifications, the subsequent learning and development experiences in and as part of professional activities are recognised as not congruent with findings from key research into professional learning which emphasises the value of ongoing and situated learning. The framework described above aims to guide development, delivery, and evaluation of much more user-centred learning.

This approach has been applied to the development of training in safety-related non-technical skills for pipeline engineers (Hayes et al. 2021). Non-technical skills are acknowledged as being critical for the safe execution of work in complex socio-technical systems (França et al. 2022). The project arose from a recognition by the Australian pipeline industry that engineers’ non-technical skills are critical in maintaining the sector’s good safety record and yet they are not systematically addressed by the sector’s professional competency training framework. This is particularly topical given the significant changes that the industry will undergo in the coming years due to decarbonisation and moves towards future fuels such as biomethane and hydrogen. Following the steps in the Professional Learning Design Framework, learning has been developed to fill this gap as summarised in Table 1.

The defined learning objective was to develop pipeline engineers’ capabilities to make decisions that reflect the paramount importance of public safety through the transition to future fuels and into the future. Note that this was
not developed as a result of a perceived deficit, i.e., there is no evidence of a specific capability gap, but rather a realisation that more could and should be done to support individual capability development. The learning outcomes (see Table 1) focus on further developing engineering capabilities required for best practice safety outcomes nurtured through experiential learning with participants interrogating their and others’ practice within the context of the potential for catastrophic accidents.

These capabilities were then identified through the application of Stage 3 of the framework. Interviews were held with 41 engineers to solicit from them what they see as the most important skills that inform their high stakes’ decision-making regarding safety. The resultant 20 capabilities fall under six key themes (Hayes et al. 2021):

C1. Use long term, foresighted reasoning, especially in the face of uncertainty
C2. Understand norms and values that inform actions
C3. Think systematically and understand interconnectedness
C4. Collaborate with and draw on the experience of others
C5. Ground decisions in reality
C6. Advocate for action and take responsibility.

To meet the learning objectives, Stage 4 of the PLD Framework was applied to identify the most appropriate educational approach to be used. When it comes to learning how to do one’s job, there is a qualitative leap in learning processes when moving from the rule-driven analysis of a novice to the fluid, continuous action of the expert (Dreyfus and Dreyfus 1986; Penney et al. 2022; Song et al. 2022). Knowledge of particular cases is critical as experts ‘operate on the basis of intimate knowledge of several thousand concrete cases in their areas of expertise’ (Flyvbjerg 2006). Cases offer, in effect, a form of experiential learning. As a result, experiential, case-based learning was chosen as the preferred approach.

In Stage 5, 16 accident cases were reviewed to identify which were the best for learning. Within empirical limitations, researchers have suggested that a good case must:

- Tell a story (i.e., have a defined setting, a logical sequence of events, and defined characters);
- Be set in the last 5 years;
- Create empathy with the central character;
- Be relevant to the readers;
- Contain an element of structured controversy;
- Be conflict provoking;
- Be decision-forcing;
- Be realistic;
- Include quotations; and
- Not be too lengthy.

Possible cases identified include:

- Major engineering failures during operations in other sectors.
- Major engineering failures linked to project activity/ major modifications/changing technology in other sectors.
• Failures of complex systems due to unexpected interconnections.
• Pipeline sector failures either in operations or linked to project work.
• Industrial accidents involving hydrogen (and other potential future fuels).

These principles have also been considered in selecting which cases to take forward, particularly the need for characters that learners can empathise with. Table 2 shows the 16 disaster cases and which cases illustrate which capabilities.

When it comes to deciding which cases best illustrate which capability, it can be seen that many of the cases are useful in illustrating the need for thinking systematically and understanding interconnectedness (C3). Getting norms and values right (C2) is also clearly illustrated as is the need for long term, foresighted reasoning (C1). Grounding decisions in reality (C5) is also important in a significant number of cases. Fewer accident cases have links to the two capabilities more closely related to interpersonal relationships and skills [i.e., collaborating with others (C4) and advocating for action (C6)]. Aspects of accident causation linked to the absence of these capabilities are less likely to be identified by technically focused investigations, and so, in some cases, no information is available in these areas. Nevertheless, these capabilities have been highlighted in some iconic accidents.

Matching past accidents to the specific capabilities in each of the above themes resulted in the selection of two pairs of accident cases that illustrate the importance of all capabilities. The selected cases are shown in Table 3. For transmission engineers, the chosen cases are the San Bruno pipeline failure and the Challenger space shuttle disaster. For distribution system engineers, the chosen cases are the Massachusetts gas distribution system failure and the Dreamworld disaster. In addition to illustrating each capability, these pairs of cases also provide one case that is in the same work environment as the learners and one that is from another sector (Hayes and Maslen 2020). The learning design includes case presentation, discussion, and role play. Application of the PLF and development of the specific capabilities have also led to the decision to develop a game-based simulation for pipeline engineers.

All development has been undertaken in parallel with consideration of how the effectiveness of the PD will be evaluated. As part of the professional learning for safety sessions, an evaluation training strategy will be developed, drawing on Kirkpatrick’s Training Evaluation Model. Summative and formative activities during and immediately after the session will assess and evaluate participants’ experience of the session, including the andragogy underpinning the

### Table 2  Links between incident cases and capabilities

| Incident                                                                 | Links to capabilities |
|-------------------------------------------------------------------------|-----------------------|
| Uberlingen air traffic control failure (Brooker 2008; Johnson 2004; Johnson et al. 2009; Masys 2005) | C B A A B A |
| Quebec Bridge collapse (Brady 2014a, b; Kranakis 2004; Pearson and Delatte 2006) | A B A A B C |
| Florida International University footbridge collapse (US Department of Labor 2019) | B B A C C A |
| Enbridge pipeline rupture and oil leak (Hayes and Hopkins 2014; NTSB 2012) | A A A C B C |
| San Bruno pipeline rupture and fire (Hayes and Hopkins 2014) | A A A B A C |
| Hurricane Katrina and failure of flood defences (Interagency Performance Evaluation Task Force 2009) | A A B C B C |
| Ford Pinto fires (Birsch 1994; Lee and Ermann 1999) | A B A C C A |
| Challenger space shuttle loss (Rogers 1986) | B B B A A A |
| Texas City refinery explosion and fire (Baker 2007) | B A A C C C |
| Flixborough explosion (Kletz 1988) | B A C A B C |
| Piper Alpha platform fire (Cullen 1990) | B B A C B B |
| Deepwater Horizon blowout (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2011) | B B A C A C |
| Longford gas plant fire (Dawson and Brooks 1999; Hopkins 2000) | A B A C C C |
| Dreamworld amusement ride failure (Coroners Court of Queensland 2020) | A A B C B A |
| Beaconsfield mine collapse (Melick 2007) | B B A B B A |
| Massachusetts gas distribution system failure (NTSB 2019) | B B A A A C |

A strong links, B some links, C weak/no links or links not known
learning experience, use of case based learning and associated learning activities, materials, delivery and structure in relation to the successful attainment of learning objectives, recognition of the importance and relevance of the identified capabilities in professional practice, and overall satisfaction of the experience. Qualitative and quantitative methods will be drawn on where appropriate and designed in parallel with the development of the session. In the medium term, the success of the professional learning for safety sessions will be assessed through assessment activities conducted in the workplace to determine knowledge acquisition, retention, relevance, and application based on the session’s learning objectives and desired outcomes enabling the evaluation of the success of the learning experience and associated approach developed. Borrowing from the technology useability literature, we will seek to determine the extent to which the professional development builds an eudaimonic orientation, i.e., a striving for authenticity, meaning, excellence, virtue, and growth in professional practice (as opposed to motivations linked more strongly to hedonistic or extrinsic material motivations for action) (Hohm et al. 2022). The evaluation may also include feedback from participants’ co-workers and, or managers to allow for a broader organisational perspective of the value of the session and associated learning.

5 Conclusion

The paper has reflected on the need to transition away from PD in safety that is founded on competencies rather than capability, where knowledge is assumed to be transferable and delivered in a discrete package separate from the workplace and associated professional contexts. The challenge for educational designers, however, is that formal professional development is an established and accepted norm in many workplaces. The challenge becomes how to transform this existing dominant approach to move towards professional learning. This paper articulates an approach using the PLD framework to design formal professional learning experiences that are informed by professional learning paradigms and thus support contextualised learning and the ongoing development of professional capability. It has been developed with safety-related non-technical skills for engineers in the hazardous industry in mind and the case study using the framework in this context is presented in detail, but the principles are likely to be applicable in other professional contexts.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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