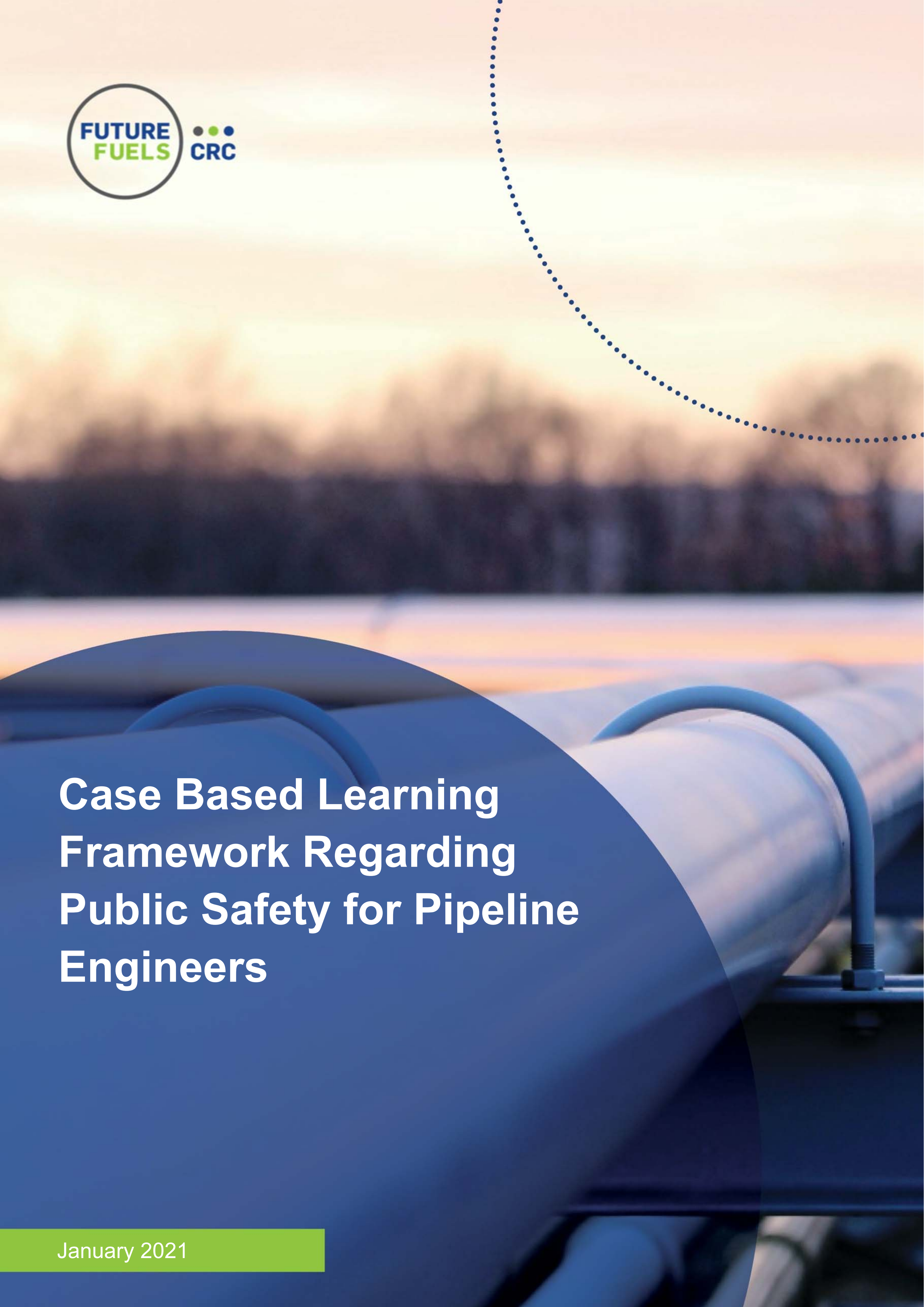

Case Based Learning Framework Regarding Public Safety for Pipeline Engineers

January 2021

Project number: RP2.3-03

Project title: Establishing a Case Based Learning Framework for Pipeline Engineers

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Project Information	
Project number	RP2.3-03
Project title	Establishing a Case Based Learning Framework for Pipeline Engineers
Research Program	Research Program 2 – Social Acceptance, Public Safety and Security of Supply
Milestone Report Number	Milestone 2
Description	A capability framework for professional pipeline engineers has been developed defining six capabilities and 20 elements that support professional practice so as to maintain public safety in a future fuels environment. Drawing on literature regarding professional experience, case based learning options and training evaluation frameworks, three professional learning modules have been scoped for consideration by FFCRC for further development.
Research Provider	RMIT University / University of Canberra
Project Leader and Team	Jan Hayes, Sarah Holdsworth, Orana Sandri, Janice Wong (RMIT), Sarah Maslen (University of Canberra)
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Approved by	Susan Jaques (Sage Consulting)
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Summary of Report

It is essential that the excellent public safety record of the pipeline sector is maintained in a future fuels environment. This requires professional engineers (amongst others working in the sector) to have the skills to be able to make the best professional decisions. Existing professional development activities focus on technical competence but the best decision-making also requires other skills to make the best choices in complex situations of significant uncertainty. In education terms, this is a need for both competence and capability. With that in mind, this project has formulated three professional learning modules to address the following learning objective:

To develop in pipeline engineers capabilities to make decisions that reflect the paramount importance of public safety through the transition to future fuels and into the future.

The proposed options for professional learning modules are shown in Table 1.

Table 1: Proposed professional learning module options

	Title	Description
Option 1a	Discussion and role play (transmission pipeline engineers)	2 x 1.5 hrs sessions face to face or online. The first is a presentation of the San Bruno pipeline failure followed by discussion of lessons to be learned etc. The second is a role play using the critical meeting in the Challenger disaster case between NASA and contract engineers. Participants will role play one of the key characters and reflect on lessons for their own professional practice.
Option 1b	Discussion and role play (distribution system engineers)	Similar to option 1a but using the Massachusetts pipeline system failure case for discussion and the Dreamworld amusement ride failure for the role play.
Option 2	The Pipeline Game	A game/simulation for groups of players (either face to face or online) to make decisions impacting safety through the lifecycle of an imaginary pipeline and see the consequences of their choices play out as the game proceeds. Possible choices to be made and outcomes seen will be developed based on past accident cases. The game/simulation will likely include a facilities modification stage linked to future fuels project work.

The conclusions regarding the best professional learning modules have been reached by working through a professional learning design framework which addresses both the educational aspects of the learning design and the safety-related content.

Based on the learning objective, learning outcomes have been defined and necessary capabilities for pipeline engineers' professional practice developed. The capabilities (shown in Table 2) are drawn from a review of relevant literature and interviews with 41 pipeline engineers.

Table 2: Interview themes grouped by capability

Capability	Interview themes
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes • Choosing with the long term in mind • Dealing with uncertainty
2. Understand norms and values that inform actions	• Using standards • Understanding risk processes and concepts • Making ethical choices
3. Think systematically and understand interconnectedness	• Understanding context • Prioritising actions in complex situations • Applying risk concepts • Taking enough time
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions • Knowing your limitations • Building a good relationship with field people • Building external stakeholder relationships
5. Ground decisions in reality	• Making practical choices • Learning from small failures • Be sceptical of models and calculations • Imagine being there
6. Advocate for action and take responsibility	• Influencing senior management and clients • Standing up for public safety

Case based or experiential learning was chosen as the best pedagogical option for development of these kinds of skills in a professional setting. The report cavasses a range of case based learning options including discussion approaches (discussion case, decision case and problem based learning) and performance based approaches (role play, gaming and game building and mock trials).

Sixteen accident cases were identified and reviewed as possible content for learning, including how each case relates to the desired capabilities.

Methods of evaluation of training effectiveness were also reviewed and principles established.

The next steps are for industry colleagues to review the proposed options and select those that should be taken forward for further development. This will require further approvals via normal FFCRC processes.

Glossary of Terms

Assessment	Determines how well learners/participants are proceeding during an educational experience (formative assessment) or how much they have learned from an educational experience (summative assessment). In best practice, participants are assessed against the intended learning outcomes. Assessments also indicate to participants ‘what they should be learning and how they should be learning it’ (Biggs & Tang, 2011, p. 191).
Capability	The *‘integration* of knowledge, skills, personal qualities and understanding used *appropriately and effectively*—not just in familiar and highly focused specialist contexts but in response to *new and changing* circumstances’ (adapted from Stephenson, 1998, p. 2).
Case based learning	A learning activity that engages learner participants in the discussion of real-world or resemble real-world scenarios or cases.
Competency	The ‘consistent application of knowledge and skill to the standard of performance required in the workplace’ (Australian Skills Quality Authority, 2019, p. 39).
Delivery mode	The format in which a module is presented, for example, online, face-to-face, studio, laboratory, and so on.
Education	While purposes of education vary according to cultural contexts, education generally refers to a normative process that involves the development of knowledge, skills, values, beliefs, and behaviour (Kemmis & Edwards-Groves, 2018). Education can be formal or informal and can include any experiences which shapes the way a person feels, thinks and acts.
Educational approach	The methodology or philosophy of education which underpins choices about the design and delivery of, in this context, professional learning modules. Educational approach is synonymous with pedagogy (see pedagogy definition).
Evaluation	Identifies the impact of the learning experience on a participant’s performance and behaviour (Topno, 2012) to assess if learning outcomes and objectives have been achieved.
Experiential learning	An immersive learning experience that allows for observation, action and reflection. It emphasises the ‘important role experience plays in the learning process’ (Kolb & Goldman, 1973, p. 2).
Informal and formal learning	Informal learning refers to learning that occurs in day-to-day personal or professional practice, while formal learning refers to learning that occurs in purposely designed educational settings.
Inquiry based learning	An educational approach that ‘foregrounds the question rather than the answer and places the locus of learning in the learner, not in the material that can be transmitted by the teacher’ (Goldman, Radinsky, Tozer, & Wink, 2010, p. 297). Rather than teaching answers, inquiry based learning frames initial questions for learners to then investigate through inquiry.
Learning	A relatively permanent change in behaviour as a result of a person’s experiences (Gross, 2010).
Learning activity	The learning experiences designed within a module to support learning that aligns with objectives and outcomes.

Learning objective/s	The learning aim of the formal learning experience, in this case, in the context of professional practice. Specifies a knowledge and/or capabilities gap in current professional practice that learning seeks to fill.
Learning outcomes	What participants will be able to do upon completion of the professional learning module to meet the learning objective/s.
Lifelong learning	'A ubiquitous process, which takes place throughout the lifespan, and across a variety of life contexts' (Field, 2010, p. 89).
Module	A formal educational experience designed to achieve learning objectives and outcomes. A module could be stand-alone or part of a series of learning modules (for example a course or subject).
Pedagogy (& andragogy)	The methodological and philosophical orientation of the education process. Pedagogy refers to this in the context of child learning, while andragogy refers to this in an adult education context. Despite this, pedagogy is commonly used in adult education.
Professional learning	Professional learning reflects the social, material, and situated nature of learning. Rather than learning about skills and knowledge as separate from the workplace, knowledge is constructed as part of the social practice innately intertwines with work practices.
Professional learning design framework	The steps to design learning that is grounded in identified professional needs, learning objectives and outcomes relevant to those needs and the choice of delivery mode and learning activities, assessment and evaluation. The framework ensures that these educational components constructively align and is an important part of learning design that informs the deliberate choices about why, what, when, where and how to teach and the associated learning objectives and outcomes.
Professional learning module	A formal educational experience that aims to develop learning outcomes that are situated in professional work practice contexts and needs. Professional learning modules contribute to life-long professional learning.
Training	Training aims to create competence in a specific practice.

1 Introduction

The generally excellent record of the Australian gas industry when it comes to public safety and security of supply relies heavily on the expertise and judgment of professional engineers. The move to future fuels and the increasing integration of energy networks challenges individuals who work in the pipeline engineering profession to maintain their capacity for making excellent engineering decisions that can impact system integrity.

With this in mind, the aims of this project are three-fold. First, we identify the core professional capabilities required to maintain the industry's public safety record. This understanding is then used to develop a program of case based learning experiences informed by the most appropriate education models to support the best decision-making. The increased complexity of energy networks and introduction of new fuel types (e.g. hydrogen) make this especially relevant. Last, the project considers how the proposed pilot learning experiences can best be evaluated for their effectiveness, including validation of the case based learning framework itself. These activities sit within a professional learning design framework that was established to guide the overall process.

This is the first phase of a larger project to deliver and evaluate the pilot education programs. It builds on case based learning workshops based on the Uberlingen air traffic control disaster delivered as part of EPCRC RP4-23.

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). 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. These skills are collectively known as capabilities. The focus of this project is therefore on capability development. Interviews with 41 pipeline engineers and a review of relevant literature has informed our development of a set of capabilities required for pipeline engineers to make the best decisions for public safety. Various case based learning options are possible and various past accident cases could be used. The research systematically reviewed these to scope up a set of three professional learning modules for consideration by FFCRC for further development.

In most of the research conducted for the FFCRC, major accidents are conceptualised as being driven by organisational factors (Reason, 1997), seeing the actions of individuals as being a function of the organisational circumstances in which they work. This project takes a different view with a focus on developing knowledge, skills and behaviours within the individual. This does not downplay the importance of organisational factors in accidents, viewing individual capability as an essential component of organisational safety as a whole. Rather, in drawing professional learning into focus, we aim to acknowledge and support the role that individuals play in safety management. Our orientation is towards empowerment and excellence, rather than shifting liability towards individuals.

The remainder of the report is structured as follows. Section 2 of the report puts case based learning by pipeline engineers for public safety into the context of continuing professional development for engineers, in particular the value of experiential learning in improving professional practice. Section 3 sets out the learning design framework that guides the rest of the activities of the project in six stages from needs identification, to learning objectives and outcomes development, professional capabilities identification, identification of educational approach, identification of appropriate activities and content material, and finally evaluation strategy.

Learning objectives and outcomes are developed in Section 4. Section 5 then describes the literature review and fieldwork used to develop the framework of six key capabilities for pipeline engineers in making the best decisions for public safety. Section 6 draws on the fieldwork interviews again to articulate what pipeline engineers see as the value of experience, including their own experience and the experience of others, particularly when it comes to accidents. The section also includes a theoretical discussion about the value of formal experiential learning options as a proxy for experience. Section 7 describes the justification for and style of case based learning, concluding which learning styles best address the capabilities developed in Section 5. Section 8 reviews 16 possible accident cases and concludes which ones are best for learning. Section 9 addresses best practice in education evaluation and Section 10 presents the final options for professional learning modules that are suggested for further development.

2 The role of continuing professional development

In this project we recognise professional learning is distinct from education of children and young adults, as well as learning in tertiary education. Professional pipeline engineers, having already completed tertiary training, hold both knowledge and skills developed through formal education, as well as professional experience, hence the term *continuing professional development* is commonly used to capture the role of ongoing training in this professional context. Continuing professional development recognises that changes in the contemporary world demand that professionals continuously learn. Continuing professional learning occurs within both a formal learning context such as professional development and training courses and as part of the day-to-day work practices shared by most employees in that profession (Rooney, Reich, Willey, Gardner, & Boud, 2012). It is increasingly recognised however that separating formal learning from day-to-day work practice learning is not helpful, and that formal and informal learning is best integrated in order to enhance continuing professional development.

Professional development and workplace training are often understood as specific and bounded. In contrast, it is argued that experiences in professional development programs, characterised as formal professional learning courses led by professional bodies or in-house activities, 'limit the potential for making the most of professional learning opportunities within organizations, particularly when considering everyday work' (Rooney et al., 2012, p. 2). This understanding of education and training has resulted in several unhelpful binaries surrounding workplace learning (see Table 3).

Table 3: Binaries that bind (and should be discounted)

Informal	versus	Formal
Experiential Education	versus	Theoretical Training
Physical	versus	Intellectual
Explicit	versus	Implicit
Tacit	versus	Explicit
Pure	versus	Applied
Action	versus	Theory
The Academy	versus	The Factory
Lived	versus	Studied
Classroom	versus	Workplace
Malloch and Cairns (2010, p. 11)		

Learning is therefore more usefully conceptualised as the outcome of an enabled active, intentional interactional engagement in experience and thinking. This is reflected in the two aspects of learning as described by Wenger (1998, p. 263):

> Education, in its deepest sense and at whatever age it takes place, concerns the opening of identities—exploring new ways of being that lie beyond our current state. Whereas training aims to create an inbound trajectory targeted at competence in a specific practice, education must strive to open new dimensions for the negotiation of the self. It places students on an outbound trajectory toward a broad field of possible identities. Education is not merely formative—it is transformative.

We believe that workplace learning or as we refer to it, professional learning, should not be considered and implemented through the binaries of formal and informal learning but be able to provide a 'common currency' and means to 'navigate the set of orthodoxies that permeate education, training, and development' (McCormack 2000, p. 398). This reflects the evolving recognition of workplace learning opportunities, and this has challenged how professional learning is understood and evaluated (Boud & Hager, 2012; Fenwick, 2009; Hager & Hodkinson, 2009).

The nature of professional learning, therefore, must evolve from its narrow conceptualisation of learning about the subject, to learning about practice conceptualised as ‘learning as participation,’ ‘learning as construction’ and ‘learning as becoming’ (Rooney et al., 2012, p. 118). Professional learning must reflect the social, material, and situated nature of learning. Rather than learning about skills and knowledge as separate from the workplace, knowledge constructed as part of the social practice innately intertwines with work practices (Boud & Hager, 2012). As a result, professional learning must recognise the complex nature of *practice* faced by engineers. This context is important to consider when approaching the design of professional learning and associated modules.

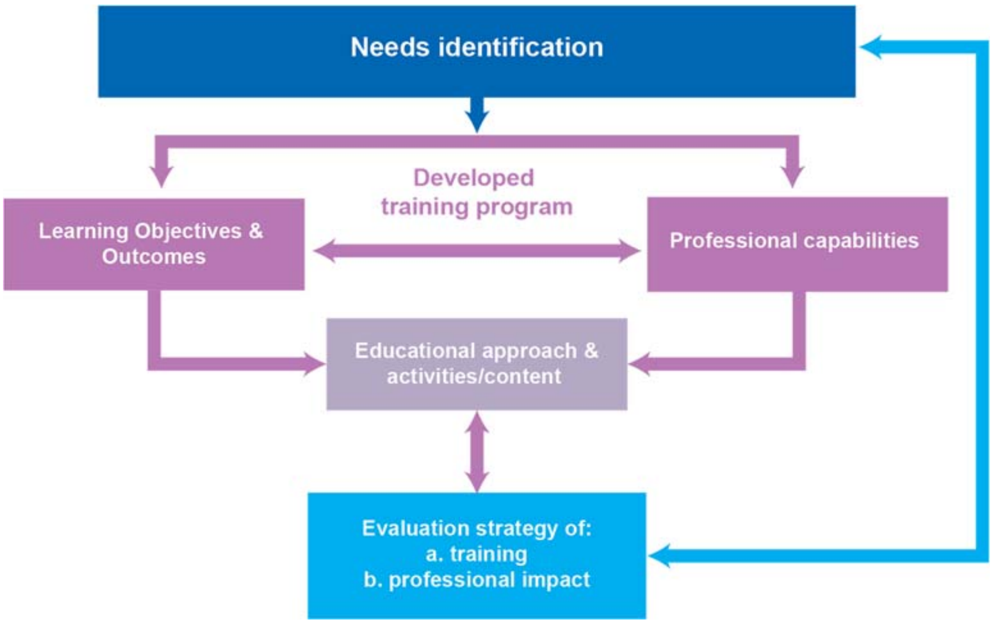
3 Development of education modules for professional learning

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 to align the delivery approach and methods to fulfilling 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.

The process begins in Stage 1 by identifying the professional gaps in knowledge/capability/skill or the aspect of professional practice that needs to be supported or enhanced. The identified professional 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. In good practice education, it is important that learning objectives, capabilities, educational approach/es, learning activities and assessment align to meet the professional needs of the learner cohort (Biggs & Tang, 2011; Holdsworth & Hegarty, 2016).

Two primary methods were used to ground choices about learning objectives and the required capabilities in professional practice. A literature review of pipeline engineering practices for public safety and associated capability needs was completed and fieldwork that included interviews with professional pipeline engineers was undertaken. 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. Following from this, the next stages of the learning design framework include Stage 4, identifying appropriate educational approaches, followed by Stage 5 which involves the design of learning activities and content for the training which align with the learning objectives and support the development of identified capabilities. Stage 6 of the learning design framework involves 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 linear. Figure 1 illustrates the process involved in the development of professional learning modules using the Professional Learning Design (PLD) Framework.

Figure 1: Professional Learning Design Framework (PLD Framework)



This PLD Framework was used to inform the development of education options in this project as is outlined in what follows.

3.1 Stage 1: Needs identification

The first stage in the PLD Framework draws on existing academic and professional evidence to determine the needs, gap in capability and associated competence and skills required by pipeline engineers for decision-making that result in safe work practices. To address the need for and type of education to be developed, drawing on both the literature and professional knowledge, the following reflective questions are explored:

1. What is the objective(s) of the pipeline engineering profession in relation to public safety, including the contemporary context of the field and the kinds of development directions facing 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?

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. The needs analysis in this project is informed by interviews with pipeline engineers in Australia (see Section 5.2) and literature on the pipeline industry (for example, see *Public Safety in the Pipeline Industry: An Engineering Practice Guide* (Czornohalan et al., 2020)).

This stage of the learning design process is described in Section 4 of this report.

3.2 Stage 2: Learning objectives and outcomes development

The second stage in designing a professional learning module 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 module evaluation. Despite the perception that evaluation occurs at the end of the module or after, the gap analysis and identification of learning objectives and outcomes are essential to systemic professional learning evaluation. Kirkpatrick's Training Model 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 organisation outcomes) and bridge the gap between individual initiatives in the workplace post training and desired organisational results.

This then allows for the professional learning module to reflect these needs and evaluate the effectiveness of professional learning against these organisational needs. This further reinforces the need to undertake this organisational needs analysis and establish the professional learning objectives at the beginning of the PLD process.

This stage of the learning design process is detailed in Section 4 of this report.

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. With respect to this work, the identification of capabilities that underpin safety related behaviours for engineers who work in design and operation of high pressure energy pipelines and associated facilities is vital. Developing key capabilities is an essential component of professional learning and the associated development of the professional learning module. As such, a capability framework was developed to inform the professional learning module's objective and to promote the development of shared skills, behaviours and competences required within the pipeline industry for the continuing delivery of safe, high-quality, and effective energy systems.

In this context, a competency is understood to be the 'consistent application of knowledge and skill to the standard of performance required in the workplace' (Australian Skills Quality Authority, 2019, p. 39). While a capability is the 'integration of knowledge, skills, personal qualities, behaviour, understanding and values used appropriately, effectively and confidently, not just in familiar and highly focused specialist contexts but in response to new, complex and changing circumstances' (adapted from Stephenson, 1998). For the purpose of this research interviews with professional pipeline engineers were conducted to identify the key capabilities that reflect the principles identified in Stage 1 that provide the foundation and rationale for the behaviours, actions, explanation and accountability of pipeline engineers and their practice. This stage of the learning design process is detailed in Section 5 of this report.

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 approach or orientation of the education module (pedagogy/andragogy), this then informs subsequent learning and teaching activities which can be used within the module, appropriate curriculum/content, and assessment methods. Kreber (1999) recognises three types of knowledge domains that must be considered in the development of professional learning and associated programs:

- Instructional knowledge, which includes knowledge about teaching strategies, lesson planning, training behaviour, learning objectives, and training session assessment strategies.
- Pedagogical knowledge is what we know about how learners learn. This informs instructional knowledge and includes an understanding of learning style, cognitive style, the cognitive and affective processes involved in learning, and group dynamics.
- Curricular/content knowledge is an understanding of the knowledge we use to develop the goals and purposes of courses that inform the curricula within them.

This stage of the module's development requires reflection on the pedagogy informing the session. Pedagogy also informs what education should do, and for whom, and why (what problems education does, and should, address). On a broad level, pedagogy shapes the relationship between learners and teachers. A simple example of the influence of pedagogy on the education module is the role of the instructor in the education process. In a teacher or instructor led pedagogy (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 pedagogy, 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 stage of the learning design process is detailed in Section 6 of this report.

3.5 Stage 5: Identification of appropriate activities and content material

The fifth stage of the PLD Framework involves identifying the learning activities suitable for developing the identified capabilities, learning objectives, and outcomes, along with content materials such as case studies to support the learning process. These activities are situated in the educational approach taken. 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 on training content, share experiences, and develop their 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 when considering the learning objectives of professional pipeline engineering training for public safety, where the purpose is to develop capability and apply learning to enhance existing practices. There are many learner-centred activities, however, a widely used activity style, which is the focus of this project, is experiential case based learning that explores learner perspectives, develops capabilities, and transforms perspectives through exploratory tasks designed around existing professional cases. The content material that the modules will draw on are past accident cases. This stage of the learning design process is detailed in Sections 7 and 8 of this report.

3.6 Stage 6: Evaluation strategy

A critical aspect of workplace learning is its evaluation, which identifies the impact of professional learning on an employee's performance and behaviour; this is vital to understand given it reflects an identified need and through education and the investment in the development of employees' skill development seeks to address that deficient in an organisation (Topno, 2012). Sound professional education begins with an organisational gap analysis and evaluates the resultant deliverable. As such, evaluation is best understood as a systematic process to determine the module's value against a developed criterion of comparison. Importantly, evaluation should not only determine whether participants have developed new knowledge and skills, but also whether they can implement this learning within their respective workplace post-completion (Boulmetis & Dutwin, 2000; Philips, 1996). This stage of the learning design process is detailed in Section 9 of this report.

4 Needs analysis and subsequent learning objectives and outcomes for public safety

As outlined in the PLD Framework, the starting point for the development of professional learning modules is to first draw on evidence from research and practice to define the professional needs that the professional learning module aims to address. This section outlines what the professional needs are for engineers regarding public safety, drawing on existing research and established professional practice principles. Drawing on this evidence of professional learning needs, subsequent learning objectives for the professional learning modules and learning outcomes are then presented.

4.1 Taking action for public safety

The professional practice of pipeline engineers has an impact on public safety. The impact is not immediately visible for several important reasons. Firstly, in Australia, there has never been a major failure of a gas transmission pipeline in an urban area. No member of the public has ever died because of the decisions of an engineer working in the high pressure gas sector. This is an excellent record (and one that is much better than is seen internationally) and yet the absence of failures means that the link between decisions and potential poor outcomes is not always clear. The second relevant factor is the complexity of the context in which engineering decisions are made. Choices made today are embedded in systems that may not yet physically exist and the implications may not be apparent for decades to come. In addition, impacts are likely to be geographically removed from where key decisions were made. A further factor related to complexity is that one poor choice will rarely lead directly to a poor safety outcome. Engineered systems are designed with multiple layers of protections in place so that any failure is effectively caused by a cumulation of faults and failures, rather than any single action or choice.

The safety literature provides an obvious starting point regarding the behaviours required from engineers to prevent accidents, particularly the literature related to learning from accidents. In the wake of an aircraft crash, chemical plant fire or explosion, pipeline rupture or oil well blowout, major investigations are undertaken, often with a focus on who was at fault and should therefore be held responsible (Dekker, 2007). More useful for ongoing disaster prevention, significant resources are also invested in determining the factors that contributed to accident causation (Carroll, Rudolph, Hatakenaka, Wiederhold, & Boldrini, 2001; Cedergren & Petersen, 2011). Such findings are documented in publications released into the public domain by standing investigating agencies (e.g. reports produced by the National Transportation Safety Board such as NTSB (2011)) and especially appointed commissions (e.g. Baker, 2007; National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, 2011) as well as academic publications (e.g. Hopkins, 2008; Snook, 2000). Recommendations typically lead to updates to procedures, standards and training but to assume that this is all that is required to prevent further accidents is to severely limit learning opportunities given the focus on competencies alone.

The expansion of the search for lessons learned from accidents has moved in recent decades to an organisational focus. In this way of thinking about accident causation (and so what lessons may be learned to prevent future accidents), those who work in organisations are cast as ‘passive actors’ whose behaviour is determined by the organisational environment in which they work. One obvious illustration of this is the well known Swiss cheese model where the unsafe acts of individuals are caused by workplace factors such as the physical environment and shift patterns which are themselves determined by organisational factors such as budgets and organisational structures (Reason, 1997). Free will has no role in this model which was produced significantly in response to safety theory at the time (in the early 1990s) when the focus on behaviour based safety approaches framed safety as an individual choice. With this focus on the organisational, there are few lessons learned from accidents that are formulated as weaknesses in professional practice. The few exceptions include the need to seek out weak signals of trouble (Haddon-Cave, 2009), to be aware that personal and process safety require different solutions (Hopkins, 2012) and the need for mindfulness of potential consequences when making decisions (Hayes, 2012). More details about organisational learning from cases are included in Section 7.3.

In our previous work, we had also investigated desired behaviours from engineers in the interests of public safety (see FFCRC project RP2.3-01 Pipeline Engineers Code of Practice). Based on consultation with a group of experts we produced a document titled *Public Safety in the Pipeline Industry: An Engineering Practice Guide* (Czornohalan et al., 2020) that presented a set of five individual practice principles and five aspects of safety-oriented culture as shown in Table 4 below. The individual practice principles are behaviours to be encouraged in the interests of public safety. This guide also makes clear that the best safety outcomes result from a combined focus on both individual behaviours and organisational cultural characteristics that support the desired behaviours.

Table 4: Safety principles from Engineering Practice Guide (previous FFCRC project)

Individual practice principles	Safety-oriented culture
Talk about public safety	Reward the right behaviours
Focus on the long term	Advocate for safety in outsourced work
Speak up for safety	Have the right structure so bad news can travel up
Think beyond compliance	Encourage and act on hazard reporting
Work only within your area of competence	Create opportunities to share stories

Drawing on relevant literature as described above and current industry needs, the following learning objectives and outcomes have been developed.

4.2 Learning objective

The considerations above give rise to the following learning objective for this project:

- To develop in pipeline engineers capabilities to make decisions that reflect the paramount importance of public safety through the transition to future fuels and into the future.

4.3 Learning outcomes

Based on this objective, and the considerations above, the following learning outcomes have been defined for this project:

- To apply lessons from previous accident cases to individual professional practice so as to maintain the industry's public safety record into the future including through the transition to future fuels.
- To support effective decisions regarding public safety.
- To understand and explain the link between professional practice and public safety.
- To know when and how to act in the interests of public safety.

Having established the learning objectives and outcomes, the next stage in the learning design framework is to determine the relevant capabilities that support these outcomes.

5 Capabilities for public safety

Following the identification of professional needs and the learning objectives and outcomes for the learning module, the next stage of PLD is to determine what engineers need to know and do in order to operate safely, what form of knowledge this is and how it is best framed to provide an input to consideration of the best types of learning to acquire the necessary knowledge.

This involves thinking deeply about the nature of knowledge that drives safety behaviours and how such knowledge links to teaching and learning. Good practice educational design is founded on learning objectives designed to nurture relevant capabilities. Capability is an individual's ability to integrate knowledge, skills, personal qualities and understanding, and to use these appropriately and effectively, not just in familiar and highly focused specialist contexts, but also unfamiliar situations.

This section draws on a wide range of disciplines on the subject of safety capabilities for pipeline engineers and reports on fieldwork to collect the views of experienced engineers on this topic.

5.1 Literature on engineering capabilities for safety

There is a broad agreement in the professional literature on the need for frameworks to support engineering best practice. Specific stakeholder groups have proposed competency frameworks, lists of knowledge elements and similar all with a view to supporting excellence in engineering behaviours. These are canvassed here along with the global work on capabilities undertaken by the UN in sustainability, which seeks to create professionals able to address social, economic, and environmental issues currently facing the world.

5.1.1 Safety literature

When it comes to safety matters, the prevailing discourse in engineering is about risk. While risk has many definitions (Aven, Renn, & Rosa, 2011), it is often used in the general population to mean something akin to danger (Hopkins, 2005). In engineering, risk means something much more specific. A typical engineering definition focuses on two dimensions: 'the extent of the consequences; and the probability that the consequences will arrive' (Ale, 2002). Thus, engineers address safety via risk in a technical manner, treating it as an objective quality of a specific system that needs to be managed to avoid rare but potentially catastrophic events. A typical example is Pasman and Rogers (2018) who claimed, 'the purpose of a risk assessment is to make a decision whether the risk of a given situation is within an acceptable range, and, if not, how we can reduce it to a tolerable level'. As such, engineering risk assessment is a formal decision-making process in which the steps in logic and final outcomes are documented for future reference. In the context of Australian pipeline engineering, these concepts have been refined and set out in AS2885 as the key repository of risk-based safety knowledge for the profession.

In the language of risk, the artefacts in place to manage risk are described as 'risk barriers' (Fisher, Greenfield, Flotaker, Stokke, & Pitblado, 2017; Turner, Hamilton, & Ramsden, 2017), 'risk controls' (Amyotte, Irvine, & Khan, 2018; Turner et al., 2017), or even 'protective measures' (Lombardi & Fargnoli, 2018; Volberg et al., 2017). In all cases the language emphasises the goal of controlling risk and preventing harm to people and/or the environment. Some risk controls are engineered systems — piping, valves and instrumentation — but they are all designed and operated by people. Actions required at work for systems to be designed and operated safely are typically recorded in a formal safety management system (McGuinness & Utne, 2014; Noh & Cho, 2010). The AS2885.3 requirements for a pipeline integrity management plan broadly follow this approach.

This way of managing safety owes much to principles of quality management formulated in the mid 20th century based on the principle that consistent action leads to consistent outcomes (Defoe & Juran, 2010). People are not considered directly but rather seen as another system component that needs to be controlled. If people are considered, they are seen as individual free agents who make various kinds of mistakes and errors (Bieder & Bourrier, 2013; Reason, 1990). A common assumption in engineering is that all errors 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 & Dien, 2013). In practice, errors are often the result of poor system design, inadequate working environment or conflicting priorities (Reason, 1990). Something that is seen as a poor choice in hindsight (especially after an accident) can be something that, at the time, is just needed to get the job done.

In this way of thinking about safety, 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. As research within the interpretivist tradition emphasises, formalised forms of knowledge do not capture knowing in its entirety (Klein, 1998; Knorr-Centina, 1999; Wenger, 1998). Rather, codified knowledge such as that captured in standards 'rests on an uncodifiable substrate that tells us how to use the code' (Duguid, 2005, p. 111). As a result, in complex hazardous systems, rules do not completely specify the necessary action in every case. In more plain language, it is often said by senior pipeline engineers that AS2885 'is not a cookbook' (Hayes, 2015). 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 & O'Leary, 2000). If safety imagination is not ensured via learning technical principles, then what other forms of knowledge are needed? Feldman and Feldman (2006) argue that collective knowledge is not an object, but a practice. This is especially relevant in a professional context as research has shown that, for experts, practice drives theory when learning, not the other way around (Dreyfus & Dreyfus, 1986; Flyvbjerg, 2001; Mauelshagen, Denyer, Carter, & Pollard, 2013; Sullivan, 2005).

This distinction between knowledge as object and knowledge as practice and the implications for professional learning is not unique to engineers learning about safety in hazardous industries. The education literature has a long history of debating similar issues, most recently in the context of increasing pressure on the tertiary sector to produce 'job-ready' graduates (Hadgraft & Muir, 2003). While use of the terms varies, in Australia, this distinction is characterised by a defined difference between competence and capability. A competent individual is able to 'perform prescribed tasks or skills to a defined standard' (Holdsworth & Thomas, 2020). Learning becomes 'the cumulative acquisition of narrow and fragmented skill sets' (Holdsworth & Thomas, 2020). Many of the skills commonly seen as critical in engineering have been decomposed in this way. The circumstances in which such skills are applied 'have a certain degree of routinization or repetitiveness about them, allowing the skills to be rehearsed and mastered separately. For these reasons, it makes sense to treat them, at least in the context of initial training, as distinct skills' (Sadler, 2013, p. 16).

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. The education literature again provides the language to describe what is needed. Capabilities are 'holistic sets of attributes and skills that empower graduates to act in differing contexts' (Sandri, 2010). When teaching and learning becomes about developing capabilities, these activities take on the sense of 'human practice, not just as a repertoire of competencies to be mastered, transmitted or shared' (Hogan, 2003, p. 209). Competence is instrumental, has value for where it leads, aims to be a means to a specific end whereas capabilities have intrinsic value—'a normative ideal of a worthy life' (Lozano, Boni, Peris, & Hueso, 2012, p. 139). In this way, ethics is also central to a capability approach to considering knowledge and learning.[1]

Despite the push in the academic literature towards knowledge as practice, the professional literature remains focused on knowledge as object and so inherently assumes that behaviours are driven by competence. There are several frameworks available regarding process safety competence published by professional and industry bodies. The Institution of Chemical Engineers Safety Centre have published the ISC Process Safety Competency Guidance (The Institution of Chemical Engineers, 2018) which sets out 18 topics. These are shown in Table 5 linked to the ISC's six functional elements of process safety which collectively define what process safety is.

The accompanying supplementary guide (The Institution of Chemical Engineers, 2019) includes a competency matrix which defines the level of proficiency suggested for each topic according to job role. It also sets out what the specific development activities for each element consists of for each proficiency level and topic. Activities are set out in the three areas of learning through experience, learning through others or formal education. Most of the material addresses technical competency specifically although there are some 'softer' skills mentioned in the leadership topic.

[1] These definitions of competence and capability are commonly accepted in the Australian education literature. Some researchers report that 'capability' does not readily translate into other European languages and so is not used. Whatever the reason, in European education literature recent studies tend to focus on extending the definition of competence to include aspects of capability, rather than seeing these as different things. Whilst definitions vary, the acceptance of a need to broaden graduate and professional education is a common theme.

Table 5: IChemE Safety Centre competency topics

Element	Topic
Culture	Safety leadership commitment, responsibility and workplace culture
Knowledge and competence	Process safety concepts Hazard identification and risk assessment Hazard awareness specific to the operation
Engineering and design	Safety in design Asset integrity Codes and standards Management of change
Human factors	Human factors
Systems and procedures	Systems, manuals and drawings Process and operational status monitoring and handover Contractors and supplier selection and management Safety systems of work Project delivery Management of major emergencies and emergency preparedness Incident reporting and investigation
Assurance	Legislation and regulations Audit, assurance, management review and intervention

In a similar way, the US Center for Chemical Process Safety (CCPS) has defined a set of elements that, together, describe a risk-based process safety management system (Center for Chemical Process Safety, 2007). As shown in Table 6 , there are four foundational pillars and 20 elements. Process safety competency is one of the elements and CCPS see this as intimately intertwined with many of the other elements on this list. Another CCPS publication (Center for Chemical Process Safety, 2015) provides a framework for organisations to develop their own process safety competency matrix by job role and organisational level, based on the specific activities and hazards present in their business. This then allows targeted training for individuals in process safety matters based on the required competencies.

Table 6: CCPS Pillars and process safety elements

Pillar	Process safety element
Commit to process safety	Process safety culture Compliance with standards Process safety competency Workforce involvement Stakeholder outreach
Understand hazards and risk	Process safety knowledge Hazard identification and risk assessment
Manage risk	Operating procedures Safety work practices Asset integrity and reliability Contractor management Training and performance assurance

	Management of change Operational readiness Conduct of operations Emergency management
Learn from experience	Incident investigation Measurement and metrics Auditing Management review and continuous improvement

Other organisations with a key interest in process safety have published similar competency frameworks including the UK Health and Safety Executive (UK Health and Safety Executive, 2007a, 2007b) and the European Process Safety Centre (2013).

It is of note that these frameworks are all based in competence (and often very technical competence), rather than the capabilities approach taken in this project.

In summary, neither the academic safety literature nor industry-based material about process safety competencies address professional capabilities to support the best safety decision-making for public safety.

5.1.2 Engineering practice literature

Also of potential relevance are engineering capabilities more broadly. Major reviews of engineering education and the engineering profession in several countries over decades have emphasised the extent to which the human side of the profession, where decisions are linked to uncertainty and are fundamentally value-driven, has been underemphasised in favour of the scientific (Duderstadt, 2010), particularly since the 1950s (Edström, 2018). This directly impacts the way in which practitioners, educators, and students talk about the profession (Archer, 2008) including the way in which engineering education is framed. Particularly within engineering education circles, the dominance of scientific discourses and the associated links to narrowly defined technical competencies has led to calls for the 'unshackling [of] engineering from its present constraints' (Johnston, Lee, & McGregor, 1996) to the extent of proposals for establishment of undergraduate, pre-professional degree programs such as a Bachelor of Arts in Liberal Studies in Engineering (Bucciarelli & Drew, 2015; Christensen, 2015). For the purposes of this project, there is not a strong tradition of educating engineers for capabilities (in addition to competencies) that we can draw on.

In practical terms, studies have shown that engineers spend only around half their work time on purely technical activities (Trevelyan, 2014). Bucciarelli's (1988) account of engineering design captures how technical artefacts are only 'capstones of social exchange and negotiation'. Instead, the engineering design process involves storytelling, which is part of the social act of arriving at a solution, and the ongoing work to develop a common language of engineering and what it means to be part of a design team (Lloyd, 2000).

This small literature on engineering professional practice and the extent to which it depends on issues beyond the technical is not reflected in the literature on engineering professional development which focuses entirely on the technical. This is a major research gap that this project goes some way towards filling, at least in the context of pipeline engineers and public safety.

There is a direct link between what the engineering profession believes to be core skills and knowledge and current moves towards engineering registration. In Queensland, practicing engineers are required to be registered with the Board of Professional Engineers Queensland (BPEQ). Similar legislation has been introduced in Victoria and will take effect from 2021 (Engineers Australia, 2020). A common way of demonstrating the required competency to achieve registration is to become a Chartered Engineer under the requirements of Engineers Australia. The defined competency standards to achieve chartered status are generic across all engineering disciplines and are divided into four units and 16 elements as shown in Table 7.

Table 7: Engineers Australia competency framework

Units	Elements of Competence
Personal commitment	Deal with ethical issues Practise competently Responsibility for engineering activities
Obligation to community	Develop safe and sustainable solutions Engage with the relevant community and stakeholders Identify, assess and manage risks Meet legal and regulatory requirements
Value in the workplace	Communication Performance Taking action Judgement
Technical proficiency	Advanced engineering knowledge Local engineering knowledge Problem analysis Creativity and innovation Evaluation

The elements take the form of desired behaviours and some relevant topics that provide broad guidance in the context of this project. Of most relevance are the units regarding personal commitment and obligation to community. The seven elements listed here have been considered in developing capabilities for this project. The four items listed under the value in the workplace unit are topic areas, rather than specific competencies or capabilities. The accompanying material is broad ranging but quite high level and so is not particularly useful in the context of the project. The last unit (technical proficiency) deals with technical competence issues.

5.1.3 Sustainability education

Education for and about sustainability is a very active area in the education research literature. Given that organisational safety is one aspect of sustainable operations for industrial organisations, it is instructive to draw on this literature for what it says regarding required capabilities for effective action. The evolving sustainability education movement has been considering the role of competencies and capabilities for the past two decades. Reflection associated with the identification and definition of sustainability competency and associated key competencies to embed into the design and teaching of academic programs has involved a range of researchers (Baartman, Bastiaens, Kirschner, & Van der Vleuten, 2007; Voorhees, 2001). Much of this was captured in Wiek, Withycombe and Redman's (2011, p. 204) seminal paper, which argued that:

> …key competencies provide an explicit and commonly shared framework for developing distinct and recognizable profiles of the academic field, the schools, the graduates, the professions, and so forth…

While much of the discussion of sustainability competencies has come from the northern hemisphere, there is considerable relevance to Australia, especially in the context of education and training quality frameworks. The literature includes many summaries of key sustainability graduate competencies and capabilities required (Barth, Godemann, Rieckmann, & Stoltenberg, 2007; Frisk Redman & Larson, 2011; Sandri, 2010; Thomas & Day, 2014; Wiek et al., 2011). The difference between competence and capability discussed in Section 3 of this report recognises a key difference in meta 'abilities'.

Despite the lack of a common language, there is broad consensus that capable graduates should be able to:

- Think systemically and understand interconnectedness
- Use long term, foresighted reasoning, especially in the face of uncertainty
- Advocate for and be involved in action
- Act in a way that is grounded in ethical considerations
- Work effectively in multidisciplinary and multi stakeholder teams.

These are reflected in the eight competencies published by UNESCO in 2017 (Rieckmann, Mindt, & Gardiner, 2017) which reflect consensus within the global academic community:

- Systems thinking competency: the abilities to recognise and understand relationships; to analyse complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty.
- Anticipatory competency: the abilities to understand and evaluate multiple futures—possible, probable and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.
- Normative competency: the abilities to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.
- Strategic competency: the abilities to collectively develop and implement innovative actions that further sustainability at the local level and further afield.
- Collaboration competency: the abilities to learn from others; to understand and respect the needs, perspectives and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.
- Critical thinking competency: the ability to question norms, practices and opinions; to reflect on own one's values, perceptions and actions; and to take a position in the sustainability discourse.
- Self-awareness competency: the ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires.
- Integrated problem-solving competency: the overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the above-mentioned competences (Rieckmann et al., 2017, p. 10).

These capabilities align closely with the set of individual practice principles developed independently for the pipeline engineers code of practice as described in Section 4.1 and so provide the most relevant theoretical framework to guide this project.

5.2 Engineers' views on safety capabilities

With so little theoretical material to inform the development of professional learning, a fieldwork component to the research was introduced. To support development of the learning design aligned with the framework described in Section 3, we have consulted with professional pipeline engineers to gather their views on capabilities that are important for public safety and also their ideas on the best training options.

5.2.1 Fieldwork method details

The target population for the interviews is practicing and recently retired pipeline engineers. The purpose of the interviews is to build an understanding of differing views on engineering capabilities necessary for excellent safety decision-making. This includes investigating the most important qualities for engineers to have in order to make the best decisions and their experience in professional development / workplace training to support development of such skills.

Interview participants were recruited in three ways:

- By direct invitation to pipeline engineers known to the research team as a result of a decade of previous research with this group,
- Via email invitation issued through the FFCRC, and
- By circulation of the invitation email to colleagues by people who received it from the research team.

Seventy five invitations were issued by us directly. Fifty three responses were received (including eight from people who heard about the project from colleagues). Forty one interviews were undertaken by video call (since the project was undertaken during the COVID-19 pandemic with travel restrictions in place). Interviewee demographic information is shown in Table 8.

Table 8: Interviewee demographic details

	Number of interviewees	Proportion of interviewees[2]
Gender		
Male	35	85%
Female	6	15%
Discipline		
Mechanical / Materials	26	63%
Process / Chemical	8	20%
Civil / Structural	6	15%
Electrical / Instrumentation / Systems	1	2%
Experience		
< 5 years	2	5%
5 - < 10 years	3	7%
10 - < 20 years	17	41%
20 - < 30 years	10	24%
30 years or more	9	22%
Total	**41**	**100%**

Interviews were conducted in a semi structured way with the conversation significantly driven by the responses of interviewees. Conversations were guided by the following questions:

1. Can you start by telling us about your professional experience? How long have you worked in the pipeline sector and what is your current role?
2. I'm sure during your career you have made decisions that had high stakes for safety and seen such decisions made by others. Thinking about a case that you have seen recently, what do you think are some of the most important skills or approaches in making such decisions?
3. Some decisions are made in the office and yet their impact might be a long way away in space and time. Do you think this poses particular challenges for making the right choice? Can you give me an example?
4. We know that decisions that can seem pretty banal in the office can have catastrophic consequences in the field. Do you think it's hard to keep this connection in mind? Can you give me an example?
5. Some decisions have to be made with incomplete information. How do you deal with this kind of uncertainty? Can you give me an example?

[2] Percentages may not add up to 100% due to rounding.

6. Engineering choices are not made in isolation—there are always other people involved—do you have ways that you try to influence safety outcomes when you are working as part of a team? Can you give me an example?
7. Do you use different strategies when dealing with people who might have more influence such as clients or more senior managers? Can you give me an example?
8. Engineering is in some ways a very technical profession. What qualities do you think are necessary for a good engineer, besides technical competence?
9. Do you see an ethical dimension to engineering decision-making? What professional qualities do you think help drive the right choices? Can you give me an example?
10. What other factors drive decision-making and what qualities help engineers make the right choice? Can you give me an example?
11. In your experience, how do these attributes link to current professional development / workplace training? What do you think would be a better approach?

Interviews were recorded with permission and transcribed for analysis.

Ethics approval for the project was obtained from RMIT's Design and Social Context College Human Ethics Advisory Network in July 2020.[3] This approved ethics application was subsequently registered with University of Canberra.[4]

The study was regarded as 'low risk' because participants were not placed at any foreseeable risk. The only personal information collected about individual participants was their name, organisational position and contact details. The primary focus for data collection from the interviews was the perceptions of individuals about important engineering capabilities for safety decision-making and associated professional development.

All interview recordings and transcripts were assigned a project code and cannot be attributed to specific individuals. All interview data has been treated as confidential. No interview data has been discussed or published, or will be, which could identify an individual participant. Industry partners of the FFCRC do not know the identity of individual participants although in some cases they may be able to guess given the relatively small pool of individuals involved.

5.2.2 Analysis of field data

Recordings of interviews were professionally transcribed and then coded in NVivo. An inductive approach was used to develop themes about capabilities. Initially, 32 themes were identified as shown in Table 9.

Table 9: Initial capabilities drawn from interviews

Initial capabilities list	
1. Action oriented	17. Knowing your limitations
2. Attention to detail	18. Lifelong learning
3. Be curious	19. Making ethical choices
4. Build networks or seek others' opinions	20. Mentoring
5. Building a good relationship with field people	21. Prioritising actions in complex situations
6. Building external stakeholder relationships	22. Problem solving
7. Communicating with peers	23. Scenarios not silos

[3] RMIT University Human Research Ethics Committee Project No. 23458 approved 28 July 2020.
[4] University of Canberra Human Research Ethics Committee reference 20204739.

8. Critical thinking	24. Standing up for public safety
9. Dealing with uncertainty or being sceptical	25. Taking enough time
10. Flexibility	26. Taking responsibility
11. Imagine being there	27. Understanding context
12. Imagining other perspectives	28. Understanding legal obligations
13. Imagining the future or taking a long term view	29. Understanding risk concepts and processes
14. Imagining worst case outcomes	30. Understanding why
15. Influencing senior management or clients	31. Using standards
16. Knowing what has gone wrong before	32. Work in a team

These themes were then grouped into six overarching capabilities informed by drawing on the literature described in Section 5.1. The number of themes was also rationalised into a final list of 20 items. The results are shown in Table 10. It should be noted that several interviewees are closely involved with future fuels aspects of the pipeline industry. There is no difference in capabilities required for public safety decision-making between the base business and the future fuels environment.

Table 10: Interview themes grouped by capability

Capability	Interview themes
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes • Choosing with the long term in mind • Dealing with uncertainty
2. Understand norms and values that inform actions	• Using standards • Understanding risk processes and concepts • Making ethical choices
3. Think systematically and understand interconnectedness	• Understanding context • Prioritising actions in complex situations • Applying risk concepts • Taking enough time
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions • Knowing your limitations • Building a good relationship with field people • Building external stakeholder relationships
5. Ground decisions in reality	• Making practical choices • Learning from small failures • Be sceptical of models and calculations • Imagine being there
6. Advocate for action and take responsibility	• Influencing senior management and clients • Standing up for public safety

Details of each of the interview themes are provided in the following sections divided according to the overarching capability.

In addition, interview data discussing other topics was also coded for analysis, including on the following topics:

- Benefits of experience
- Benefits of field experience
- Benefits of case studies
- Where stories come from.

Some of this data is described in Section 6.1.

5.2.3 Use long term, foresighted reasoning, especially in the face of uncertainty

Four themes in the interview data address the need for pipeline engineers to think in the long term, particularly in cases where uncertainty is high. These themes are:

- Imagining worst case outcomes
- Choosing with the long term in mind
- Dealing with uncertainty.

They are discussed in turn below.

5.2.3.1 Imagining worst case outcomes

Many interviewees emphasised the importance of understanding the potential consequences when making decisions. As one interviewee described, 'It's kind of like you're almost trying to run a hypothetical disaster analysis with every decision that you make.' (I06) As another interviewee explained, he uses the prompt 'then what' to work through options all the way through to the ultimate consequences. 'The two words … "then what". If I do this, then what? Oh, that might happen. If that happens, then what? That's a method I've used to help me think through the options. … Not being able to envision that the decision might have a bad outcome has caused a lot of problems.' (I07)

But keeping consequences in mind is difficult. Poor choices in highly routine aspects of an engineer's work can have serious consequences for example 'as an integrity engineer you've always got to keep in mind is that a … missed line on a spreadsheet could mean the difference between a leak and not having a leak.' (I35) 'You do it day in and day out, so you just eventually may become complacent and just not really understand what the decisions you are making may impact in the future.' (I09) especially when 'some of the engineers are not fully understanding the consequence of that because they have not seen it with their naked eyes, just on some documents.' (I14) A key capability for good decision-making is therefore 'you've got to have the big picture of understanding what [failure] means in terms of the community consequences.' (I17)

Some interviewees learn about this link between their work and the potential for disaster by personal involvement in an accident. As one interviewee explained, 'I think about my own experience and the reason why I've ended up doing a risk job is because I do have lots of operational experiences where people were killed and gas was released lots of times in various unplanned ways and so for me, like, I find my decision-making around that very different to some of the engineers that … haven't experienced an incident themselves.' (I26) Another interviewee also had personal experience of disaster, telling us, 'I was involved in a fatality incident, so you see firsthand what happens and you see the consequences of something failing, and it lasts with you for a long time … It scared the bejesus out of me, and I started paying attention a lot more after that, I tell you.' (I28) There is also significant learning to be had by people who have had these experiences sharing them with others. 'When you hear those firsthand accounts of people that were there at Longford when it blew up and things like that, that really sits with you. And it's a way of getting the experience or sort of living through the experience that that person might have had without having to have it yourself.' (I01)

Others have field experience of a different kind. Sometimes even planned activities can emphasise the energy contained in the system. As one interviewee explained, 'being in the nearby vicinity—or even seeing and hearing and feeling gas blowdown, and just understanding the power that is there and the energy that is released when you blow down a pipeline' (I23) is enough to cement the link between engineering decisions and worst case outcomes.

But not everyone has experienced such things and so past accident cases have a key role here. Experienced engineers note ‘pipeline engineers … live in a very low frequency but very high consequence world. That’s the world we live in. So thinking of … San Bruno and those sorts of things, yeah, of course they’re in my mind because that’s what we’re dealing with.’ (I15) Cases such as San Bruno are a ‘good indication of worst case scenario that could entail with a failure of a high pressure gas pipeline.’ This is important when estimating risk because ‘to have those things in the back of your mind helps to visualise the impact.’ (I04)

Talking about the worst case consequences also helps communicate the risk to others. This includes people from outside the pipeline sector such as property developers. ‘The developer people who come in would be bolshy, and then they realise that you could kill lots of people, and they’d become very cooperative. … Nobody wants to be responsible for causing serious harm. ... Once people realise that these risks are real, they genuinely want to work to keep the risk at a manageable level.’ (I05)

Talking to professional colleagues, pipeline sector disasters are important but interviewees also noted that accidents from other sectors as ‘a really good reminder to bring up on what the sort of things that can occur.’ (I21) Useful examples raised by interviewees included Piper Alpha, Deepwater Horizon, Longford and aviation sector cases.

Being able to articulate the ultimate consequences of a pipeline failure, not just in technical terms but to acknowledge that pipeline engineers make choices that impact people’s lives, is an important aspect of the first capability. Ultimately thinking about the worst case consequences makes the impact of decisions more real. As one interviewee put it, ‘if you bring the consequences or the decision close to your heart or your head, you have more vested interest, more skin in the game. … decisions made where you have skin in the game are more important and made with better depth than if it’s just—if it doesn’t matter, if your decision doesn’t matter.’ (I08)

5.2.3.2 Choosing with the long term in mind

Taking a long term view in the interests of public safety involves more than just being able to imagine worst case outcomes. Another key theme requires that decision choices are then made with those consequences in mind. As one interviewee explained, ‘just because we haven’t seen some serious failures here in Australia, doesn’t mean that they will not happen. As engineers, we should always think that they may happen, and we prevent them.’ (I39)

As one interviewee explained, ‘it would be easy to fall into that trap of saying, “well, I made the right call for now, but what does that call mean in 10 years’ time?” Would that poor decision be at the root of an event that happens far enough into the future that I can’t imagine it?’ (I01) As another interviewee put it, this has to be top of mind when considering repairs: ‘my worry is “are we doing enough right now to make sure that this isn’t a regular occurrence?” And in maybe the next five to 10 years we’re not getting a whole load of these types of failures.’ (I02)

Engineers working in operational asset integrity management tend to learn this the hard way by being responsible for assets ‘some which weren’t designed in the ideal way. So, they actually get to learn and have to manage what happens if you do do it on the cheap or if you don’t use an optimum solution, you have problems. Some of them will cost you millions of dollars per year, literally, to manage.’ (I13) This is a public safety issue because ‘catastrophic failure is a heightened version of the far more common—having to repair assets.’ (I13)

This is a matter of not only thinking about the state of the assets in the future but the future decision-makers themselves and the need for good records, despite the increased time taken in the short term. As one interviewee explained, ‘If you haven’t written it down you haven’t done it, so documenting exactly what you do is probably the number one attribute that you want from an engineer. You want someone that’s going to write everything down because they’ll stand the test of time.’ (I16)

Taking a long term view is not always easy. The need to take a long term view is most likely to be challenged in a project environment where ‘you see that there is this tension where the capital works budget … is forcing a bunch of decisions because they’re trying to get this thing in the ground and get onto the next job. Whereas [ideally] they’ve made the best decision over the long term and operators have to live with that.’ (I18) Many interviewees mentioned the importance of project work thinking deeply about the future ‘having consideration for what’s going to happen further into the future. How are people going to maintain it? How’s it going to be inspected? If there is an issue with it in the future, how is that going to present itself, and how might somebody discover it?’ (I19) and also ‘understanding what the future land uses and future utility installations might look like around a pipeline.’ (I24)

Interviewees told many detailed stories of how past decisions impact their current activities, providing them with the prompt to consider how their choices might play out in the future. One interviewee summarised this capability as ‘thinking whole-of-life’ (I30) or as another interviewee summarised ‘a stitch in time saves nine’ (I31).

5.2.3.3 Dealing with uncertainty

Pipeline engineers often make decisions in conditions of uncertainty, especially when trying to consider the longer term. Many interviewees talked about how best to deal with uncertainty in making decisions.

The first issue that interviewees talked about is the need to be aware of uncertainty and how important any uncertainties might be in terms of coming to an appropriate decision i.e. whether the uncertainty has material consequences. As one interviewee described, ‘at least understanding the problem well enough to know what you don’t know, or know what the uncertainties are, and say, well I don’t know this exactly, but you’ve got to understand what the limits of that uncertainty is, and it may be significant or it may not be.’ (I18) As another interviewee explained, ‘you have an understanding of the sensitivity [of the outcome to] your unknown piece of information and how important it is to make the decision.’ (I01)

Several interviewees used the language of risk to describe making choices in uncertain situations. ‘It’s always going to be a little bit subjective. And the only way, then, is to bring it back to a common factor. You look at the different consequences, the different likelihoods, and assess the outcome accordingly. It is a difficult one, and it’s where having something to compare to certainly helps. And that’s where experience comes into it, is to have those comparisons.’ (I23) Another interviewee thinks about uncertainty in risk terms, telling us: ‘I try and think about it in terms of risk. I don’t understand this facet, right? But what’s the worst thing that happened if I completely misunderstood this facet, right? … You're never going to understand everything, right? There's always going to be some uncertainty.’ (I06)

A key strategy for dealing with uncertainty is to be conservative as one interviewee explained, ‘I guess sensitivity analysis sort of stuff, that’s a technical way of dealing with it. Assuming the worst case and doing a calculation based on that or a scenario based on that, assuming the best case, assuming the most likely case, and looking at all the options and going from there, depending on I guess the consequence, you might have to take the conservative route and just assume worst case.’ (I25) Another interviewee gave this example of a similar thought process, ‘if it’s a safety issue, the conservatism is important, if safety is potentially at risk, then you’ve got to be conservative. … maybe you could leave, let’s say, damaged pipe in place the way it is. And maybe with some composite wrap, to help reinforce the area. But if it’s—if there’s any doubt that that will be fit for purpose then you should be taking more conservative action. And that might be cutting it out. It might be welding on a full reinforcing sleeve, so if it did ever—reinforce the area. But theoretically if anything did fail at least it’s encapsulated in a fully welded sleeve. … So, that if it’s a safety issue but you don’t have all the facts, then be conservative with your solution.’ (I13)

Another common strategy for dealing with uncertainty is seeking views of others: ‘So he may not know the answer, but he’ll know somebody who does, which he can call pretty quickly.’ (I09) This can involve finding people with specific expertise: ‘Well we push it out to as many other experts who incorporate other experts in related fields that we can.’ (I37) Or simply considering a range of different views on a problem as in the case of interviewee 36: ‘There’s not one person that’s got all the answers in order to try and get the various parties involved from the construction team and the quality team … everybody’s got a slightly different view on these things.’ (I36)

5.2.4 Understand norms and values that inform actions

The second capability is understanding the norms and values that inform action regarding public safety. Interviewees spoke about norms and values in three areas:

- Using standards
- Understanding risk processes and concepts
- Making ethical choices.

These are discussed in turn below.

5.2.4.1 Using standards

Since the target group of interviewees was pipeline engineers, many of them work with AS2885 and spoke about the need for engineers in their discipline to know and work with the standard. Engineers' technical competence is also strongly grounded in knowledge and understanding of the standard, but there are capability questions linked to standards too such as understanding the difference between normative and informative aspects and also appreciating that the standard itself has limits so that black letter compliance is not always necessary or even appropriate. As one interviewee pointed out, there is a range of skills required to successfully use the standard 'none of which is technical at all.' (I05)

Some interviewees highlighted that some of their colleagues treat the standard as if it is a 'cookbook' (I37). People like this 'tend to just want to comply with the code and not really understand the fundamentals of what's actually sitting behind the code and what it actually means.' (I15) As one interviewee noted, the reason for this might be partly to avoid criticism in that 'a lot of people I think feel that if they follow a strict black letter interpretation of the standard, then no one can criticise them.' (I05)

But the danger then is that 'there's always cases that don't quite fit the rule book' (I24) and applying things out of context can create problems. As one interviewee noted, 'there's, yeah, a lot of focus on, you know, the black letter, what the words sort of say rather than sort of fleshing out kind of what it actually means and often that results in some less than ideal sort of conclusions. I have seen people making stuff less safe but it is black letter compliant.' (I34). Another interviewee emphasised the importance of 'having a broader understanding of how decisions can impact safety, and in particular the various stakeholders, I think is very critical.' (I24)

An interviewee with a lot of experience with the standard pointed out that the introductory part (AS2885 Part 0) includes a section 'which essentially says, "This is the Standard. You don't have to follow it. You can do anything else you like, provided that you produce equivalent or better results and it's justified and approved."' (I05) In his view, this section aims to 'encourage people to think, to make their own decisions. … We know the Standard can't cover all possible circumstances, so we need to recognise that and encourage people to recognise when they've reached the limit of what the Standard says, and to use their own sense and judgement.' (I05)

Another key issue to consider is that norms change. The standard itself is regularly updated and as one interviewee pointed out 'you need to just continually keep refreshing knowledge and—to understand what the requirements are now before you proceed on a particular project.' (I21) In addition, this interviewee emphasised that the expectations of other stakeholders change too. 'The expectations of the regulators are changing as well, so you have to keep abreast of that. You need to—it's a continual learning process and that's one of the capabilities. If anybody comes into it with a closed mind saying, "This is the way to do the job, this is the way I've always done it," it just doesn't work because stuff changes all the time. You need to be continually learning and updating your knowledge on what's going on.' (I21) This quote emphasises the point that the required capability goes well beyond an understanding of the specific limits of the current version of the standard and is rather supporting an attitude of refreshing knowledge when required and promoting lifelong learning.

5.2.4.2 Understanding risk processes and concepts

Another body of knowledge with strong language and process norms that influences pipeline engineering practice is risk and risk management. The risk process set out in the industry standard follows the typical steps of threat identification, application of controls, assessment of residual risk (both frequency and consequence) and application of further controls as necessary until risk is acceptable. Many interviewees spoke of knowledge of the risk process and understanding of how it works in practice as key skills for pipeline engineers.

Interviewee 5 in particular emphasised that understanding of risk goes well beyond technical competence in doing calculations, although in his view not all engineers understand this. 'I think a lot of engineers perceive, or particularly younger engineers, can perceive risk as being a technical discipline, you can calculate the risk and put numbers on it, the probability of death of one person in a certain period, that sort of stuff. Whereas, the more you work in industry… you realise that it's all subjective. It's all about meeting what society can reasonably expect.' (I05)

When it comes to driving engineering outcomes, views were mixed about which step in the process is most important. Interviewee 15 thinks that the most important step in the risk process comes in identifying threats. He makes the point that once the credible threats are clearly defined, his job is almost done in the sense that complex decisions are resolved and the remaining tasks are very well defined. 'If somebody had said to me these are the threats you've got to deal with then my job is 90% done. It's thinking about what are the other things that I haven't thought about which could cause a failure, and really going back to that fundamental thinking of what are the other treats that exist which I haven't addressed [that might cause a failure in the future], as opposed to dealing with a threat and getting it wrong.' (I15)

In the view of another interviewee, a clear understanding of consequence is most important in assessing risk and coming to the best conclusions on risk controls. In his view, making good decisions is 'just really about doing a proper risk assessment and understanding the consequences properly, and how many people might be affected in the public, and then how much risk reduction was each control measure really giving you, and by not having it, what did that raise your risk to?' (I26)

Many interviewees focused on difficulties in realistically estimating the frequency of events with the potential for both significantly overestimating or underestimating the likelihood of particular scenarios. Several interviewees mentioned the importance of background knowledge of past failures in coming to realistic conclusions. This can come from having experienced people involved in the process as this interviewee explained: 'you might have some people in the room saying oh, this is theoretical, we've never heard of it and then you've got some of the experienced guys saying, well hang on, I've seen that happen two or three times and so that has in some cases resulted in a change in thinking within the workshop group because you've got some guys in there that have actually experienced this stuff and seen it happen whereas other people might say oh, that's never going to happen.' (I40)

Even so, judgement is required in relying on past history as this interviewee sets out: 'it just simply is really understanding what the likelihood actually is, and not just relying on what might have happened historically as an indicator of what might happen in the future. And then being pretty realistic about the consequences as well, and knowing what controls you have and how effective they are.' (I30) The point is made that the past cannot predict the future and yet an understanding of what has happened before is important to ground the risk assessment in reality (see also Section 5.2.7).

In the view of another interviewee, disagreement about risk arises from a lack of common understanding of the specifics. In his view, 'I think that most of the time when you have differing views on risk, whether it involves the likelihood or the consequence most of the time it's around well difference of opinions due to the underlying root cause or failure mechanism of how it would occur. And, once you thrash that out with whoever that is, whether that's a group or an individual, most of the time you usually come on to a similar consensus.' (I35)

Ultimately, the risk management process provides a framework for thinking but as one interviewee described, the analysis must ultimately be linked to action. In his words, 'and when we're doing risk management, I'd rather talk about what is the control rather than is the risk high or low. That's interesting, but what are we doing about it?' (I08)

5.2.4.3 Making ethical choices

The majority of pipeline engineers identified an ethical component to their practice. They referred to engineering ethics using the language of doing the 'right thing' (I07). Others referred to actions, such as speaking up when they observed decisions that could lead to a breach in ethical obligations: 'I always think in terms of ethics, I always think ethically you can't keep quiet so you have to kind of speak up and all those things' (I06).

The most dominant way that harm was conceptualised was with respect to the management of risks so as to protect public safety. In the words of one, 'Safety is all about protecting people, and that's fundamentally an ethical issue' (I05) Another said that engineering is ethical if we're talking about 'consequences that affect the general public' (I30). Some pipeline engineers were particularly conscious of the risk to the public where high pressure transmission pipelines ran underneath a suburb. The residents of these areas are not necessarily aware of the risks, and are not consulted in developments, giving engineers an additional ethical burden.

Engineers who had been part of the industry for many decades had observed a shift in the scope of ethics to include environmental protection: 'Instead of just "holding paramount the safety of the public", that obligation has been extended in recent years to include responsibility for ecological issues, and I strongly agree' (I07). Some participants referred to environmental matters in terms of longer term protection of the environment or sustainability: 'Especially for future generations. That's part of what the Future Fuels CRC is all about' (I02).

A couple of participants also referred to ethical aspects of the business environment. One participant noted the need to be aware of, and guard against, modern slavery: 'All our supply and the ethics behind supply chain things has become very prevalent' (36). Others referred to the importance of not giving commercial advantage to friends: 'I've seen the playing field was not level. Tender probity … Fairness and honesty is the right thing' (I07).

Engineering decisions happen in an organisational context. This requires an awareness of potential business pressures and how individuals can advocate for ethical choices in this context. Participants focused on their role as a technical 'line of defence' against organisational decision-making that could risk violating ethical obligations:

> 'I won't change my decision-making because it's hard to get to or expensive … I think as my role I see it's the line of defence, the integrity engineer is the line of defence and needs to be pretty clear from that end and let the ambiguity be managed at a higher level.' (I35)
>
> 'Ethically right is technically right, it's the same thing. And I think once you start making technical compromises then the entire industry loses.' (I28)

Interviewees said that they speak about ethical matters in technical terms in order to maintain professional credibility and to communicate the nature of the risk. One said: 'If the client's not aligned with you, you just try and objectify everything as much as possible, so they can just see it' (I26). Another explained: 'I very much use … not alarmist type terminology. But just probably pure facts' (I35).

Overall, ethics is seen by many interviewees as important, but not something that is commonly discussed. Decisions are described and justified in technical, rather than ethical, terms.

5.2.5 Think systematically and understand interconnectedness

Four themes in the interview data address the need for pipeline engineers to think systematically and understand the interconnectedness of what they do. These themes are:

- Understanding context
- Prioritising actions in complex situations
- Applying risk concepts
- Taking enough time.

They are discussed in turn below.

5.2.5.1 Understanding context

The first theme linked to a capability about thinking systematically is a need to understand the context of decision-making. As one interviewee put it, pipeline engineers need 'an ability to understand all the different factors that are at play' (I01). Others spoke of the need to have a 'holistic view' (I19) or an appreciation of the bigger picture. 'I think having the big picture more so than just "I've got to get this job done". Having the maturity to see there's more to the job than just this task. So the task is part of the bigger picture.' (I08) Another interviewee agreed that 'having the bigger picture understanding is probably, for me, one of the key things.' (I24).

A wide variety of context factors were mentioned by interviewees including legal obligations, public expectations, business needs and operating contexts such as cultural factors and local environment around the pipeline. The views of stakeholders other than simply technical experts were seen as important, including the people who will be operating the facility, the local community, regulators, planning authorities, councils and developers.

On the one hand, context factors can have a direct impact on the threats to pipeline integrity and so controls need to be engineered but they also impact wider engineering choices. As Interviewee 39 told us, 'when we look at a solution we actually need to look at it from different aspects, otherwise it's not a viable solution, and the business will not become a viable business either, and that's the reality.' (I39)

No doubt this means that engineers feel they must understand the financial environment within which they work. As one interviewee explained, 'I guess there's some business outcomes that need to be had and that's obviously driving cost down and you can certainly meet the intent of legislation/standards/codes of practice or whatever, by having a pragmatic understanding of issues and limitations. That would drive I guess a better business outcome, while still being compliant to the requirements of what you're trying to achieve.' (I03) But business needs go beyond the purely financial and include having a 'broader understanding of societal risk outside that of your engineering discipline as well, how people are going to react. Pipelines is a great example because a lot of the pipelines go through third party land and suburbs of cities for example in some cases'. (I03)

At the end of the day, the common framework to assess these differing factors is risk as this interviewee explained, 'I think, from a business perspective, it's really just, "What is the risk that we're managing here?" I mean, everything we do has some level of risk associated with it, and the judgement you have to make isn't beyond what we expect and what would be reasonable, and what the community would expect, I suppose. So, I think you're right, there's an element of more and ethics and a whole bunch of other stuff beyond engineering that goes into it, when you think about it.' (I17)

5.2.5.2 Prioritising actions in complex situations

Several interviewees spoke of the need for pipeline engineers to know how to prioritise actions in complex situations. As one interviewee put it, engineers need to be able to 'work out where to put your company's resources.' (I01) There are always multiple courses of action available but 'you've got to sort of try and strike a balance and understand what's important and what's not.' (I18)

As technical requirements increase and infrastructures ages, it is not uncommon for engineers to have to address issues that impact significant parts of the system. They then need to prioritise which parts of the system should be upgraded and when. As one interviewee explained this task, 'then you go back and prioritise or you say, "Well, we did have this many kilometres. We could start with the worst one, which is this age," which was an older one, which is in a higher densely populated area or something, and you target that and create a longer-term plan, which takes more time to deliver, but it sort of says this is our approach to get there, and we're not going to do it in a year's time, but we'll get there eventually.' (I27)

The reason for needing to develop a long term plan for issues such as this is that 'people are always resource constrained, so you really have to say okay, well I can't deal with everything all the time, so I have to focus my attention on the important things first and then less important things down the list … I kind of feel it would be nice to be able to do absolutely everything but you do have to have these lists of things that are—that you can work on now and things that are lower down the list that you work on later.' (I31)

Similar to the issue of complex contexts described above, the key mechanism for prioritising is consideration of risk.

5.2.5.3 Applying risk concepts

Once the broader context of an issue is understood, pipeline engineers often draw on risk processes and concepts as a way of describing interconnectedness and developing priorities.

Risk assessment is a way of combining both macro and micro considerations about a particular scenario as this interviewee describes: 'In my work, at the moment, you've got to have the technical understanding of how the thing that you're working about might happen, or might be prevented, and then you've got to have the big picture of understanding what that means in terms of the community consequences.' (I17)

Risk assessment also encourages engineers to think in scenarios which is different to the way in which engineering work itself is organised. Engineering work by its nature is grounded in a range of disciplines, but at the end of the day all components of the system function together, no matter which discipline did the original design. For this reason, another engineering capability linked to systematic thinking is to think in scenarios, rather than discipline-related silos. Several interviewees made this point with one interviewee giving the following example. 'The process guy over there thinks he's okay and the structure guy over here thinks he's okay and it's only when somebody sitting at the top looks at the two of them and says, "They both are okay in the right situation but then this situation where you're pushing the envelope with flow, you need that robust design to support the piping to ensure that you don't have a vibration issue there."'(I16)

Another form of siloed thinking that is unhelpful is when an entire project becomes a silo separated from the operational environment in which the facilities will ultimately have to work. As one interviewee described the situation to avoid, 'I think it's just about people have conflicting objectives and organisations are siloed, and the project's measured on schedule and cost, they're not measured on long-term performance and long-term safety of what they're installing.' (I26)

Overall, thinking about multiple dimensions of risk promotes systematic thinking and consideration of interconnectedness. As one interviewee described, one of the most important capabilities in pipeline engineering is 'thinking about the potential scenarios of whatever the situation is … considering how those could play out and what the significance is of failure in lots of different areas … and then really once you then understand the risks then you can kind of consider the appropriateness of the solutions I guess to suitably manage those risks within a reasonable period of time, and I think those things [are] kind of fairly significant as well understanding how bad things could be and then whether the solutions … actually mitigate that in a sufficiently advanced period of time. … I think the first thing about whether it's public safety or any of the other kind of driving factors is understanding the risk that you're actually dealing with and how the situation you had is likely to develop.' (I31)

5.2.5.4 Taking enough time

A final aspect of thinking systematically is being thorough and taking time to make the right choice. As one interviewee described, the skill is finding the right balance—'not being rash and prompt in your decision but not procrastinating too much.' (I23)

5.2.6 Collaborate with and draw on the experience of others

Four themes in the interview data address the need for pipeline engineers to collaborate with and draw on the experience of others. These themes are:

- Build networks or seek others' opinions
- Knowing your limitations
- Building a good relationship with field people
- Building external stakeholder relationships.

They are discussed in turn below.

5.2.6.1 Build networks or seek others' opinions

Engineering work is rarely a solitary exercise and many interviewees spoke at length about the value they find in consulting others including other members of their own engineering discipline, members of other engineering disciplines and industry members more broadly. To put it in the simplest terms, asking others is valuable because 'they may know something that I don't, a second opinion is always important.' (I41)

To begin with engineering experts in their own discipline, there are formal systems in place for checking engineering design work and some interviewees saw more informal consultation as based on the same idea. As one interviewee explained, 'that's why we have checking and approval processes in place to ensure that the single decision that's made is backed up by others. Just to be sure that—not necessarily the only decision is met, but a right decision has the right outcomes. And be that right outcomes with safety or with economics or whatever it needs. You've got someone else involved in the decision, validating your thoughts.' (I23)

Having others to draw on requires effort to build networks and seek out those who are able to helps as these two interviewees explained: 'having a good network helps the decision-making so you can test your thinking against people; you can bounce ideas off others' (I08) and 'get other people's opinions, to seek out who the experts in the industry are to give you their view, as well.' (I13)

The value of feedback extends beyond experts in one's own field as this interviewee told us: 'I get feedback as well because a lot of issues have got multiple interests and multiple causes, so you try to understand. You wouldn't—you get other people's involvement in it and other people's opinions before you escalated things.' (I21) This person consults other engineering disciplines, field personnel and maybe other business functions such as commercial.

This interviewee takes a similar approach when dealing with novel projects: 'we push it out to as many other experts … in related fields that we can. But that's not to try and distribute or push away the responsibility. We know that we're responsible and accountable for [the infrastructure]. But you can get their input and at least take that into account, so we've certainly done that.' (I37) Importantly, he emphasises that the responsibility still lies with the decision-maker, despite any advice given.

Giving advice to others takes time. More experienced interviewees who tend to be called upon more in this context see this as an important part of their job. In some companies there are formal mentoring arrangements but in others it's more about seeing supporting less experienced engineers as important and making time 'for there to be good conversation.' (I23) Some experienced pipeline engineers see their role as including 'preparing the next generation.' (I29). This includes 'allowing graduates and younger engineers to learn from our experiences to accelerate it but also allowing them to make their own decisions and recognising that they can look at problems in a unique way and it may be the best way but you just have to work with them to identify why they've made that decision and what have they forgot[ten].' (I29)

Another issue is that networks take time to build as this younger interviewee explained when talking about a more experienced colleague: 'So he may not know the answer, but he'll know somebody who does, which he can call pretty quickly. I think that's a definite hole in somebody with my level of experience. You don't have the connections.' (I09)

5.2.6.2 Knowing your limitations

Related to building networks is knowing your professional limitations and so when calling on others is essential. Many interviewees noted the importance of 'knowing your limitations' (I04) and 'knowing when you need to call other experts.' (I06)

Given that the stakes are high, getting it right is important as this interviewee explained: 'I think you've got to respect experience. Don't assume things. I think you've got to not be so arrogant that you think you know everything or know the answer. It's good if you know what you don't know and accept that, and then talk to people who do know. Don't try and fudge your way through.' (I18) As another interviewee explained a similar sentiment 'faking it 'til you make it doesn't work in this kind of an environment.' (I08) As Interviewee 17 summarised, 'You need to know what you don't know, and not pretending you know something you don't.' (I17)

One specific contest in which admitting that you don't know is useful is in meetings. If you don't understand, chances are others don't understand either. As one interviewee explained, 'I've always said, "Excuse me, there's something I don't quite understand here." The number of times I've done that in a meeting, and heads around the table start nodding, "Yeah, I didn't understand it either, I'm glad you asked it." It's just paid off. You've got to do the right thing.' (I07) The idea of asking the 'dumb' questions led several interviewees to quote versions of the aphorism "There's no stupid questions. There's only dead people." (I07)

Really knowing your limitations requires self-awareness as one interviewee described 'being aware of what you're good at and what you're not and how you behave and how you make decisions and how you take in information, so a lot of stuff about self-awareness.' (I08)

5.2.6.3 Building a good relationship with field people

A key aspect of this capability is building good relationships with field personnel. This supports Capability 5 which emphasises the importance of making decisions grounded in reality. As one interviewee described, whether it's 'a fitter, or it's a site supervisor, or an HSE supervisor … having a good understanding and conversation, and good relationship with those people is key to success in the industry.' (I10)

Several interviewees noted that the need for engineers to go to site has reduced as a result of Google Earth and other technologies which give some visibility over site and surrounds without leaving the office. These innovations are 'good and helpful and saving time and traffic and cost' (I14), but what suffers is relationship building with the people who work in the field. Another interviewee explained the benefit by saying 'I just really encourage people on my team to actually just pick up the phone or have a video call with operations people. They're the people that are in the field doing the work. They can provide a lot of context that isn't immediately apparent just sitting from your desk in a capital city.' (I30)

Another issue with a lack of relationships between office-based engineers and field workers is an excessive reliance on written procedures prepared without field input. Interviewee 21 shared his experience on this issue, telling us 'people are starting to rely on the paperwork rather than on the people, which you cannot do. You can't do it without the people being part of it. You can't do it with paperwork alone. You can do it with people alone if you've got the right people. That was the old way of doing it, but it wasn't perfect. The best is good paperwork and good people who know what's in it and understand it.' (I21)

The way to get around this issue is to consult with operators and other field personal at an early stage to give them ownership over the outcome. As this interviewee explains, he tries to engage field personnel by saying '"We design it for a year and you've got to operate it for 30 years," so I use that to get the operatives on board and I do try and include them in designs to make things more operable and this is without going into the ergonomics and the human factor type thing but just ownership. I think it provides—it gives—that means the operatives have got ownership of what actually goes in at the end of the day.' (I29) As another interviewee told us, 'you've got to be able to listen and empathise, and be willing to change it to something that is safer.' (I20)

5.2.6.4 Building external stakeholder relationships

Many pipeline engineers have roles that also benefit from building relationships with external stakeholders. This can include councils, other utilities, specialist suppliers, developers, regulators and many others.

The key capability here is to be able to 'think about it from different parties' perspectives.' (I24) Having this skill is really important as this interviewee explains: 'people that can see it from all angles and know how those different people might work or approach things is really helpful.' (I30)

This is especially important in cases where there are conflicting objectives. Sometimes a bit of give and take is required as one interviewee explained. 'It's having that bigger picture view that you might get a win in one situation, but you might have to deal with that party again in a different context, where you're reliant on them to give a little to get what you need. Safety has always got to be at the forefront, and the safety objectives always need to be met, but as I said, there's different ways to get there often. And I think it's important to work with the stakeholders to get to landings that the people can accept and/or at least have a really clear explanation of why you need to do something in a particular way, so that whilst there may be parties that don't like the outcome, hopefully if they understand it they can accept it.' (I24)

5.2.7 Ground decisions in reality

Four themes in the interview data address the need for pipeline engineers to make decisions that are grounded in reality. These themes are:

- Making practical choices
- Learning from small failure
- Be sceptical of models and calculations
- Imagine being there.

They are discussed in turn below.

5.2.7.1 Making practical choices

When it comes to making decisions grounded in reality, the first theme from interviews is the need to make decisions that are practical. Impractical engineering decisions clearly can have a poor impact on operability and constructability and so pose workplace safety risks to field personnel but such problems can also pose risks to the public. Impractical designs invite short cuts in construction and operation that can have consequences for facility integrity and so public safety.

As Interviewee 06 told us, 'what you do in the office has real-world consequences and so you can try and imagine it, but the best way to is to go and actually see it.' (I06) Another interviewee recounted that 'the best designers would be are the ones that have got the construction experience, the ones that have come from the field or not come from the field but spent time in the field. They're your best designers because they've got the practical experience.' (I16)

And similarly 'you need to understand that when you're doing something, you're in a hole in the ground full of dust in Western Queensland in 40 plus degrees, that it's not, perhaps, going to be perfect, like lab conditions.' (I17) Also 'you can see what people are up against out there. It's kind of hard to visualise unless you've kind of gone and had a look.' (I06)

Seeking to make practical choices is an important aspect of the capability to make decisions that are grounded in reality but there are other aspects including understanding what has gone wrong in the past.

5.2.7.2 Learning from small failures

In the capability on taking a long term view, we have already addressed the need for pipeline engineers to be able to imagine worst case scenarios. This theme is similar, but focuses on a knowledge and understanding of smaller failures and the insights they bring regarding possible system failure mechanisms in the future that can then be taken into account in decision-making.

When it comes to major accidents, Australia has a good safety record but 'because of the age of the [pipeline system], we have quite a good wealth of history.' (I19) This includes many small faults and failures. A benefit of having such collective experience to draw on is that individual engineers have the opportunity to 'get to understand those failure mechanisms intimately.' (I20) It is very important to ground technical competence in a knowledge of past failures and their causes, in particular, the benefit of 'learning from your own mistakes and other people's mistakes that you can share within the organisation … if something's happened and someone's made a mistake and there is assessment, they will then go and say, "Hey, I've picked this up and I've shared that with other people," so I guess you're building up a library of things that can go wrong.' (I27)

Understanding historic performance of an asset more broadly also puts any current system observations into context. This is critical because 'for an asset engineer … to understand the importance of an observation of something changing, one needs to understand why it has changed, is this abnormal behaviour, has it behaved like this before, and that's where a historic knowledge comes into play.' (I28)

Historic performance is also important in understanding industry technical norms which directly impact decision-making as this example from Interviewee 30 shows: 'A lot of these controls are there because people recognise they're good practice, and a lot of them stem from previous incidents, right? One might be, say, whether you're going to put in protective top slabbing. You might be a bit lackadaisical about it and just say, "It's really low probability, it's hard to install, it's expensive for this poor proponent, maybe we just won't do it." But an experienced engineer would know that there's been incidences before, it's certainly plausible, credible, and that it is justifiable, and that you'd do it for a reason, so there is definitely a connection to historical incidents.' (I30)

Knowledge of past failures is also shared in workshop-based review techniques such as Hazard and Operability studies (HAZOP) and safety management study workshops (SMS). As one interviewee explained, 'that has in some cases resulted in a change in thinking within the workshop group because you've got some guys in there that have actually experienced this stuff and seen it happen whereas other people might say oh, that's never going to happen.' (I40)

Other interviewees told us that they work hard to 'take any learnings from things that happened elsewhere and see if there's lessons that we can learn from the things that other people have experienced, and whether we have any vulnerabilities to those same risks.' (I19)

5.2.7.3 Be sceptical of models and calculations

Another important aspect of grounding decisions in reality is to be sceptical regarding the outputs of models and complex calculations.

Several interviewees spoke of needing to examine results of field tests critically, rather than simply accepting them at face value. This applies to both data generated from inspection methods such as intelligent pigging but equally to results of hydrotesting. Others spoke of the need to do rough hand calculations as an order of magnitude check on the results of complex modelling. As one interviewee explained, 'Common sense and ability to know the answer before you calculate it is a skill that I really try to instil … Doing that little sniff test is really critical for those … to make sure that we're not coming out with some farfetched idea that's so far off the mark, if not silly.' (I16)

5.2.7.4 Imagine being there

The final aspect of the capability of grounding decisions in reality is another form of sense check. Two interviewees spoke specifically about an imaginative check that they make on decisions that can impact safety—they imagine themselves or their family standing near the facility in question.

One interviewee described his decision-making practice when 'looking at how you're going to do something in the field, I try to transport myself I guess to some extent, by saying, "Okay, if I can put myself in a situation where I've been in a similar situation, would I be actually comfortable to actually do that operation? … It's got to feel very safe in the office environment to feel reasonably safe in the field environment. That's the way I judge things anyway.' (I15)

Similarly, another interviewee asks himself ‘would I be comfortable being there? Would I want to be standing there next to the operations person while they're doing that?’ (I27)

5.2.8 Advocate for action and take responsibility

At the end of the day in order to impact public safety outcomes, engineering decisions need to lead to action. In many cases, engineers may not be in a position to directly initiate action themselves but rather will be seeking to influence others. The interview data shows two core themes in this area:

- Influencing senior managers and clients
- Standing up for public safety.

They are discussed in turn below.

5.2.8.1 Influencing senior managers and clients

In many cases, pipeline engineers need to convince those more senior than they are in their organisation of the need to take action on matters that can impact public safety since more senior people are in control of the necessary resources. Many interviewees talked about the capabilities needed to successfully put forward the case for change.

The first point is for engineers to be confident in their position and advocate for what they believe is the right course of action. As one interviewee explained, the key is to ‘have an answer already that they can agree with.’ (I09) Another interviewee put it this way: ‘they want to hear a solution rather than a problem. So we always try and lead with the solution rather than the issue.’ (I36)

Not doing this can lead to problems with getting the best engineering outcome accepted. One interviewee explained that ‘the trap I see is a lot of people aren’t very firm in their recommendation. A lot of executives will say, “Don’t come to me with five options, you’re supposed to be the expert, I want you to make or recommend a pretty strong decision, and if your justification sounds quite valid then we’ll go with it.”’ (I30) On the other hand, executives want to have confidence that options have been considered and carefully evaluated and engineers must be prepared to answer hard questions (to be ‘grilled’) and defend their position. Another interviewee described his experience of presenting tough cases to senior management in these terms: ‘it’s about being well-prepared. It’s about going through all the—why have you landed where you’ve landed? What were the other options? Why did you consider them not to be as good as what you ended up with? And it’s really just working through—being not defensive, being open to their questions, knowing that it’s to ensure that we’re landing on the best option.‘ (I13) Importantly, this interviewee sees the robust questioning as part of the process to ensure that the best option has been chosen, rather than as pushing back on his recommendation per se.

The next issue is how to go about making the case for safety-related action. Many interviewees said that it was important to use the language of risk and of business in making the case. As one interviewee told us, ‘It’s best to talk in terms of risk and probabilities.’ (I06) Another interviewee would make the case in these terms: ‘“The cost of doing this is X, the risk that we’re exposed to if we don’t do it is whatever it is, and here are the options,” that’s usually a good way to frame things.’ (I17)

Making the case can also include a reminder of legal obligations. Many interviewees said that they invoke compliance with standards as a reason for needing to spend money. As one interviewee said, ‘I always try to hide behind the standards in many respects, and publications because if there is a peer reviewed publication, if there is a book, if there is a standard, if there is a reference; you don’t actually need to say, “I believe we should do this.” Say, “This is what the standard says, that’s it. We have to do it.”’ (I39)

Many interviewees counselled caution about invoking accident cases in putting forward cases for action. As one interviewee described the right tone of the conversation, ‘you want to sound like you're being reasonable and you're making a sensible, thought out decision, not jumping to any conclusions.’ (I27) Comparing any given situation to a disaster case can easily be seen as fear-mongering and many interviewees cautioned against this:

> ‘You can’t … Chicken Little people’ (I06)
>
> ‘you don't want to seem like you’re sensationalist’ (I27)

> ‘It just sounds like running around with your hands in the air saying, “You’re going to die, you're going to die,” you know, like it's kind of—might seem like someone who’s making a big fuss over something that—yeah’ (I27)

> ‘Don’t want to be tarred with that brush of being that sky is falling kind of person.’ (I33)

Making what can be seen as exaggerated claims gives the impression of trying to avoid responsibility as two interviewees explained:

> ‘“This is your ultimate get-out-of-jail card”. To get them to agree to your position is ultimately, “This thing could blow up, and you’re not agreeing with me so I’m going to tell you it’s going to blow up, and that’s my way of getting my way or trying to come out on top in this particular argument.”’ (I01)

> ‘It’s a bit like the boy who cries wolf; I think that some engineers have consultants especially trying to protect themselves. It can actually undermine—you put down a thousand recommendations and things that people need to do, of those thousands they need to do which are the ones they need to deal with? If you give them a thousand, they’re not going to do any which makes the situation worse.’ (I15)

Despite the need for caution, interviewees were also clear that it is important to get across to decision-makers what the credible worse case consequences could be. This interviewee tried to explain the balance that is required. ‘One side is going into a manager’s office waving your arms around going, “Oh my God, this pipeline is going to blow up and kill heaps of people”. That’s obviously not the right way to go. But sitting down and having a conversation going, “There is a potential consequence and this is what that consequence could be, however, this is what we are proposing controls wise, we believe that will lead to a likelihood of this and here is our risk, but we are just trying to make sure you understand this potential consequence because it is significant”. There is different ways you can have the conversation.’ (I38)

Similarly, it is important for decision-makers to be aware of major disasters but the time to introduce new ideas to decision-makers who may not be familiar is not in the heat of the moment, but rather as part of routine business in the spirit of learning and improvement. This includes lessons to be learned from major disasters and possible best practices from elsewhere. Interviewee 01 described this as ‘trying to plant the seeds of the ideas in those people … trying to get them on the bandwagon.’ (I01) Very specific analogies where an engineer can say, ‘“This exact situation we’re in now very closely replicates the build-up to this particular incident”‘ (I01) can be used with caution but as described above, sweeping comparisons are not appreciated.

Similar considerations apply for those in jobs selling professional services and dealing with clients. Engineers in those kind of positions also develop skills in getting their point across to those who hold significant power. As one interviewee described, ‘we’re not going to construct something the way that the client just wants us to and we have pushed back harder and ultimately got the client to agree with the way we would like to construct it.’ (I16)

These kinds of situations tend to be managed with escalating levels of communication starting with ‘emails or conversations obviously in the first case but sometimes if you feel something is getting shutdown in a conversation, putting pen to paper or sending an email is the next step for me … and hopefully we all end up on the same page where perhaps we understand where they’re coming from and we all agree.’ (I40) If that fails the next step might be to call a meeting. The way in which the case is made requires similar skills to those described above for dealing with senior management.

5.2.8.2 Standing up for public safety

The converse of trying to initiate action on an issue aimed to improve public safety is to take action to try to stop something that has a potential adverse impact on safety outcomes.

Several interviewees mentioned the importance of individual engineers being able to ‘speak up, and being confident enough to back up your claims as well, especially if you don’t agree with something’ (I04) or in the words of another interviewee, ‘making sure [engineers] have the courage to speak out or to sit on their convictions when they’re sure of something.’ (I01)

Engineers, especially but not only at a senior level, are regularly put into a position where they need to make a decision ‘about whether you pull the job up, or you pull up some work that is part of a KPI or part of it is going to impact the budget, and you’ll make a lot of project managers upset because you have to stop the job because you’ve got a nagging bad feeling about a technical safety matter’. (I01) As several interviewees, told us, this is not easy but in the words of Interviewee 06, ‘I think that’s your job if you’re a principal engineer, you’ve got to be a pain in the bum.’ (I06)

Ironically, it is more experienced engineers who may be more willing to admit that they are unsure about something as this interviewee explains: ‘There is so much stuff that you have to know that you can never know everything and it takes a long time and quite a bit of experience, in my experience anyway, to get to the stage where you’re comfortable saying, “I don’t understand that,” or “I don’t think that’s right. Let’s think about it.”’ (I21) However, in his view it is important for even junior engineers to develop the capability to speak up so that ‘if you’re in a situation—if you’re looking at a bit of pipe work or something like that and something feels wrong or you have a little bit of experience or something you’ve seen in the past makes you think, “That’s not quite right,” put your hand up and do something about it.’ (I21)

Another interviewee noted that things can still go wrong even when processes have been followed and that engineers should pay attention to their gut feel. As he described it, ‘don’t think that you can ignore the voice in your head and think that the process is going to protect you now. If something ever feels [like] there is still a risk or it’s something you can’t quite put your hand on, but something is still there that’s a bit of a threat, then there probably is. And you need to actually stop and re-assess. Because what I’ve found in the incidents I’ve witnessed throughout my career so far, is that by and large, someone always knew something was a bit up, but they persevered anyhow. ... Because it just seems to be that any of the incidents I’ve observed, at least one person knew something that was progressed with they should have stopped.’ (I22)

Finally, one interviewee pointed out that not making a decision is a decision in itself and this can also be difficult, depending on the circumstances. As he explained, ‘in some ways, refusing to make the decision, or saying, “I can’t make it because I don’t have information” is as important as being able to say, “I have enough information to make this decision.” In fact, it’s more courageous to say, “I can’t make the decision yet, I cannot tell you this is safe because I don’t know enough about this particular aspect.” Because usually people want you to make the decision and move on. And when you say that, that usually holds up something or costs money, or delays the project, or in some way puts you on the critical path for that problem.’ (I01)

6 The value of experience in professional practice and teaching

Following from the identification of capabilities that align with the learning objective and outcomes, the next stage in professional learning design is to articulate the educational approach that forms the foundation of the learning modules. As previously outlined in this report, the professional learning modules for pipeline engineering for public safety have been informed by the need for ongoing professional learning that is situated in work practice contexts and also the range of capabilities identified in the previous section. With this context, this section will now draw on the theory of education and interview data to present the educational approach that informs the design and selection of appropriate teaching and learning methods (case based learning and associated activities) as well as assessment of learning outcomes.

6.1 Learning from experience

While the interview data has been analysed in the context of capabilities for public safety in the previous section, it also points to the value of educational approaches and learning experiences that align with the learning objectives set out in Section 4. The positive impact of learning from experience was explained by just under half (n=17) of the pipeline engineers interviewed, with more describing the role of field experience (n=26) and learning from cases (n=27) as part of their professional practice. Amongst these interviewees, there were participants who described learning from their own experiences, participants who described learning from others' experiences (disaster/accident cases) and those who use their experiences of accidents or those of others (disaster/accident case examples) to communicate potential risk. The value of learning from personal experience, or that of others, is being able to see, and learn from, the outcomes of decisions. In the case of accidents or disaster case examples, being able to see the consequences of 'poor decisions' or learning from other people's errors helps pipeline engineers to recognise the level of complexity involved in decision-making along with the need for continual learning in this context. These accident/disaster examples also provide a proxy for real-life experience.

6.1.1 Personal professional experience

A number of participants noted how their experience has influenced their decision-making practice. This included being able to draw on learning from previous experiences to decision-making. For example one participant noted that when confronted with a familiar situation their past experience helps them to think 'I've been involved in this in the past in a similar decision-making process and I've got the past learnings that help me understand how to make decisions going forward' (I38). Professional experience also assisted in providing additional precautionary measures where needed based on prior experience in a particular situation. As noted by one participant ''because of my experience… I… added some additional safety factors on my assessment. And that was due to just my experience around certain things that can go wrong' (I35). Past experiences also help engineers to identify patterns that may pose risk, 'what feels like gut feeling is in fact experience. That gut feel is generally experience, subconscious experience spotting a pattern, you know, that something might not be quite right…' (I06) Professional experience of a major accident was also noted by an interviewee who said 'I was involved in a fatality incident, so you see firsthand what happens and you see the consequences of something failing, and it lasts with you for a long time… It scared the bejesus out of me, and I started paying attention a lot more after that, I tell you' (I28).

It was noted by some participants, however, that experience comes with time in the profession and this has become undervalued overtime by industry, as expressed by I08: 'I think we downgrade real experience as if it's not important, but sorry, 25-year-olds don't have experience and shouldn't be making big decisions'. The challenge for early career engineers to gain experience was noted by another participant who said, 'unless someone says to you, teaches you directly and says, "Watch out for these things."' (I06), the inexperienced engineer will not be aware of what to look for to manage risk in their decision-making. Therefore, professional learning to give pipeline engineers a greater awareness of how their individual professional practice affects public safety, must work to provide learning from experience, particularly for those who have not had such experience.

Another aspect that was discussed in the interviews was the value of field experience in professional practice for achieving public safety outcomes.

6.1.1.1 Field experience

Several participants described the benefits of field experience for helping ground office-based decisions in the real world. 'Field experience is essential. You need to understand what you're doing, what it looks like' (I21) and as stated by another participant, 'unless you've actually had hands on experience, it's very difficult to know what the real risks are or the consequences that you might not be immediately aware of' (I36). The benefits of field experience were further described by another participant, 'because I understand and spent a lot of time in the field, I'm able to bridge that potential gap in geography between people making decisions in an office space on what a computer tells them and some idea of how that plays out in the real world or what people may think of that in the real world… I've seen a lot of fundamentally unsound assessments based on what a computer tells you is possible and that needs an injection of real-world experience. It is definitely a geographically-induced problem, but it's also got to do with the way engineers are gaining their experience at the moment' (I01).

The need to integrate both office and field experience in order to keep the consequences in the field in mind while working in the office was noted by one participant (I03) while another stated that field experience was important 'to actually get a feel for where the pipe is and what's around it' (I13). The benefit of this was noted by another participant who stated that 'You can see what people are up against out there. It's kind of hard to visualise unless you've kind of gone and had a look… you'll learn things that only can be learnt from going and speaking to people and seeing it in real life' (I06).

Other participants noted that they felt there was a lack of field experience in current practices and this was an issue (I08) and that those with field experience 'are very important to the industry' (I09). Another participant noted that 'more site-based experience in the first couple of years after professional life' (I10) would be an advantage for professional engineers, given that 'it's hard to learn what is unsafe out on site when something's being built unless you're there and you witness it' (I20).This field experience was also said to broaden understandings of practice (I11) and important for informing decision-making practices. 'I think having field experience is critical to support some of the decision-making; it just gives you a better understanding of (particularly) the third party threats, which is probably the threats that we all worry the most about' (I24).

In addition to understanding the real-life location of a pipeline, the practices of those working in the field and third-party risks and potential consequences, stakeholder management is also noted to benefit from field experience by understanding the people on site (I41).

Despite the value of professional experience, including field experience, for deepening understanding and responding to risks and appreciating consequences, many engineers, particularly early career engineers have not had this experience or experience of accidents or pipeline disasters. This is where learning from the experience of others or accident and disaster case examples was noted as important by the interview participants.

6.1.2 Learning from the experience of others

In the absence of having lived experience of a disaster event, a number of participants felt that learning from the experiences of others is important for understanding consequences of decisions. As one interviewee described:

> 'I've never been involved in a large-scale disaster… And when you hear those firsthand accounts of people that were there at Longford when it blew up… that really sits with you. And it's a way of… living through the experience that that person might have had without having to have it yourself….If you don't expose yourself and hear those sort of case studies… then you can't necessarily imagine the outcome of a poor decision as easily' (I01).

The transformational and long-lasting impact on professional practice from learning about a disaster (in this case Piper Alpha) was described by one participant who said that reading the Cullen report:

> 'had a huge impact on my career and my thought processes throughout my career. One of the things I remember quite vividly is just reading through the list of names of people that had been killed as part of the incident. I remember getting to page five and thinking wow, this is really the impact… these kinds of things really can happen and when they do happen they can impact on just about everyone' (I03).

The value of having awareness of multiple disaster cases is also in their use to communicate potential risks and consequences to others. For example, 'the more of these incidents you're aware of, the more you have in your toolkit. The ability to raise an analogy or a reminder at a timely point that might tip the discussion away from what you think is a dangerous situation' (I01).

As one participant noted in the context of drawing on other disaster cases, 'how you actually communicate the importance of what you're doing when the individual hasn't had a lived experience, or any context, is quite critical' (I28). The value of using example cases or stories to communicate consequences of decisions was explained by another participant, 'because with the stories, people can see where the decision has been—let's say the wrong decision or they've made one decision and something has gone differently to where that decision was and the consequences have gone to where they don't want it to go and something has gone out of control' (I29).

Interviewees named a number of major accident cases such as the Deepwater Horizon blowout, Longford fire and explosion, San Bruno pipeline rupture, ethane pipeline fatality, Piper Alpha fire, Ghislenghien pipeline rupture, Moomba pipeline failure and Norwegian hydrogen refuelling station explosion, however disaster cases outside of the oil and gas industry were also noted by interviewees as incidents they had learnt from. These cases included the Florida University footbridge collapse, airline disasters, Chernobyl and the Lac-Mégantic rail disaster.

Overall, interviewees expressed positive attitudes towards the value of drawing on disaster cases both from in the industry and outside of the industry. In fact, learning from cases has strong links to expertise development. 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 & Dreyfus, 1986). 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). For the purposes of disaster prevention, it is therefore desirable that pipeline engineers can draw on rich case studies to inform their everyday actions, in particular about what the consequences of their choices could be. Drawing on their stock of cases, people can ask themselves, 'what's the story here?' and then 'now what should I do?' (Weick, 1995).

6.2 Inquiry based professional learning

As a number of participants noted, fortunately not everyone has firsthand experience of accidents or disasters in the their professional practices, particularly in the Australian pipeline context. Furthermore, as noted by a number of participants, field work experience of what is on site and how things are done in practice, rather than on paper, is less part of current day engineering practice. Therefore, in Australia, younger engineers and those without experience of accidents are left without the valuable learning that many interviewees noted that they gained from such experiences. In addition, given professional learning modules are part of formal training, a proxy for this professional experience is needed. Both data from the interviews, along with theory of experiential learning discussed later, highlight how examples of real-life disaster or accident outcomes can provide this proxy for real life experiences.

In the context of designing a professional learning module, the value of drawing on the experience of others in disaster or accident cases to achieve the stated learning objects and capabilities is evident from the data. Educational theory of inquiry based, experiential learning and the use of cases can further explain why real-life experiences of cases, as noted by interview participants, is so important for professional learning.

As such, the professional learning module options in this report are developed from an inquiry based constructivist educational approach that requires the learning to be developed from, and situated in, current concepts and issues related to the specific disciplines and professional practice. Inquiry based learning is a structured approach to learning with participants learning within a framework supported by a driving question or problematic scenario. Participants identify issues and questions that further develop knowledge through reflection and application to problem responses. As a curriculum approach, inquiry based learning builds from a natural process of inquiry in which students experience a 'need to know' that motivates and deepens learning. Inquiry based learning requires guidance from the facilitator: providing structure and support for students as appropriate to their developmental stage. The value of this learning approach is that participants recognise the purpose associated with their learning, due to the 'real world' task/s and issue/s, increasing their motivation and learning. Learners are challenged to participate actively, think critically, and reflect. This approach leads to participatory teaching methodologies that enable learning based on a problem-solving approach, which in turn has been built on principles such as diversity, empathy, equity and tolerance. Such approaches enable the development and delivery of learning activities aligned to experimental learning developing discipline knowledge and skills.

Three education methods that encompass active and inquiry based learning pedagogies are project based learning, problem based learning and the use of cases or case studies. Although each approach has a slightly different orientation, with different levels of engagement by the learner and educator, there are many similarities between them.

- Project based learning involves learners, either individually or in groups, undertaking an investigation and development of a product.
- Problem based learning (PBL), similar to project based learning, is a learner focused approach to learning based on solving open-ended problems but is more knowledge focused and encourages loops of inquiry, analysis and articulation.
- Case based learning, case studies or scenarios in education enables educators to draw on real experiences to engage learners in their learning in a structured way.

Importantly, these methods are valued for their ability to develop learner capabilities. Capability education does not lend itself to typical learning approaches where structured, content-driven events such as lectures and workshops predominate. Capability is best developed through less traditional methods that incorporate structure to support learning but do not dictate content or prohibit the exploration of complexities that are inherent in safety and pipeline engineering. The three teaching methods nurture capability development as they require learners to engage with ambiguous and unfamiliar contexts in a meaningful way, learning by doing or experiential learning (Fraser & Greenhalgh, 2001). Development of capabilities identified in Section 5 can be best achieved using inquiry based methods.

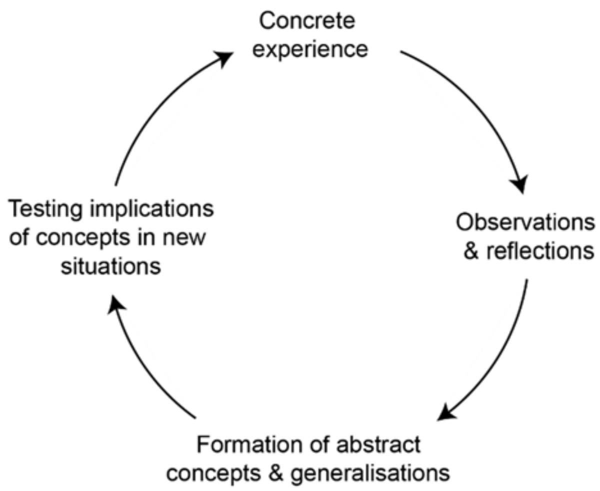
In order to develop these capabilities through inquiry based learning, there is a need for participants to firstly engage with a scenario, apply knowledge and skills in response to the scenario, and reflect on the outcomes of their response as well as their own actions and learning through the inquiry process. The emphasis on learning from reflection on ‘doing’ aligns with the theory of experiential learning, a popular educational approach that builds from inquiry based learning.

6.3 Experiential learning

To develop professional knowledge and action, an essential facet of development must include ‘learning from learning’ (Nicholls, 2001, p. 38). Edwards (1998) and Nicholls (2001) both argue that the discourse of lifelong learning has shifted to one of reflexive challenges requiring ‘the professional to learn and understand the learning that has taken place’ (Nicholls, 2001, p. 39). Two elements central to positive learning outcomes include reflection (Nicholls, 2001; Schön, 1988) and critical thinking (Cheetham & Chivers, 1996; Kolb, 1976). Nicholls (2001) argues that reflection should be at the centre of our practice and that this is core to professional learning. Reflection can be defined as thinking about action to improve it. Schön (1988) distinguishes ‘reflection *in* action’, which is akin to immediate decision-making, from ‘reflection *on* action’, which provides a longer and deeper view. What is needed is for reflective practice to become second nature in all aspects of practice. Reflective capacity on both a personal and professional level is crucial to the development of the professional learner within the workplace environment, but this needs to be combined with critical thinking if an alternative practice is to result.

Experiential learning provides learners with the opportunity to apply what they have learnt to ‘real’ scenarios. Further, and as described by Kolb (1976) experimental learning is when the learner is immersed in experience that allows for observation and reflection; this he illustrates using a four-stage experimental learning cycle (see Figure 2).

Figure 2: Kolb's (1976) experimental learning cycle



Kolb's (1976) experiential learning cycles are founded on the principles of observation and subjective development of a new theory that then informs new ways of practice. Assuming alternative forms of practice are adopted, these new learning theories should inform such practice and lead to the creation of new concrete experiences (CE). These new experiences lead to reflective observation (RO) and in turn the formation of abstract concepts (AC). Finally, the cycle is completed using these abstract concepts to guide decision-making and experimental action to solve problems (AE).

Kolb's approach allows us to identify and understand learning experiences that can point to practical implications. While Kolb's experiential learning cycle explains how learning through a particular experience occurs, it does not tell us if it can be transferred to other situations. Nicholls (2001) argues that for improvement in an individual's everyday environment to occur, additional learning through a second set of learning cycles with deeper critical reflection is required. The need for a second set of learning cycles as a means to affect change in behaviour was recognised by Argyris and Schon (1974) in their 'theories-of-action' theorisation, which recognises that an individual holds an underlying rationale for a particular action. They argue that if an individual is to improve their professional effectiveness, their theories of action must be built and then rebuilt; this can take place at two different levels:

- Single-loop learning: 'development is limited to the linear acquisition of new micro-theories that conform with the basic principles of the old theories' (Ho, 2000, p. 31). Learning is focused on developing new skills and strategies that reinforce existing goals and beliefs; theories of action are maintained as there is no engagement in self-reflection.
- Double-loop learning is often the result of recognising that current practice underpinned by an individual's theories-of-action creates a conflict in practice. Double-loop learning uses self-reflection as a means to bring about a change in fundamental goals and beliefs.

Ho describes three significant sources of dilemmas identified by Argyris and Schon (1974):

- Dilemmas of *incongruity* arising from the lack of congruence between espoused theory and theory-in-use
- Dilemmas of *internal inconsistency* arising when the professional realises that coexisting beliefs and values within the theory-in-use have become increasingly incompatible
- Dilemmas of *effectiveness* arising when the professional finds that it becomes increasingly difficult to achieve intended goals (Ho, 2000, p. 32).

Central to double-loop learning is a transition between theories-of-action, which often involves conflict. As existing theories-in-use are self-maintaining and often unrecognised, conflict allows individuals to become aware of their existing theory-in-use, and admit to the sources of dilemmas. The confrontation will then create tension, leading to resolution of the dilemmas and, thus, to changes in the espoused theory or theory-in-use.

Ho (2000, p. 34) concludes that: the process of change lies in 'first making people aware of their espoused theory and theory-in-use to confront them with the mismatch between the two'. The conditions for change to occur include the need for a psychological means to a new conception. Ho (2000) suggests that training with a focus on change program should have the following four elements:

- confrontation
- self-awareness
- availability of alternative
- building commitment to a new conception.

Experiential learning recognises that learning is part of the social construction of knowledge, that there are multiple ways of understanding professional practice and that these are often shaped by workplace norms. Schatzki (2002, p. 77) identified that 'teleoaffective structures' provide overarching purposes and moral and emotional commitments that shape and structure practices in the workplace. These structures directly relate to and influence individual action and form 'mediating preconditions' constructed by practitioners, known as practice architectures (Kemmis & Grootenboer, 2008). Kemmis (2008) argues that 'practice architecture' both enables and constrains practitioners and practices. Kemmis (2009) argues that practices are not the products of individuals; rather, they are social products, and an individual's practice occurs within a practice architecture. As such, experiential learning allows participants to reflect on these existing structures and how they inform practices and outcomes.

Kemmis (2009) argues that professional architectures and their associated mediating preconditions enable and constrain individuals' conduct. A practice theory brought to professional learning recognises that the application of knowledge and skills constitutes a new instance that is dependent on the context in which it is realised. A change in professional practice is not merely a matter of changing the understandings (sayings), skills and capabilities (doings) or values and norms (relatings) of practitioners, but also understanding the influence of practice architectures. Thus, rather than skills and knowledge being 'transferred,' they are continuously constructed (and reconstructed) in daily practice. Consequently, professional learning models must integrate 'the many traditions underlying its construction' and incorporate the theory and practice modes of learning and explicit and tacit forms of knowledge' (Raelin, 2008, p. 65). This is the value of using real cases in inquiry based experiential learning modules, as the real life contexts highlight these professional structures and how professionals negotiate these to achieve project outcomes.

Kolb's approach allows us to identify and understand learning experiences that can point to practical implications. While Kolb's experiential learning cycle explains how learning through a particular experience occurs, it does not tell us if this learning can be transferred to other situations. Both the development and evaluation of professional learning needs to give consideration to the workplace that it serves and within which it takes place. Subsequent assessment should often be open-ended, involve unbounded sets of information, and there may be ongoing redefinition of the goal of the task. This requires participants to develop skills to establish and adapt goals according to available information, seek out relevant and valid information for the task, and continually monitor their own progress.

6.4 Summary

In summary, in order to give pipeline engineers a greater awareness of how their individual professional practice and associated capability should reflect the paramount importance of public safety through the transition to future fuels and into the future, educational modules situated in and connected to professional practices are essential. Furthermore, inquiry based education is well suited for learning outcomes that ask participants to: identify and apply lessons from previous accident cases to maintain the industry's public safety record; understand and explain the link between professional practice and public safety; and know when and how to act on better decisions in the interests of public safety. The use of real-life cases, as supported in experiential learning, is valuable for providing participants the opportunity to reflect on and apply their learning in the context of existing examples of professional practices and their outcomes. The interview data reinforces the learning value and influence such cases can have on informing professional practice in the context of public safety.

7 Learning from cases

The fifth stage of the PLD Framework involves identifying the learning activities suitable for developing the identified capabilities, learning objectives, and outcomes. A widely used activity, which is the focus of this project, is experiential case based learning that explores learner perspectives, develops capabilities, and transforms perspectives through exploratory tasks designed around existing professional cases. In this section, we introduce case based learning including how it is used in ongoing professional development within and beyond the engineering domain, and what we know about its function and limits in relation to learning about disaster prevention. Case based learning does not imply a single learning model, and so we also investigate the different approaches that have been taken to case based learning—role play, simulation, game building, group-based reasoning, and film and live performance—with attention to their traits and relative strengths and weaknesses according to the literature.

7.1 Why cases?

Scholars have long appreciated the role of stories (of cases) in human cognition. Stories structure the meaning of experiences, drawing together the significance and implications of individual actions and events (Polkinghorne, 1988; Schank, 1990; Schank & Abelson, 1995). They also reflect the context-specific nature of much understanding (Driscoll, 1994; Kintsch, 1991; Klein, 1998). In diverse professional contexts, the work itself is an exercise in narrative. For instance, in law, lawyers tell and retell stories about events on behalf of their clients in order to support, or counter, their cases (Bennett & Feldman, 1981). A study of storytelling between newly qualified and experienced anaesthetists showed that technical know-how as well as experiences of horror and their implications for attention to patient safety were captured (Iedema, Jorm, & Lum, 2009). In hazardous industry, too, engineering professionals 'debate' and resolve technical and organisational questions through narrative-based strategies (Maslen & Hayes, 2020b). Organisational life itself has been shown to be an exercise in storytelling that constitutes action and interaction orders that, for example, can be mobilised to limit budget disputes (Czarniawska, 1997), manage stakeholders (Berry, 2001), present a particular political position (Gerteis, 2002) or to claim authority (Linde, 2009).

In requiring participants to undertake narrative-based reasoning (Edgell, Hull, Green, & Winchester, 2016; Maslen & Hayes, 2020b), cases offer, in effect, a form of experiential learning. As described in Section 6, experiential learning refers to a suite of approaches that focus on 'doing', as opposed to the seeing and listening that dominates lecture environments (Specht & Sandlin, 1991). Studies have suggested that experiential learning increases 'dynamic' knowledge—'highly interrelated chunks of knowledge that can be placed into action and are not confined to a predetermined set of contextual environments'—essential to problem solving (Feinstein, 2001). This is in contrast to the kinds of tasks that respond well to rule-driven approaches. As described in Section 6, this dynamic knowledge is relevant to development of engineering capabilities.

Cases are also vital in supporting a 'safety imagination', allowing workers to make links between the small, even banal, things that happen in every workplace and the potentially disastrous cumulative consequences of failed risk controls that are not addressed (Pidgeon & O'Leary, 2000). As Helms Mills, Thurlow, and Mills (2010) describe 'we rely on past experiences to interpret current events'. In this way, a story about a major crisis is much more than simply the compilation of a set of facts. It provides an interpretation of 'the significance that events have for one another' (Polkinghorne, 1988).

7.2 Use of cases in professional education

In undergraduate and ongoing professional education, case studies are most commonly used in medicine, law and business schools although use of this technique varies. Case based learning is ubiquitous in medical and legal education where cases are presented as real-life examples that aspiring professionals need to learn to directly inform their later professional decision-making. The discussion of cases is largely fact-driven and deductive and so designed to improve aspiring professionals' problem solving ability (Yoo & Park, 2014). In this environment, 'the instructor is the story teller. The student is the audience' (Herreid, 1997) and so learning is largely an individual (rather than group) experience. Even in this environment where cases are used to learn facts, recent publications have emphasised the extent to which case based learning can also be used to develop other less tangible but nevertheless important professional qualities such as a self-concept and professional caring (Kantar & Massouh, 2015).

Case based learning has also become ubiquitous in business schools, particularly under the influence of the Harvard Case Method (Jain, 2005). In this context, the use of cases is quite different. Cases are still problems to be solved (as in medicine) but with a much higher degree of uncertainty regarding the best solution. These cases are termed 'open' cases, as opposed to the 'closed' cases that can be preferred in other domains. As such, a teacher using case base learning in business 'never expects a discussion to go the same way twice; there are always novelties and unexpected turns in the conversation' (Herreid, 1997). The difference is partly because 'business education stresses the human condition and the subjective view' (Herreid, 1997). As Merseth (1991) explained, 'to a remarkable extent, the purposes and use of the case method turn on the nature of the body of knowledge that exists in the professional field'. In this type of case based learning where multiple solutions are possible, 'the learning comes from actually participating in the search for solutions' (Tripathy, 2008).

Cased based learning is much less common in engineering education. It has also traditionally had less of a focus on professional practice than law or medicine (Trevelyan, 2014). Instead, mostly engineering education is 'conventional' (Entwistle, Nisbet, & Bromage, 2005), principally focused on the transmission of rules and theories in lecture-based formats, despite research that has questioned the effectiveness of such approaches (Felder & Silverman, 1988; Mills & Treagust, 2003). There is increasing interest in innovative approaches to meet the demands of contemporary workforces, including the use of specific cases. Particularly in the context of tertiary education, the potential for problem based learning, which includes but also extends beyond the use of cases, is championed by some scholars as providing learning opportunities more closely aligned to the realities of professional engineering work (Lehmann, Christensen, Du, & Thrane, 2008; Perrenet, Bouhuijs, & Smits, 2000; Yadav, Phillips, et al., 2011; Yadav, Subedi, Lundeberg, & Bunting, 2011). Within this open inquiry approach, learning occurs in facilitated small groups and is centred on an unfamiliar problem, situation or task as defined, in part, by the student themselves (Savery, 2006). Other scholars have argued for project based learning in engineering, which is similarly self-directed and collaborative, but is more focused on the application of knowledge in combination with discipline courses on mathematics, physics and so on (Mills & Treagust, 2003).

As in the medical and business contexts, the guided inquiry of case based learning is another pedagogical approach that is gaining traction in engineering (Mitchell & Smith, 2008). Case based learning is distinct from other approaches in that, while learners are presented with a problem and are provided a space for open-ended exploration of the issues, there is greater structure allowing for learning to be more efficient, goal-directed, and focused on the key points of a given case (Srinivasan, Wilkes, Stevenson, Nguyen, & Slavin, 2007).[5] In a comparative study of case based learning in engineering and medicine, Bédard, Lison, Dalle, Côté, and Boutin (2012) found that, in engineering education, it was perceived to be of greater importance that the tutor act as a content expert. At the same time, it was also found that the collaborative nature of case based learning exercises in engineering reflects the collaborative nature of engineering and so implicitly prepares students for this work context. Pietroforte (1998) detailed the benefits of case based learning for civil engineering students focused on studying iconic failure cases such as construction collapses, structural failures and catastrophic building fires in detail. He noted that it is particularly valuable to give students an 'understanding [of] the environment of the engineering decision-making process and the variables that may affect it'. Some engineering educators have taken this path (Angelides, Poulopoulos, Avgeris, & Haralampous, 2000; Golias, Angelides, Marnas, & Vrakas, 2005), but case studies are still not a mainstream engineering education technique. Hallowell, Tatum and Rowings' (2014) article on future challenges and opportunities for construction engineering in particular noted that increased use of case based learning should be encouraged.

7.3 Learning from cases in a hazardous industry context

In a context in which organisations work to prevent failures before they occur, organisational learning forms part of disaster response, though it can be unclear whether this learning has happened post-disaster, as in the many cases of so-called 'failure to learn'. Some scholars have argued that in the time immediately following a disaster, organisations are most focused on and receptive to changes, leading to the argument that 'organizations responding to disasters learn in leaps—disaster by disaster—rather than smoothly over time' (Carley & Harrald, 1997, p. 312). This line of argument also assumes that the learning takes place in 'categories, one disaster type

[5] A comparative study of problem and case based learning in two medical students found that students overwhelmingly preferred case based learning due to its efficient use of time, greater accuracy and stronger emphasis on feedback. Medical students also felt case based learning more closely mirrored the realities of work, in which problem-solving is guided by senior colleagues rather than the result of open inquiry.

at a time' rather than in ways that are taken as generalisable across sectors. Even if this is the case—that an organisation has the ability to learn the most immediately following a major disaster, and may be at least more receptive to lessons within their 'category'—there is a prerogative to look to maximise the lessons that can come from a case given their infrequency.

Despite a working interest in specific cases, research aimed at supporting disaster prevention typically looks across a wide range of accidents to identify common causes and how to prevent them. With the insight that organisational factors contribute to disaster (Reason, 1997), has come the realisation that lessons on best practice to avoid recurrence are transferable across sectors. Knowledge about disasters mainly takes the form of models of causation with lists of factors to look for. As early as 1988, Kletz proposed a set of common factors in accident causation in the process industries that could be used to guide safety management specifically in that sector (Kletz, 1988). Other scholars have sought to distil lessons from disasters that are more broadly applicable. Based on his review of mine disasters and fatal incidents in Australia, Britain, Canada, New Zealand and the USA over two decades, Quinlan (2014) identified ten major causal pathways: engineering, design and maintenance flaws; failure to heed warning signs; flaws in risk assessment; flaws in management systems; flaws in system auditing; economic or reward pressures compromising safety; failures in regulatory oversight; worker or supervisor concerns that were ignored; poor worker or management communication and trust; and flaws in emergency and rescue procedures. Following this initial analysis, Quinlan looked for and found these factors in causal analyses of major disasters in other sectors, too. He maintained that these factors applied beyond the mining industry and so are broadly useful as foci for accident prevention.

In an effort to draw a more direct link between risk modelling and the causes of past accidents, Moura, Beer, Patelli, Lewis, and Knoll (2017) identified a list of 66 common attributes that they suggest form the basis of assessment of the validity of risk and safety studies. The list is based on their analysis of 238 accidents from a range of industries including aviation, hydrocarbon exploration, production and processing, and nuclear. Their framework is designed to be used as a risk assessment validation scheme but effectively includes a list of causal factors that should be considered in a high-quality safety study. Grant, Salmon, Stevens, Goode, and Read (2018) reviewed accident causation models by Leveson, Rasmussen, Perrow, Dekker, and Hollnagel to establish a list of common tenets that recognise system performance. They found many common features such as a focus on vertical integration, feedback loops, nonlinear interactions and emergent behaviours amongst other things, with each tenet capable of leading to either safe or unsafe system states. However, they also noted that they found 'little literature … whereby the dominant models had been tested in a predictive context' (Grant et al., 2018, p. 108). As described in Section 5.1.1, the safety literature on lessons learned from accidents focuses strongly on organisations and systems, with much less focus on what accidents mean for learning in the context of individual professional practice.

There is a second strand of safety research that has begun to address how engineering students and practitioners directly engage with stories of specific cases. While there is an established tradition of using hypothetical and historical scenarios in emergency management training (Pijnenburg & Van Duin, 1990; Smith, Dowell, & Ortega-Lafuente, 1999; Wybo, 2004), there is only a small literature specifically on the use of disaster cases in education regarding disaster prevention. For engineering students, proponents have argued that stories of previous disasters offer a historical appreciation of what can go wrong and introduce an organisational model of accident causation (Saleh & Pendley, 2012). Rae (2016) has written more critically about this practice, working to identify its purpose and value. Stories create a transformative learning environment because they link new knowledge to real-world environments and because they require work and imagination on the part of the learner. In Rae's words, 'A student has not fully attained a concept until they have had a chance to apply it themselves and relate it to their own experiences'. Rae argued the use of cases in this way may be better at communicating some forms of knowledge more than others. They are disconnected from the evidence and so the details can be muddled: nuances can be rendered black and white, speculation can become fact, and causation can be inferred through the temporal aspects of the story's telling.

Our previous contributions have shown how operational personnel in multiple sectors—chemical plant, nuclear power station, air traffic control—tell and listen to the stories of their colleagues as parables to nurture their ability to imagine possible outcomes and maintain a safety imagination (Hayes & Maslen, 2014). One participant described an experience of a major incident, which later became a story, in terms of 'being blooded', which served to fundamentally shift his sense of what was possible in future moments of decision-making. These experiences/stories need not be about a major disaster; even a relatively small unexpected event could 'scare' individuals into thinking differently. Stories are also embedded in work practices to support decision-making in the moment, as practitioners imagine possible narrative trajectories for their decisions. How would I go about telling a colleague's family if something went wrong? What if this decision landed me on the front page of the newspaper? These stories are not limited in their reach to the experiences and reasoning of individuals. Rather, stories are also a means through which engineers share lessons with colleagues including junior personnel.

In the project that preceded this piece of work, we have also addressed case based learning in a semi-formal professional development context. We detail these findings in relation to discussion approaches in Section 7.4.1.

7.4 Modes of case based learning

There are many approaches to case based learning. Tutors can use cases to teach different skills (analytical, conceptual, methodological, interpersonal). They can also use cases to focus on finding solutions or exploring different points of view. Depending on the pedagogical aims, the way that cases are facilitated differs, from various discussion-based approaches, to debates and role plays. Various disciplines favour some approaches to case based learning over others. In the following, we outline some approaches that are most pertinent to engineering professionals: discussion approaches; debate approaches; performance based approaches; and gaming approaches.

7.4.1 Discussion approaches

Many approaches to case based learning involve a facilitated discussion following presentation of case material. Discussion methods are commonly used in business (i.e. the Harvard method), law, and medical contexts, as noted in Section 7.2. Most simply, these approaches involve presentation of case material followed by facilitated discussion to support learners to appreciate the nature of the problem and possible solutions. The case material can take many forms, including verbal presentation, written, or film. The discussion can have differing levels of intervention on the part of the facilitator, and discussion questions can have different foci. In the following, we detail three broad 'versions'.

7.4.1.1 Decision case

A decision case takes as its focus a judgement or decision, requiring students to grapple with a problem that requires resolution. The goal of a decision case is to support learners' investigative, analytical, and problem solving skills. There is also a consideration of the consequences of different courses of action. As in an analysis case, learners are presented with a short scenario including the background to the problem and the actors involved that the learner/s need to respond to. Case materials include the scenario as written in a short paragraph, in addition to other documentation (charts, tables, graphs, letters and so on) that learners can work with to more fully appreciate the situation and how it might be solved. A more 'open' discussion typically follows.

Our own previous use of the Überlingen case most clearly fit in this category. Facilitators first introduced the case and screened a short film about the disaster. Facilitators then supported a small group of participants (4-12) to discuss the case for around one hour, with guiding questions focusing on the causation of the disaster, and any implications that this might have for participants' work. We observed that, in working through the case, participants adopted both abstract and narrative reasoning strategies to make sense of the new case. Engineering risk management principles provided one abstract framework for discussion of the efficacy of professional judgments and drawing equivalences across industries. Knowledge of organisational safety provided another set of abstract principles, providing a way to debate causation and so who was at fault, as well as providing a conduit through which discussants could extend their understanding of safety management. Participants also drew on a variety of stories as part of their reasoning including: personal stories or stories they had heard firsthand; well-known disasters; and narratives that were more hypothetical in nature, speaking about a potential course of events based on their observations. Engineering stories were persuasive, able to shift the thinking of colleagues in a way that other ways of reasoning sometimes could not. These two strategies were not mutually exclusive. Stories could serve to illustrate an abstract principle and abstract principles could be supported by stories (also see Edgell et al., 2016).

Within the group context, stories were principally used to explore issues that were not clear-cut and the stories themselves could be partial or ambiguous. Should we view the actions of Peter X in not stopping the project work as his failure to speak up? Or is this a case of organisational failure to have procedures in place to manage the operations/project interface? While both of these are possible realities and have links to participants' own experience, through analogy, the engineers worked to settle on the second interpretation in this case so as to apply a specific lesson to their own work. As one speaker commented, 'There's no better way to win an argument than with actual practical examples that you can bring up'. The members of the group that were highly respected due to more experience and organisational seniority told more and longer stories, often to debate points with their peers. This suggests that the status of the teller affects authority to tell stories in company environments (Linde, 2009). These debates not only related to values-oriented judgments. Participants used stories to settle technical questions with their peers. They interrogated elements of the scenario by applying multiple narrative lenses, in order to collectively assess and agree on the interpretation that fitted best (analogical reasoning). The engineers were very comfortable with turning to analogical strategies to address uncertainty, doing so on their own rather than as a result of facilitator prompts. The interpretations that they arrived at were also typically well resolved and in keeping with the arguments of specialist incident investigators.

One of the potential weaknesses of this approach is that some group members dominate the discussion. However, we observed that this case based learning format was highly collaborative (Maslen & Hayes, 2020a). In no group was there any difficulty in having a 90 minute conversation regarding the case in which participants engaged with the material and each other. However, workshops with fewer people necessarily had fewer opportunities for multiple interactions with colleagues. In workshops with larger numbers of people, the facilitators tried to ensure that everyone had an opportunity to voice their views although some speakers were more dominant than others. It seems likely that the conventional norm of 6 to 10 people in a group discussion such as this would be the optimal training number although some variation appears to be possible without a significant impact on the outcome (Bryman, 2001; Gilbert, 2001). Reflective of the collaborative nature of reasoning and learning in the workshops, we observed that it was important to have at least some personnel in the room with higher levels of expertise. In groups where there was a mix of experience levels, conversations tended to flow most freely, with those more experienced tending to share their observations and those less experienced asking questions or deferring to their senior colleagues' judgments. The facilitators reflected after Workshop 5 with only four participants that this group size would not have been workable had not all participants been highly experienced. All participants were able to actively contribute, though there was not the same pedagogic tone within the group as in cases where experience levels were mixed. There also appeared to be some advantages to having a mixture of engineering disciplines within training groups as we saw some cases in which participants learned from each other as a result of seeing different things in the case under study due to their differing backgrounds.

7.4.1.2 Directed case

Facilitators can also use cases within this format to develop learners' understanding of core concepts and factual information. It has development of critical thinking skills as a secondary objective. In this format, again, learners are presented with a short scenario. This approach differs in that the scenario is accompanied by a series of 'directed' questions, typically with closed-ended answers in which there is a clear right or wrong answer (Cliff & Curtin, 2000). The teacher or facilitator is tasked with regularly posing these questions to the group, that participants are then encouraged to publicly answer, in order to check comprehension, clarify misunderstandings, re-emphasise content and provide space for additional commentary or information. Evaluations of this approach claim that it is a good option in content-rich programs of study, with a similar capacity for the teacher to present facts and concepts, but with more space for critical analysis resulting in stronger outcomes for students (Cliff & Curtin, 2000). Due to the 'closed' format of cases (where there is a single 'right' answer), and the focus on the content, this is a commonly preferred strategy in some scientific and medical areas of study, such as anatomy, physiology and chemistry (Ayyıldız & Tarhan, 2013).

In one version of this approach, participants/students are provided with the case materials, such as a short video, in advance with the expectation that these are engaged with at home ahead of the session (termed the 'flipped' case) (Herreid & Schiller, 2013).

Given that this type of case is about learners finding the right answer in a complex situation, it is less useful in fostering the capabilities described in Section 5 where outcomes are more nuanced. It could be used, for example, as a way of teaching technical skills in the pipeline sector such as how to interpret inspection data or data from corrosion monitoring.

7.4.1.3 Problem based learning

Problem based learning (PBL) evolved over five decades ago from a student-centred, multidisciplinary educational philosophy led by North American health science educators (Barrows & Tamblyn, 1980). Medical educators recognised the need for students to develop a combination of a hypothetical-deductive reasoning process and expert knowledge in multiple domains set within a professional learning context. PBL was adopted in other medical schools during the 1980s and 1990s and became an accepted instructional approach across North America and in Europe (Savery, 2006).

PBL is structured, self-directed learning around an ambiguous and complex real-world problem, often initially not well-defined, with multiple or no known solution. In the attempts to solve the problem, learners develop critical thinking and problem-solving skills, problem synthesis skills, imagination and creativity, information search and evaluation skills, ability to deal with ambiguity and uncertainty, oral and written communication skills, and collaboration skills (Savery, 2006; Savery, 2015). Central to the methodology is the integration of content knowledge with skills development applicable to real-life situations. Working in groups, students interspersed team time with their independent investigation, reflection, and feedback, all 'guided' and challenged by the instructor.

Both case based learning (CBL) and PBL focus on the learner and the educator as a facilitator, and a problem is central to the learning process. However, the key distinguishing feature between the two is that PBL involves open rather than guided inquiry. It is less structured and has a stronger emphasis on developing self-directed learning, where the instructor plays a more passive role. Further, CBL provides cases that have solutions, whereas PBL offers problems that are often yet to be solved (Barrows & Tamblyn, 1980; Savery, 2006; Savery, 2015).

This method is used in student education to simulate professional working arrangements. Much of the work of professional engineers takes the general form of problem based learning. Using this method in the context of this project would involve setting an open ended public safety-related problem to be solved and then reflecting on the choices made. Given that it would hardly be distinguishable from normal working life, this option has not been taken forward for further development.

7.4.2 Performance based approaches

7.4.2.1 Role play

Role playing is a form of case based learning in which learners assume roles/characters and interact within a given scenario in order to prepare them for a situation they may encounter in their future working lives. The interactions are defined by a set of rules that govern the scenario (Hale Feinstein, Mann, & Corsun, 2002). Often, these role plays are based on common practical scenarios that may be encountered in a given profession (Andersson & Andersson, 2010), though there are also instances in which a role play can be based on an atypical case, such as a disaster.

The pedagogical intent of role playing is the creation of an 'authentic' learning environment, particularly when it comes to the development of interpersonal skills (Craig & Amernic, 1994; Hale Feinstein et al., 2002; Maier, Solem, & Maier, 1975), and the function of different actors in a given work context (García-Barrios, Speelman, & Pimm, 2008). In an engineering context, university students reported that courses taught through role play gave them a sense of the responsibility involved in being a practicing engineer (Andersson & Andersson, 2010).

However, reviews of the impacts of simulations compared with other teaching approaches have found mixed results (Randel, Morris, Wetzel, & Whitehill, 1992). While role play generates a general enthusiasm among learners the method introduces some risks (Craig & Amernic, 1994; Umapathy, 1985). First, that in the process of role playing, learners fall back on stereotypes or prevailing behaviours as they are aware of them (Craig & Amernic, 1994). Relatedly, as role playing relies on the interactions of individuals, some of whom may be novices, learners/actors may or may not respond in ways 'congruent with the objectives of the learning activity' (Hale Feinstein et al., 2002, p. 735). Management of this challenge requires that facilitators give 'baseline' understanding ahead of the activity. With learners enjoying this as a learning format, there is also the risk that, rather than being taken seriously, the role playing is thought of as fun rather than of educational value (Craig & Amernic, 1994; Loui, 2009). For the teacher, developing and facilitating role plays effectively is also far more demanding than other pedagogical modes (Druckman & Ebner, 2008).

In the context of public safety capability development, a role play could draw on a specific accident case in which learners are allocated roles of real people who made decisions that contributed to the accident development. Role playing decision-making processes from a range of perspectives can give insights into the logic of various courses of action. Role play could also be used in a normal operations context to practice particular communication skills such as having a difficult conversation on a safety matter with a colleague or superior. This has good potential for learning and has been taken forward for further consideration and development.

7.4.2.2 Gaming and game building

While some scholars do not substantively distinguish between role play, and the related strategies of simulation and gaming, others have argued that these are distinct enough that we need to treat them separately to understand their operation and evaluate their effectiveness (Hale Feinstein et al., 2002). Addy et al. (2018) note that game based learning often requires case based problem-solving nurturing the development of transferrable knowledge and skills. Gaming involves elements of role play, but is typically practiced by teams that are tasked with making managerial decisions such as the deployment of resources in a given scenario within a round- or turn-based framework (Horn & Cleaves, 1980; Wolfe, 1985). The learning environment in gaming is less dynamic due to the round-based approach, as time pauses while a decision is made and then progresses in leaps. Decisions are also bound by the outcomes of the previous round, and so developing 'what-if' scenarios, as we would seek out in the case of developing major accident prevention knowledge, is difficult if not impossible (Hale Feinstein et al., 2002). Teachers who have adopted game-based learning methods have concluded that such approaches increase student motivation, when compared to the lecture format (Hattie, 2009; Prensky, 2001).

Scholars have addressed game-based learning in engineering environments, though not specifically in the context of cases. Among masters level engineering students, one study used an online game to introduce the theoretical knowledge on structural concrete. The method was evaluated as meeting minimum learning requirements with extra 'joy' from students (Ebner & Holzinger, 2007). Other studies have investigated the use of games to teach various topics in engineering, such as construction management, digital signal processing, reaction kinectics, thermodynamics, supply chain management, and matters of sustainability. These are not always centred on a case or scenario. A review of the literature in this area points to four types of games (Deshpande & Huang, 2011), including drill based (to observe a particular phenomenon), exercise based (to select the appropriate technique to solve a set problem), and problem based (to trial different approaches based on different assumptions to resolve a challenge or problem). Only the fourth type relates to cases—termed 'mini-case' in which students are given a scenario and are typically tasked with coming up with a solution in this context. Four studies in industrial engineering (i.e. in production planning and control, and enterprise resource planning) have adopted a computer based 'mini-case' approach (Adelsberger, Bick, Kraus, & Pawlowski, 1999; Bringelson, Lyth, Reck, & Landeros, 1995; Lee, Lau, & Ning, 2006; Leger, 2006). All of these studies are focused on gaming for students (as opposed to practitioners). In software engineering, four studies report on a mini-case approach (Claypool & Claypool, 2005; Drappa & Ludewig, 2000; Emily & André, 2004; Martin, 2000).

Some scholars have adopted the language of 'edu-LARPing' (educational live action role-play) to describe these game-based experiential learning strategies, though there is very little research published under this banner. The idea was pioneered by Hellström (2016, 2017), who adapted 3D Game Lab to deliver secondary school political science through 'quests' and 'experiences' via the platform. These activities were supported by micro-lectures from the teacher. Other studies have applied this teaching approach to secondary economics (Koziej & Hellström, 2018) and drama (Mochocki, 2013). Looking at the application of this method, it perhaps differs most in its platform rather than its goals and function when compared to other gamified education, seeking to adopt a platform that students (here, millennials) are used to (based on their hobbies) into the education format (Cavaliere, Mulvaney, Seawright, & Swerdlow).

In comparison to being a participant in a role play, being the designer has substantial pedagogical benefits. This variety of case based learning is termed game building. In the words of Gamson (1972, p. 67), 'playing a game may be a more active experience than listening to a lecture, but developing a game is more active still'. Game building is underpinned by an 'enactivist' pedagogical approach that sees learning as embodied evolving through action in the world and knowing as co-authored rather than the result of the transfer of information from teacher to student (Li, Clark, & Winchester, 2010). Game building requires far greater clarity on the part of the learner over the roles, rules, goals, and resources within a given scenario (Ebner & Efron, 2005; Greenblat, 1975). In game building, learners are invited to construct their own game, in some cases in anticipation of it being played by others (Li, 2010). The literature emphasises designing digital games. Scholars have pointed to the ability of this approach to develop subject matter (such as in the mathematics and science domains) and generic skills such as problem solving, critical thinking, and creativity (Bottino, Earp, & Ott, 2012; Li, 2010). Evaluation has emphasised the enjoyment and empowerment of students (Li, 2010).

Scenario-based simulations are increasingly being used to generate hypothetical environments, where students interact to apply previous knowledge and practical skills to real-world problems. Additionally, capabilities including but not limited to communication, group work, leadership, and decision-making may be developed. Collaboration and knowledge sharing result from individuals working within a team. Simulations add a dynamic element to learning ‘representing reality, claiming fidelity, accuracy, and validity’ (Vlachopoulos & Makri, 2017, p. 4).

A well-designed game regarding design, construction, operation and modification of a pipeline could be an excellent tool for learning in this context. One advantage of a game over some other options is that it would particularly allow learners to explore the temporal aspects of decision-making in line with one or all the capabilities. As games and simulation are designed around learning goals it is up to the game/simulation developer to determine which capabilities will be the focus of the learning activities.

7.4.2.3 Public hearings and mock trials

Other performance based approaches centre on a particular scenario, such as a public hearing or mock trial. Again, learners are presented with a scenario on which the public hearing is based. Some group members role play as members of the hearing board. Others role play as different actors presenting to the board. This teaching approach is typically conducted over multiple sessions, to give participants the necessary time to develop the scripts or rules relevant to their roles. For instance, the hearing board would typically develop conduct and procedural rules to govern the behaviour of presenters and their own judgments. While presenters can work from pre-developed scripts, they can also benefit from developing their own scripts, though this is more labour and time intensive.

Relatedly, a mock trial also requires participants to assume different positions within a given scenario playing out in a trial context. Mock trials are understandably most commonly practiced in the law domain, but can also be of interest to students and practitioners in other fields to develop an understanding of the legal consequences of their actions. Mock trials can be facilitated in a formalised manner, though they can also be more informal. Their formal rules require two opposing sides, each with an attorney and witnesses. After a brief introduction, each side presents its case within allotted times, with time for cross-examination. Mock trials typically require work in advance to develop position papers that guide the role playing.

During the fieldwork linked to this project, some interviewees mentioned previous mock trial sessions held in the pipeline sector. They were clearly memorable, but the main lessons people had taken from these sessions were about the difficulty of defending one’s actions post hoc. Despite some level of enthusiasm, such sessions are not the most appropriate method of teaching to develop safety capabilities other than perhaps developing an appreciation of the personal consequences of being involved in an accident. This option has not been taken forward for further development.

7.5 Conclusions / summary

Of the discussion-based approaches to case based learning, a decision case best supports inquiry into the engineering capabilities that we identified. This approach allows for a more open-ended exploration of a case, supporting Capabilities 1, 2, 3, and 5 in particular. Of the performance based approaches, role play and gaming are most aligned with the capabilities. As part of a broader discussion of a case, inclusion of role play allows for learners to adopt the position of different decision-makers and so better appreciate their point of view, as well as providing an opportunity to practice advocating for safety and so on (Capabilities 4 and 6). Building on the MIT approach, gaming allows us to develop a form of experiential learning that takes in all of the capabilities as they will be called on over the life of a pipeline (Capabilities 1 – 6). In general, there was a good appetite among our research participants for opportunities for case based learning, including performative elements. With this in mind, and informed by the literature, we have developed a suite of case based learning options to take forward that include elements of case discussion as well as role play and gaming (see Section 10).

8 Accident cases

Having established the learning objectives, outcomes and capabilities, and identified the educational approach and case based learning activities most suited to public safety decision-making, the next stage of the work is to identify appropriate content material for the modules. Major disasters in hazardous industries are memorable because of their tragic consequences and rarity and so are effective cases for learning. This section presents a review of past accident cases to identify those that may be useful for learning the specific capabilities identified.

8.1 Cases chosen for review

The focus is on real disaster cases, but there are some decisions to be made regarding the mix of Australian versus overseas incidents and pipeline sector accidents versus accidents in other hazardous industries. In order to address possible liability / legal constraints and / or lack of information regarding real incidents, another option to consider is use of composite or imagined incidents as cases for learning in addition to real cases.

Possible cases may include:

- Major engineering failures during operations in other sectors e.g. Chernobyl, Bhopal, Three Mile Island, Space Shuttle explosions, Longford and Piper Alpha.
- Major engineering failures linked to project activity/major modifications/changing technology in other sectors e.g. Uberlingen, Westgate and other bridge failures, Grenfell Tower.
- Failures of complex systems due to unexpected interconnections e.g. The North East USA Blackout (2003), Wivenhoe dam and the Brisbane floods and the South Australia blackout.
- Pipeline sector failures either in operations or linked to project work e.g. San Bruno, Ghislenghien, Varanus Island pipeline explosion and the Massachusetts gas system failures.
- Industrial accidents involving hydrogen (and other potential future fuels) e.g. cases raised by ARIA (2009).

Several authors in the business school tradition of case based learning have summarised what makes a good case (Johnson et al., 2012; Tripathy, 2008) although Johnson and colleagues in particular noted that research is limited in this area. 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 five 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.

These principles have also been considered in selecting which cases to take forward, particularly the need for characters that learners can empathise with.

The accident cases chosen for analysis as candidates to support learning are shown in Table 11.

Table 11: Accident cases chosen for detailed consideration

Incidents	
1	Uberlingen air traffic control failure
2	Quebec Bridge collapse
3	Florida International University footbridge collapse

4	Enbridge pipeline rupture and oil leak
5	San Bruno pipeline rupture and fire
6	Hurricane Katrina and failure of flood defences
7	Ford Pinto fires
8	Challenger space shuttle loss
9	Texas City refinery explosion and fire
10	Flixborough explosion
11	Piper Alpha platform fire
12	Deepwater Horizon blowout
13	Longford gas plant fire
14	Dreamworld amusement ride failure
15	Beaconsfield mine collapse
16	Massachusetts gas distribution system failure

The cases were chosen because they are examples of failures of engineered systems that have significant consequences. Several were mentioned by interviewees and others appear in the pipeline engineering practice guide (Czornohalan et al., 2020). Others were included to give a mixture of pipeline sector cases and cases from other engineering-based sectors and also a mixture of Australian and overseas cases. Most have strong central characters whose decision-making can be explored. Accidents considered but ultimately not included were:

- Kjørbo hydrogen station fire and other hydrogen incidents
  Given the focus on future fuels, we sought to include accident cases involving future fuels into the disaster case set. There is not as yet sufficient information about the causes of the Kjørbo filling station to include it in this analysis. Similarly, for the 2019 hydrogen tank explosion at Gangwon Technopark (Korea). These may be included as more details become available.
- Magellan ammonia pipeline failure
  Another case involving a future fuel that might be of interest is the Magellan anhydrous ammonia pipeline failure in 2016. There is an NTSB pipeline accident brief available (see https://www.ntsb.gov/investigations/AccidentReports/Pages/PAB2001.aspx). The rupture was triggered by fatigue cracking due to external corrosion under disbonded coating although the NTSB analysis does not go in to the details of why corrosion management failed so questions of engineering capability are not addressed.
- Gellingen (Ghislenghien) pipeline failure
  This major pipeline accident in Belgium in 2004 killed 24 people, mostly emergency services workers who were attempting to control the gas leak. The pipeline failed due to third party damage that occurred during construction of a car park over the pipeline. The line failed two weeks after the construction work was complete. This disaster clearly illustrates the damage that can be caused by a pipeline rupture, but there is not sufficient information available (at least in English) to use this as a detailed learning case targeting engineering capabilities (such as decisions made around management of third party work near the pipeline).
- Lac-Megantic train derailment in Canada
  In this case 47 people died when a goods train comprising 63 tanker cars full of crude oil that was stationary above the town of Lac Megantic rolled into the town and derailed. It was parked unattended

overnight and the brakes were not correctly set. It is a good example of an organisational accident because the preconditions that led to the crew making this critical error had developed over an extended period. It is relevant to the pipeline industry as rail tankers are an alternative form of fuel transportation but it is not such a good example for engineering capabilities as the failures are largely operational and/or systemic.

Summaries of each case are included in the Appendix along with comments regarding how they illustrate the importance of each of the pipeline engineering capabilities.

8.2 Matching cases to capabilities

Having reviewed the details of each possible case, Table 12 summarises the relevance of each case to each of the target capabilities. Taken from Section 5, the capabilities are:

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

Table 12: Links between incident cases and capabilities

Incident	Links to capabilities					
	C1	C2	C3	C4	C5	C6
• Uberlingen air traffic control failure	C	B	A	A	B	A
• Quebec Bridge collapse	A	B	A	A	B	C
• Florida International University footbridge collapse	B	B	A	C	C	A
• Enbridge pipeline rupture and oil leak	A	A	A	C	B	C
• San Bruno pipeline rupture and fire	A	A	A	B	A	C
• Hurricane Katrina and failure of flood defences	A	A	B	C	B	C
• Ford Pinto fires	A	B	A	C	C	A
• Challenger space shuttle loss	B	B	B	A	A	A
• Texas City refinery explosion and fire	B	A	A	C	C	C
• Flixborough explosion	B	A	C	A	B	C
• Piper Alpha platform fire	B	B	A	C	B	B
• Deepwater Horizon blowout	B	B	A	C	A	C
• Longford gas plant fire	A	B	A	C	C	C

• Dreamworld amusement ride failure	A	A	C	B	B	A
• Beaconsfield mine collapse	B	B	A	B	B	A
• Massachusetts gas distribution system failure	B	B	A	A	A	C

Note:
A = strong links
B = some links
C = weak/no links or links not known

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 we have no information in these areas. Nevertheless, these capabilities have been highlighted in some iconic accidents.

8.3 Possible cases for learning

All accident cases considered have some merit for professional learning but thinking about the target audience of pipeline engineers, there would seem to be two pairs of cases that work particularly well. These cases also constitute good cases for learning based on the list in Section 8.1.

Firstly, for transmission pipeline engineers a combination of the San Bruno disaster and the Challenger space shuttle loss provide a pair of cases that cover all capabilities and include one case from the sector and one from a very different sector. For each of these cases, there is a large amount of written and multimedia material available to use as the basis of excellent content so these would seem to be a good choice.

For distribution sector engineers, a similar pair of cases are the Massachusetts gas distribution system failure and the Dreamworld accident. Again these cases cover all capabilities between them and include one case with familiar technology and one that is from a different sector. There are comprehensive investigation reports in each case.

As summarised in Table 13, these pairs of cases therefore provide content for decision case and role play learning options as discussed in Section 7.5.

Table 13: Discussion and role play learning options

	Decision case	Role play
Transmission engineers	San Bruno	Challenger
Distribution engineers	Massachusetts	Dreamworld

Also as highlighted in Section 7.5, gaming provides another possible learning option. One possible design would be a game focused around safety decision-making over the life of a pipeline including design/construction, operation and modification. Various accident cases also provide possible ideas of problems that could arise at various lifecycle stages as shown in

Table 14.

Table 14: Relevance of accidents to lifecycle stage

Lifecycle stage	Relevant accident cases
Design and construction	Quebec bridge, Florida International University footbridge, Hurricane Katrina flood defences, Ford Pinto, Piper Alpha
Operations	Enbridge pipeline, San Bruno pipeline, Challenger, Texas City refinery, Piper Alpha, Deepwater Horizon, Longford, Dreamworld, Beaconsfield
Modification	Uberlingen, San Bruno pipeline, Flixborough, Massachusetts

These ideas are further developed in Section 10.

9 Evaluating professional learning modules

The final stage in the PLD Framework and a critical aspect of professional learning is evaluation. Evaluation identifies the impact of a learning module on a professional's performance and behaviour. This is vital to understand, given that when the module is designed using the PLD Framework, all components of the learning design (objectives, outcomes, capabilities, educational approach, activities and content material) should align to the professional practice needs identified in the beginning of the PLD process. The needs are what the professional learning module ultimately seeks to address through the investment in employees' professional development (Topno, 2012). This section will now outline the most suitable approach to evaluation of professional learning modules.

9.1 Literature review

9.1.1 Importance of but difficulty in evaluating training

Good professional learning programs begin with an organisational gap analysis and end with the evaluation of the resultant learning (Gopal, 2008). As such, evaluation is best understood as a systematic process to determine the value of the learning module set against a developed criterion of comparison. Importantly, evaluation should determine whether participants have developed new knowledge and skills but can implement these within their respective workplace post-completion (Boulmetis & 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).

9.1.2 Workplace development/training evaluation models

There exists a lack of a definitive approaches to professional learning and its evaluation. However, an evaluation program must address the critical aspects of training, including the development of the professional knowledge base; competence and capability in professional action; and reflection (Kreber, 1999; Nicholls, 2001). For this project, training evaluation models that are systematic in their analysis have been reviewed to guide the development of suitable evaluation for our proposed professional learning modules. These evaluation models are designed and implemented around a series of inter-related components or levels. Of the various models presented, the most widely applied method is the Kirkpatrick Model (Reio, Rocco, Smith, & Chang, 2017). Kirkpatrick's four levels of evaluation introduced in a series of articles (Kirkpatrick, 1959a, 1959b, 1960a, 1960b) form the Kirkpatrick Model. Kirkpatrick's (1998) four levels are: (i) participants' reactions; (ii) participants' learning; (iii) changes in participants' behaviour (job performance); and (iv) desired results (organisational impact) (Kirkpatrick & Kirkpatrick, 2005).

The learner's reactions to the program are the focus of Level 1 and include assessment of the content, materials, instructors, facilities, delivery methods, etc. Evaluation at this level can be used to modify the program and ensure organisational support for the training program. Level 2 focuses on content evaluation and what the participants learned, as reflected in a changed attitude, increased knowledge, and/or skill. The extent to which employees apply their newly acquired knowledge and skills on the job is the focus of Level 3. This level of evaluation addresses learning transfer in the workplace. Level 4 is where organisations attempt to measure actual organisational changes due to training and place a monetary and/or numerical value on those changes (Kirkpatrick & Kirkpatrick, 2005; Kirkpatrick & Kirkpatrick, 2016). Despite the complexity, the evaluation across the levels increasingly provides more information. Kirkpatrick's levels represent a continuum of complexity from the individual to organisational performance (Reio et al., 2017).

While enormously influential, Alliger and Janak (1989) have critiqued Kirkpatrick's model on the assumption that each successively level is correlated, and that there is a causal relationship that informs each level as the learners progress through the program (Coldwell & Simkins, 2011). As such, and importantly, it has been argued that these levels and their inter-relationship must be recognised, and an evaluation strategy should 'assess one or more of these components and the inter-relationships between them.' (p. 145). Many subsequent evaluation training models have been developed on the foundation of the Kirkpatrick's model; however, they deviate slightly in light of recognised critiques. The proceeding section presents the most frequently used models other than Kirkpatrick's model and identifies their similarities and differences.

Bushnell (1990) developed the systems approach known as the input, process, output (IPO) three-stage model. These three stages reflect Kirkpatrick's first three levels. The input stage refers to the training program's delivery elements and its effectiveness, including trainer ability and materials, facilities, and equipment. The process stage reflects the delivery of the program. Short-term benefits characterise the output stage. Bushnell addresses Kirkpatrick's fourth level as a summative evaluation of the long-term benefits to the organisation's bottom-line by attempting to show the worth of training in financial terms (Reio et al., 2017).

Brinkerhoff's (1983) Six-Stage Evaluation Model is a circular, systematic approach to evaluation across six-stages. Five of the six stages theorised by Brinkerhoff closely reflect Kirkpatrick's model with the inclusion of an additional stage, stage one, which addresses what Brinkerhoff believes Kirkpatrick's model omits—an examination of the training needs analysis and instructional planning and development. Further, steps one to three are similar to Kirkpatrick's Level 1 evaluation and Stage 1 advocates for a needs assessment and identification of the training goals, Stage 2 evaluates the program design, and Stage 3 evaluates program implementation. (Brinkerhoff, 1987). Stage 4 evaluates the learning and is identical to Kirkpatrick's Level 2. Stage 5 evaluates behaviour and is similar to Kirkpatrick's Level 3 evaluation. Stage 6 evaluates how much learning transferred to the results, as does Kirkpatrick's Level 4.

The CIPP evaluation model, developed by Stufflebeam (1983), focuses on four phases of evaluation, including context, input, process evaluation, and product evaluation, to improve the functioning of a program. Context evaluation determines the extent to which the developed program goals and objectives match the organisation's assessed need, and how accurately these reflect the organisation and relevant work culture. Input evaluation involves examining the intended content procedures and activities of the program and determining if these support the goals and objectives identified in the needs assessment and context evaluation. This assessment assists in determining if the program's implementation best meets the assessed needs and goals and objectives. Critical to the CIPP evaluation model is the process evaluation, which is ongoing and systematic monitoring of the program. It guides the implementation of program strategies, procedures, and activities, and is a means to identify successes and failures. Product evaluation measures and interprets the attainment of training and development objectives. This stage evaluates organisational improvement achieved in the short term and long term and any intended and unintended consequences of improvement efforts. This frames the program evaluation not merely on its outcomes but also in terms of continuous improvement, accountability, costs, and program needs (Topno, 2012).

The context, input, reaction, and outcome (CIRO) model, another four-level framework, was developed by Warr, Bird, and Rackham (1970). Context evaluation involves obtaining information about the current situation to determine training needs and objectives. The context level identifies and evaluates training needs based on collecting information about performance deficiencies and based on these, sets training objectives at three levels:

- The ultimate objective: Elimination of a specific organisational deficiency.
- The intermediate objectives: The changes to the employees' work behaviours necessary if the ultimate objective is to be achieved.
- The immediate objectives: New knowledge, skills, or attitudes that employees need to acquire to change their behaviour and so achieve the intermediate objectives.

The CIRO assessment's input level analyses the effectiveness of the training courses in terms of its design, planning, management, and delivery. The reaction level systematically collects and analyses the reactions of program participants to make improvements. This level is similar to Kirkpatrick's Level 1, reaction evaluation (Reio et al., 2017).

The final level is the evaluation of the outcome in terms of what happened as a result of training. This is measured at three levels: immediate, intermediate, and ultimate evaluation, similar to Kirkpatrick's levels of learning and behaviour (Reio et al., 2017). Immediate evaluation attempts to measure changes in knowledge, skills, or attitude before a trainee returns to the job and best reflects the training program's effectiveness. Intermediate evaluation refers to the impact of training on job performance and how learning is transferred back into the workplace. Finally, the ultimate evaluation attempts to assess the impact of training on departmental or organisational performance in terms of overall results (Topno, 2012). Topno (2012) argues that a central difference between the CIRO and Kirkpatrick model is that the CIRO model advocates for measurements taken before and after the training has been carried out. Topno (2012) critiques the model in that it fails to consider behaviour and is best suited to management training.

Kaufman and Keller (1994) developed a five-level evaluation model designed to improve Kirkpatrick's model. The five-level evaluation model, while aligned with Kirkpatrick's four, is expanded by a fifth level that examines consumer satisfaction and societal impact. Level 1: Input and Process of Kaufman and Keller's evaluation model, is founded on the Kirkpatrick model but has been expanded to include enabling and reaction. Enabling evaluates the quality and availability of financial, physical, and resources (Topno, 2012). This level is an input to Reaction, which evaluates the efficiency and acceptability of the methods/processes in training. Level 2 is acquisition and evaluates the competency and mastery of a test group or individual in a controlled setting. Level 3 evaluates the application, by the individual or groups from the program, of the content of the training program. Level 4 evaluates the organisational outputs or the contributions and payoffs of the entire organisation, as attributed to the training. Return on investment is one metric used to determine overall success. Level 5 is the evaluation beyond the organisation and examines how programs enhance society and the environment surrounding the organisation (Kaufman & Keller, 1994; Reio et al., 2017).

Holton's three-level Human Resource Development (HRD) evaluation and research model (Holton, 1996) identifies three outcomes of training—learning, individual performance, and organisational results, all of which are still similar to Kirkpatrick's Levels 2, 3, and 4. The missing element is the first level, reaction (Holton, 2005; Holton, 1996). Holton stressed that reactions should not be considered a primary outcome of training. He believed that favourable responses and learning are not necessarily related (Holton, 1996; Holton & Naquin, 2004). His model shows reaction as influencing the learning outcome; thus, its influence is not entirely disregarded. Holton's model shows the expected result from training and the influences that promote or inhibit them. It is an excellent addition to the roster of training evaluation models since it identifies several variables known to affect the effectiveness of a training program.

Regardless of the evaluation model adopted, a critique of the most frequently used approaches suggests that an evaluation model should include a systematic, formative framework instead of a summative outcome and objective-oriented evaluation should be applied after the completion of the training program. This formative evaluation should focus on the entire education process and its achievement of clearly identified objectives that reflect the developed training program's desired changes. Assessment across all levels should be developed and informed by assessment techniques and indicators suitable for the descriptive and subjective nature of the assessment models. Factors that influence the success of the training program but sit outside of the learning must be considered, and where possible identification of causal relationships between the evaluation levels should be considered. There needs to be consideration of the complex relationship between behaviour and impact as acquired knowledge and skills necessarily equate to the behavioural changes or job performance.

This project's evaluation strategy, therefore, draws on the four levels of evaluation as articulated by the Kirkpatrick Evaluation Model. The Kirkpatrick Evaluation Model is the most widely accepted training evaluation model and best aligned with our approach to professional learning. In line with Kirkpatrick's model, the evaluation strategy is embedded in the professional learning module's design phase, as reflected in the Professional Learning Design (PLD) Framework. Also, and drawing on Brinkerhoff's (1983) Six-Stage Evaluation Model, the completed gap analysis determined the industry's required learning needs and informed the developed learning objectives. As part of a systemic approach, participants' development towards achieving the learning objective and outcomes will be assessed and evaluated during, immediately after, and when learners are back in the workplace. The evaluation strategy is presented in the proceeding section below.

9.2 Assessing and evaluating professional learning modules

To address the required systematic approach to learning and, therefore, evaluation it is important to understand the relationship between evaluation and assessment. Assessment refers to learners' performance; it helps identify if the participants are learning and where improvement in that learning is needed. Assessment is the on-going process of documenting knowledge, skills, attitudes and beliefs, usually in measurable terms. The goal of assessment is to make improvements and provide feedback as opposed to simply being judged. It allows for the determination of learner progress and facilitator/module effectiveness and as such it is process-oriented. Evaluation refers to a systematic process of determining the merit value or worth of the instruction or programme though the process of making judgments based on criteria and evidence. Evaluation helps to determine if the learning module has been effective i.e. if the learners have successfully met the module's objective and goals. It is product oriented and provides closure. Assessment improves the quality of learning while evaluation judges the quality of the product (both module and learner).

In short, evaluation determines if the learning outcomes of the module have been achieved (learner focused), and assessment determines the effectiveness and quality of the module (facilitator and module development focused). Both assessment and evaluation use methods and measures to judge student learning and understanding of the material for purposes of grading and reporting. However, assessment tends to focus on formative methods while evaluation focuses are most often thought of as summative methods for grading. The purpose of both summative and formative evaluation and assessment are identified in Table 15.

Table 15: Purpose of both summative and formative evaluation and assessment

Purpose of formative assessment of learners	Purpose of summative assessment of learners	Purpose of formative evaluation	Purpose of summative evaluation
To identify if the learners meet the pre-requirements of the module.	To assign grades or to identify what has been learned.	To ensure the needs of the learner are met.	To determine how objectives were met.
To determine if learning has taken place.	To establish proficiency.	To keep focus on learning objectives.	To determine if module had an impact.
To measure performance.	For placement or tracking.	To improve teaching to increase the potential for learning.	To determine learner satisfaction.
To gauge progress.	To satisfy CPD requirements.	To keep motivating students.	To determine if module is worth repeating and areas for improvement.
		To tailor teaching and module structure to the learners' needs.	To determine cost-effectiveness.

Adapted from Smith and Ragan (1999)

To gauge the effectiveness of the learning module it is important to evaluate and assess the module both while it's 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). Some examples of associated methods are listed in Table 16.

Table 16: Summative and formative evaluation and assessment methods

Techniques for formative assessment	Techniques for formative evaluation	Techniques for summative assessment	Techniques for summative evaluation
Demonstrations/practical exercises	Interviews	Post-test	Post-test
Performance evaluation	Assignments	Final paper	Surveys
Discussion questions	Surveys	Projects	Interviews
Observations	Focus groups	Performance	Peer evaluation
Pre-tests	Pre-tests/post-tests	Portfolio	Standardised test
Embedded questions/tests	Peer evaluation	Certification test	End of module evaluations
Intermediary tests/quizzes	Observations	Comprehensive final exam	
Practice tests	Reflective writing		
Reflective writing	Discussion		
Interviews	Minute paper		
	Informal discussion		
	Pilot study		

Adapted from Smith and Ragan (1999)

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 module. Kirkpatrick's evaluation Level 3 and 4 focuses on assessment of knowledge in the workplace and more broadly evaluate the success of the module.

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 requires 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 pedagogy and the designed learning outcomes and identified critical behaviours (see Section 4). In the case of evaluating the participant's attitude towards the task this may be determined by the trainers 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. As part of the development of the learning strategy and as identified in Stage 2 of the development framework, Kirkpatrick identifies the needs to determine critical behaviours and required drivers. This stage of the professional learning evaluates an individual's demonstration of critical behaviours as supported by the required drivers within the organisation. For the majority of individuals this level offers the truest evaluation of a program's usefulness. This can be carried out through observations and interviews. Surveys and close observation after some time are necessary to evaluate significant change, importance of change, and how long this change will last. Online evaluations tend to be more challenging to integrate. Three hundred and sixty degree feedback is a tool that many businesses use to evaluate these outcomes. Assessments can be developed around applicable scenarios and distinct key efficiency indicators or requirements relevant to the participant's job. Observations should be made to minimise opinion-based views of the interviewer as this factor is far too variable, which can affect consistency and dependability of assessments. Taking into consideration the opinion of the participant can also be too variable of a factor as it makes evaluation very unreliable, so it is essential that assessments focus on more defined factors such as results at work rather than opinions. Self-assessment can be handy, but only with an extensively designed set of guidelines.

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 of 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.

9.3 Conclusion

Kirkpatrick's Model is the most widely accepted description of best practice in formal education evaluation and so evaluation plans for our proposed professional learning modules will be based on this approach. How this applies in the case of each of the learning designs proposed is discussed for each option in Section 10.

10 Selected training options to take forward

Drawing together the conclusions regarding both preferred educational design and appropriate safety-related content, three professional learning module plans have been developed. These options emerged from the discussion of accident cases in Section 8 and are a combined workshop/role play (Option 1a and 1b – see Sections 10.1 and 10.2) and a game where engineers make safety-related decisions through the lifecycle of a pipeline and see the consequences of their choices play out (Option 2 – see Section 10.3).

All options are grounded in professional capabilities needed to support the base business of pipeline companies but include specific aspects linked to future fuels. Given the current working environment, preference has been given to online delivery where possible.

Section 10.4 covers some learning options that were considered and rejected as they do not support an educational design consistent with the principles of experiential learning described earlier in the report.

10.1 Discussion case and role play for transmission pipeline engineers (Option 1a)

10.1.1 Learning objective

- To develop in pipeline engineers capabilities to make decisions that reflect the paramount importance of public safety through the transition to future fuels and into the future.

10.1.2 Learning outcomes

- To apply lessons from previous accident cases to individual professional practice so as to maintain the industry's public safety record through the transition to future fuels.
- To make better decisions regarding public safety.
- To understand and explain the link between professional practice and public safety.
- To know when and how to act in the interests of public safety.

10.1.3 Key topics and related concepts

The proposed module targeting transmission pipeline engineers is a face-to-face workshop run in two 1.5 hour sessions, each exploring a case study using case based learning activities and reflection designed particularly for transmission pipeline engineers.

The first 1.5-hour session will involve a reflective discussion of the San Bruno pipeline rupture accident case. This allows workshop participants to explore the San Bruno case study, reflect on the decisions that were made in the lead up to the incident and discuss challenges and opportunities for different decisions. The focus will be on decisions regarding integrity management. A discussion case was selected in the first session to introduce participants to an accident case in a familiar professional context. The San Bruno case involves a transmission pipeline and is suitable as a discussion case that presents case material followed by a facilitated discussion to support participants to appreciate the nature of the problem and possible alternative responses that better support public safety. The San Bruno case is useful for reflecting on the importance of the following capabilities in particular:

- Use long term, foresighted reasoning, especially in the face of uncertainty
- Understand norms and values that inform actions
- Think systematically and understand interconnectedness
- Ground decisions in reality.

The second 1.5-hour session will involve a role play activity using the Challenger accident case. Challenger was selected to support learning about engineering decision-making in a non-engineering context which encourages participants to extrapolate learnings to their profession. Role playing is a form of case based learning in which participants assume roles/characters and interact within a given scenario to prepare them for a situation they may encounter in their future working lives. The Challenger was selected for the second session as it is a useful case study to reflect on the importance of the following capabilities in particular:

- Collaborate with and draw on the experience of others
- Ground decisions in reality
- Advocate for action and take responsibility.

Overall, the approach taken in this module option aligns with traditional conceptions of case based learning and is informed by experiential learning that allows for participants to experience the case studies, reflect on their experience and learn from this reflection and potential application to their professional practices.

10.1.4 Learning Activity 1: San Bruno pipeline failure discussion case (1.5 hours)

Engage: To engage participants, instructors introduce the first accident case, the San Bruno transmission pipeline failure:

> *In 2010 a gas transmission pipeline ruptured in San Bruno, a suburb of San Francisco. The result was an explosion and fire in which eight people died, many were injured, and 38 homes were destroyed. The events were triggered by project work but the source of the problem was soon found to be a weld poorly made in 1956 when the pipeline was installed. Integrity management activities in intervening years failed to find the problem.*

The discussion case activity begins with an introductory narrative of the disaster drawing on material provided in the NTSB Report and other documents from the NTSB investigation, the Hayes and Hopkins book, material available from the CPUC followup investigations and photos/video of the location and incident.

Explore: After participants listen to the case study scenario the next part of the activity involves an analysis of responses and alternative decision-making process to avoid the accident. Participants analyse the situation in small group discussions. Guiding questions could include:

- How did the integrity management (IM) system work at PG&E?
- How were worst case scenarios considered?
- What were the key inputs to IM at PG&E?
- How is risk considered in the formulation of IM priorities?
- How does grandfathering of standards requirements for maximum allowable operating pressure impact operation and integrity of the system?

Explain: Participants develop explanations for what they have observed by reflecting on the following questions in groups:

- Why did PG&E think that risk in the system was falling before the accident?
- What assumptions were made and how did these manifest in decisions made?
- What questions could senior management have asked that might have highlighted the gaps in the system?
- How might the organisation have assisted the IM engineers in making better choices?
- If you were hired to fix IM at PG&E after the accident, what are the key things you would have done?

Elaborate/Extend: Participants solidify understanding by connecting what they have learned to their own professional practice by reflecting on the following questions:

- What are the similarities to my own professional practice?
- What do I need to do to help avoid such an incident in my own work practice?
- Are there any aspects of my professional practice that I could improve on or work to maintain? For example:
  - How can I think long term and act in uncertain situations?
  - Can I improve how I apply Standards in my professional practice?
  - How might I be able to better identify the connections between my decision-making and potential outcomes?
  - How might I ground my decisions in reality?

- What are ten key criteria/lessons that you will draw on to inform your decision-making practices in the future?

10.1.5 Learning Activity 2: Challenger role play/game (1.5 hours)

Engage: To engage participants, instructors introduce the second accident case, Challenger. The role play activity begins with instructors showing the beginning of the BBC documentary 'A Major Malfunction' and stop the video at 17.45 to set the scene.

Participants are then shown a graph depicting O-ring damage data from previous flights and are prompted by instructors to talk through what the graph is indicating in risk terms.

After this initial discussion, participants are then assigned a role by dividing the group into three. One group plays the role of Larry Malloy, NASA Manager (Solid Rocket Booster Project), another group plays the role of Roger Boisjoly, Engineer at Morton Thiokol Inc and the third group plays the role of Allan McDonald, Director, SRB Project at Morton Thiokol Inc. The situation is then presented: Larry says that the launch should go ahead and given the data 'no other decision is possible'. Roger says the launch should not go ahead and that loss of the shuttle 'is predetermined. I knew in my gut it would fail'. Allan has to decide whether to support his engineers or give way to the argument to launch made by his client, NASA. The group is then given 10 minutes' preparation time before being invited to present their case regarding the launch decision from the perspective of their assigned role.

After a group discussion, instructors then play the documentary clips showing how these decisions played out in practice, the Challenger launch and subsequent loss of the shuttle to conclude the role play component.

Explain: Participants develop explanations for what they have experienced by reflecting on the following questions in groups:

- What are the underlying assumptions for the person in the role you played? What was their agenda? What were the challenges they faced in making decisions?
- What were alternative courses of action and how might the person whose role you played acted on these?
- How might the person in your role better:
    - Collaborate with and draw on the experience of others?
    - Ground decisions in reality?
    - Advocate for action and take responsibility?

Elaborate/Extend: Using the understanding gained in the previous stages, participants should build and expand on this though the application to real-world situations they have experienced and their workplace. Key questions could include:

- Do any aspects of the scenario presented in the accident cases relate to your own professional practice? Why/why not?
- How might you apply the lessons learned in your future practice?

10.1.6 Evaluate

Evaluation will take place in at least two stages.

During and immediately after completion of the module

Assessment and feedback of the module content and learning experience will be ongoing in practical exercises, observations, and discussion questions.

Immediately after the completion of the module, to assess the learning experience and evaluate if participants achieved the prescribed learning objectives, participants will complete a short semi-structured interview and/or survey. The questions would explore the following themes:

- Participants' understanding of role and safety and their development of capability

- Views of the module compared with other exercises, and their preference of learning mode.

<u>Assessment of module 3 – 6 months after completion</u>

Three to six months after completing the module, a follow-up assessment and evaluation of the module will be completed by participants. Follow-up reflection activities will be emailed to participants, such as a short survey with a mix of open and closed questions. Participants will reflect on their experience, including what they learned and the relationship between the module and the workplace. The responses will be assessed against the learning objectives and designed deliverables.

10.2 Discussion case and role play for distribution system engineers (Option 1b)

10.2.1 Learning objective

- To develop in pipeline engineers capabilities to make decisions that reflect the paramount importance of public safety through the transition to future fuels and into the future.

10.2.2 Learning outcomes

- To apply lessons from previous accident cases to individual professional practice so as to maintain the industry's public safety record through the transition to future fuels.
- To make better decisions regarding public safety.
- To understand and explain the link between professional practice and public safety.
- To know when and how to act in the interests of public safety.

10.2.3 Key topics and related concepts

The proposed module targeting distribution system engineers is a face-to-face workshop run in two 1.5 hour sessions, each exploring a case study using case based learning activities and reflection designed particularly for distribution engineers. The learning design is similar to option 1a, but the cases used are more relevant to the target audience.

The first 1.5 hour session is focused on the Massachusetts distribution pipeline failure in a discussion case activity. Participants are asked to evaluate the decisions made in the case study and develop alternative decisions to achieve better safety outcomes. A discussion case was selected in the first session to introduce participants to an accident case in a familiar professional context. The Massachusetts distribution pipeline failure case involves a distribution pipeline and is suitable as a discussion case that presents case material followed by a facilitated discussion to support participants to appreciate the nature of the problem and possible alternative responses that better support public safety. The case was selected as it supports reflection on the following capabilities in particular:

- Think systematically and understand interconnectedness
- Collaborate with and draw on the experience of others
- Ground decisions in reality.

The second 1.5 hour session focuses on the Dreamworld amusement ride failure. A role play game will enable participants to explore the scenario and the decision-making that occurred in the lead up to the accident. This case was selected for highlighting the importance of the following capabilities in particular:

- Use long term, foresighted reasoning, especially in the face of uncertainty
- Understand norms and values that inform actions
- Advocate for action and take responsibility.

Overall, the approach taken in this module option aligns with traditional conceptions of case based learning and is informed by experiential learning that allows for participants to experience the case studies, reflect on their experience and learn from this reflection and potential application to their professional practices.

10.2.4 Learning Activity 1: Massachusetts pipeline failure discussion case (1.5 hours)

Engage: To engage participants, instructors introduce the first accident case, the Massachusetts pipeline failure:

> *In September 2018, a series of fires and explosions occurred in north eastern Massachusetts when high pressure natural gas was released into a low pressure system. A hundred and thirty one structures were damaged, one person was killed and 29 people were injured. A cast iron gas main was being replaced with polyethylene by a contract pipeline service firm (Feeney Brothers). The mechanical work was completed but the pressure sensing lines from an upstream pressure regulator remained connected to the old main, meaning that the pressure regulation system opened, exposing the new system and downstream piping to upstream pressure.*

The case study could be presented using material from the NTSB Report along with pictures or media videos of the aftermath of the failure and those affected.

Explore: After participants listen to the case study scenario the next part of the activity involves an analysis of actions taken and alternative decision-making processes to avoid the accident. Participants analyse the situation in small group discussions. Guiding questions could include:

- Why did the system fail? What went wrong?
- What were the key inputs to design?
- Was the division of responsibilities between the operating company and the contractor clearly defined?
- Within the operating company, was the division of responsibilities between Engineering and Maintenance clearly defined?
- Who was responsible for checking the design?

Explain: Participants develop explanations for what they have observed by reflecting on the following questions in groups:

- How were worst case scenarios considered? How was risk considered in design?
- How was operational impact of mechanical work managed?
- Why did those involved think that the work was safe?
- What questions could senior management have asked that might have highlighted the gaps in the system?
- How might the organisation have assisted the project engineers in making better choices?
- If you were hired to fix project systems after the accident, what are the key things you would have done?

Elaborate/Extend: Participants solidify understanding by connecting what they have learned to their own professional practice by reflecting on the following questions:

- What are the similarities to my own professional practice?
- What do I need to do to help avoid such an incident in my own work practice?
- Are there any aspects of my professional practice that I could improve on or work to maintain? For example:
    - How might I be able to better identify the connections between my decision-making and potential outcomes?
    - How might I be able to better collaborate with and draw on the experience of others?
    - How might I ground my decisions in reality?

- What are five to ten key criteria/lessons that you will draw on to inform your decision-making practices in the future?

10.2.5 Learning Activity 2: Dreamworld role play/game (1.5 hours)

Engage: To engage participants, instructors introduce the first activity showing pictures or video footage of Dreamworld and the Thunder River Rapids Ride to set the scene.

After this initial discussion, participants are then assigned a role to explore a variety of engineering, operational and management perspectives and the decisions made in the lead up to the accident. Possible roles could be:

- Ride operator (4 years' ride operating experience at Dreamworld)
- Ride operator assistant (trained on the day of the accident)
- Training supervisor (responsible for training staff)
- Ride technician
- Engineering and technical manager (4 years' experience at Dreamworld)
- Engineering consultant (hired by Dreamworld management to assess the ride)
- Upper management
- Parent company.

The information about the role provided to participants includes their job description, reporting lines, and knowledge about the history of the ride and tasks for the day.

The case study scenario could cover modifications made to the ride in the years before the accident, past problems with the ride, engineering certification of the ride and/or actions on the day of the accident.

Reflective questions can assist in decision-making points. For example:

- What is the situation—what do you know about it from the case information?
- What issues are at stake? (Opportunity for linking to theoretical readings)
- What problem(s) need to be solved? (Opportunity to discuss communication versus conflict, gaps between assumptions, sides of the argument)
- What are all the possible options? What are the pros/cons of each option?
- What are the underlying assumptions for [person X] in the case—where do you see them?
- What criteria should you use when choosing an option? What does that mean about your assumptions?
- What decision will you make?

After a decision is made by each participant or team, the scenario moves on and more information is provided. Materials such as news broadcasts could be used to prompt reflection on key points. The ABC's 7.30 report could be particularly useful for this.

To conclude the role play, participants are shown the full description of the accident as presented in the 7.30 Report.

Explain: Participants develop explanations for what they have observed by reflecting on the following questions in groups:

- What were the problems that arose in the lead up to the incident?
- What are the underlying assumptions for the person in the role you played? What was their agenda? What were the challenges they faced in making decisions?
- What were alternative courses of action and how might the person whose role you played act on these?
- How might the person in your role better:
    - Think long-term and act in uncertain situations?
    - Apply Standards in professional practice?
    - Advocate for action and take responsibility?

Elaborate/Extend: Using the understanding gained in the previous stages, participants should build and expand on this though the application to real-world situations they have experienced and their workplace. Key questions could include:

- Do any aspects of the scenario presented in the accident cases relate to your own professional practice? Why/why not?
- How might you apply the lessons learned in your future practice?

10.2.6 Evaluate

Evaluation will take place in at least two stages.

<u>During and immediately after completion of the module</u>

Assessment and feedback of the module content and learning experience will be ongoing in practical exercises, observations, and discussion questions.

Immediately after the completion of the module, to assess the learning experience and evaluate if participants achieved the prescribed learning objectives, participants will complete a short semi-structured interview and/or survey. The questions would explore the following themes:

- Participants' understanding of role and safety and their development of capability
- Views of the module compared with other exercises, and their preference of learning mode.

<u>Assessment of module 3 – 6 months after completion</u>

Three to six months after completing the module, a follow-up assessment and evaluation of the module will be completed by participants. Follow-up reflection activities will be emailed to participants, such as a short survey with a mix of open and closed questions. Participants will reflect on their experience, including what they learned and the relationship between the module and the workplace. The responses will be assessed against the learning objectives and designed deliverables.

10.3 Game based simulation scenario (Option 2)

10.3.1 Learning objective

- To develop in pipeline engineers capabilities to make decisions that reflect the paramount importance of public safety through the transition to future fuels and into the future.

10.3.2 Learning outcomes

- To apply lessons from previous accident cases to individual professional practice so as to maintain the industry's public safety record through the transition to future fuels.
- To make better decisions regarding public safety.
- To understand and explain the link between professional practice and public safety.
- To know when and how to act in the interests of public safety.

10.3.3 Key topics and related concepts

Pipeline engineers know that safety is important despite a clear lack of feedback regarding the impact of poor decision-making, given the excellent safety record of the Australian industry. From a learning perspective, the downside is that learning occurs when learners (re)construct their mental models, habits, and beliefs through active engagement with the issues and thinking through feedback associated with their experiences (both good and bad). The safety record means that such opportunities are limited. Game and simulation learning provide participants with a framework of rules and roles through which they can learn interactively through a live experience. They enable learners to experience situations they don't normally access and to make decisions they might not be prepared to risk in reality.

The proposal is to develop a game/simulation for groups of players (either face to face or online) to make decisions impacting safety through the lifecycle of an imaginary pipeline and see the consequences of their choices play out as the game proceeds. Possible choices to be made and outcomes seen will be developed based on past accident cases (as described in Section 8.3). The game/simulation will likely include a facilities modification stage linked to future fuels project work.

Pipeline engineers will participate in a game simulation module that will allow them to experience, in real time, the complexity of the local and distal, short and long-term impacts of professional decision-making and associated capabilities vital to informing such actions within a controlled learning environment. The game simulation will compress and/or expand time and space, allowing learners, for example, to experience decades in the life of a hypothetical pipeline in a few minutes and offer multiple outcomes to the dilemma presented over this period. This 'real-time' experience is important for pipeline engineers given their decisions and actions have the potential to contribute to catastrophic accidents.

10.3.4 Learning activity

Engage and Explore: Constructivist methods of education focus on experimentation that provides rich feedback from close engagement with the material. This game-based simulation module will present the complexity of operational and strategic issues associated with public safety through lifecycle stages of a hypothetical high-pressure gas pipeline and/or an old operational pipeline that requires extension that traverses rural to metro areas within a large state in Australia. The overall objective of the game simulation is for participants to safely manage the pipeline lifecycle as a range of 'events' occur across its lifecycle that may lead to catastrophic outcomes for safety. The 'events' will be drawn from lessons learned from previous catastrophic accidents (from across different industries and locations) and contextualised into a hypothetical pipeline context.

Within the module, the learner will assume a role that bears some level of responsibility for the operational safety of a high-pressure gas pipeline or associated work/operations around the pipeline that may present a risk to its integrity. Participants will play-act as their character to reason their way through controlled ambiguity (a presenting problem, challenge, or a debate) within which they must make decisions. Participants will be directed towards goal-oriented problem solving involving multiple stakeholders and the need to make meaningful choices that reflect day-to-day professional practice. As part of the design of the module, key incidents or situations will arise, based on actual events from the case identified by the project that led to catastrophic consequences. These events will be adapted to a pipeline design/construction/operation/modification scenario and presented as a problem that requires solving and managing by participants. Participants will be required to make decisions within the context of their hypothetical organisation and the information provided. The outcome will depend on the choices made by the participants. Participants may be aligned to different stakeholder groups or sections within an organisation or team and each will bring something different to the game as well as requiring them to combine their knowledge in order to make progress.

The simulation and associated 'events' will be designed such that participants will need to draw on the capabilities identified in Section 5 which will be mapped to different 'events' and woven into active individual and group reflection activities throughout the learning experience.

The reflective experiences will enable participants to subconsciously and actively experience the capabilities as part of their hypothetical practice and to consciously reflect on the importance of these capabilities when reviewing the outcomes of decisions made. This game simulation will embed engineers in a learning environment that encourages reflection on the perceptions, attributions, and other mental models used to interpret experience as well as the substantive lessons of the situation.

Explain: Learners develop explanations for what they have already observed. In the simulation, guided by a set of parameters, the learners undertake to solve problem 'events' that threaten the integrity of the pipeline and compromise public safety. Each 'event' will be developed within the context of 'real' pipeline activities but the fundamental 'threat' will be drawn from real case examples identified as part of this broader project. Additionally, the resultant decisions/actions will align and require participants to draw on the key capabilities and good practice behaviour underpinning this project, identified as essential to pipeline engineering practice. As part of the learning process, participants will be required to participate in two stages of reflective practice:

- As decisions/actions are being made at each 'event' participants will reflect on the skills/capability employed in the process as well as their agreement with the outcomes decided upon.
- A reflection on the overall management of the pipeline and the role of all stakeholders.

Elaborate/Extend: Solidify understanding by connecting what they have learned to something real. Given the 'event' is based on real cases, as the debrief progresses the cases as they played out in society will be explored to illustrate that, while being discussed as a hypothetical event, the relevant capability is important given what happened. Further, discussion in relation to the participants' own assessment of their capabilities and their relevance to their professional practice will also be explored. Key questions could include:

- Do any aspects of the scenario presented in the accident cases relate to your own professional practice? Why/why not?

- How might you apply the lessons learned in your future practice?

10.3.5 Evaluate

Evaluation will take place in at least two stages.

<u>During and immediately after completion of the module</u>

Assessment and feedback of the module content and learning experience will be ongoing in practical exercises, observations, and discussion questions.

Immediately after the completion of the module, to assess the learning experience and evaluate if participants achieved the prescribed learning objectives, participants will complete a short semi-structured interview and/or survey. The questions would explore the following themes:

- Participants' understanding of role and safety and their development of capability
- Views of the module compared with other exercises, and their preference of learning mode.

<u>Assessment of module 3 – 6 months after completion</u>

Three to six months after completing the module, a follow-up assessment and evaluation of the module will be completed by participants. Follow-up reflection activities will be emailed to participants, such as a short survey with a mix of open and closed questions. Participants will reflect on their experience, including what they learned and the relationship between the module and the workplace. The responses will be assessed against the learning objectives and designed deliverables.

10.4 Other options considered

There are other possible professional learning options that were raised in industry discussions that we do not propose to take forward but are worth documenting in order to explain why.

Both options support individual lifelong learning for pipeline engineers but do not provide experiential learning in the way our professional learning framework describes as best for learning.

10.4.1 Online database and Safety Alerts

The approach to learning would be to provide an online communication platform that gives pipeline engineers the opportunity to engage with and share in short, written narratives of disaster. In the empirical research that we conducted as part of this research (see Section 5) engineers described keeping abreast of safety matters and their implications for their practice through searching online for incident information, and through ad hoc information on incidents disseminated via email. There was evidence that access to cases in this way was not as well developed as practitioners would like.

In this context, an online database of cases could be established. Cases could be either an historical disaster case, or a recent event. Some of these incidents could be within the pipeline sector, others could be drawn from other sectors, providing they have relevant lessons. Future fuels cases could be added as information becomes available. Links to additional resources could be provided, as well as questions to encourage reflective practice, and some activities for the workplace. New cases could be notified to users via a Safety Alert system.

This approach does not align with traditional forms of case based learning in which learners are engaged in real world scenarios in interaction with participants face-to-face with a facilitator (see Section 7). Instead, this is a form of self-directed, ongoing professional development inspired by the case based learning philosophy designed to engage practitioners in learning outside a formal learning situation. Features such as the reflective questions and workplace activities serve as a (relatively weak) proxy for the group interaction and facilitator questions. Given that this does not conform to the pedagogical design principles established in the report, we do not recommend taking this option forward for further research on experiential learning.

10.4.2 Podcast series

Consideration was also given to preparing a series of podcasts on relevant accident cases, their causes and lessons to be learned. Podcasts would be downloadable for engineers to listen to at their convenience and as such would promote individual professional learning. Many of the cases listed in Section 8 would be amenable for this kind of treatment. As with a database, additional resources could be made available to encourage reflection and discussion but this would be completely at the discretion of users and not really part of the learning design of the podcast series per se.

Again, this approach does not align with case based learning principles. It sets the podcast commentator up as an expert providing information for listeners to absorb, rather than someone providing material to form the basis of a facilitated group discussion. Listening to podcasts does not of itself provide an opportunity for reflection. There is also no chance to hear different views and learn from them, no problem solving component to the learning design and no space to practice skills. Given these major limitations, this option is also not recommended for further research.

11 Conclusions

Existing professional development opportunities for pipeline engineers linked to public safety are focused on technical competence. This project addresses the capabilities that are also required to ensure that public safety is maintained in the transition to future fuels and into the future.

Drawing on the six stages of a professional learning design framework, four options for further development are proposed for consideration as shown in Table 17.

Table 17: Proposed professional learning module options

	Title	Description
Option 1a	Discussion and role play (transmission pipeline engineers)	2 x 1.5 hrs sessions face to face or online. The first is a presentation of the San Bruno pipeline failure followed by discussion of lessons to be learned etc. The second is a role play using the critical meeting in the Challenger disaster case between NASA and contract engineers. Participants will role play one of the key characters and reflect on lessons for their own professional practice.
Option 1b	Discussion and role play (distribution system engineers)	Similar to option 1a but using the Massachusetts pipeline system failure case for discussion and the Dreamworld amusement ride failure for the role play.
Option 2	The Pipeline Game	A game/simulation for groups of players (either face to face or online) to make decisions impacting safety through the lifecycle of an imaginary pipeline and see the consequences of their choices play out as the game proceeds. Possible choices to be made and outcomes seen will be developed based on past accident cases. The game/simulation will likely include a facilities modification stage linked to future fuels project work.

12 Implications and recommendations for industry

The output of this project are options for consideration by industry for further development.

13 Next steps and future works

This report is the final deliverable for project RP2.3-03 Case Based Learning Framework.

Following initial feedback from industry partners, proposals are now being developed for further work in accordance with Table 17.

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15 Appendix

Accident Case 1: Uberlingen

Description: Iconic air traffic control accident. Two aircraft collided in Swiss-German airspace in 2002 resulting in 71 fatalities. Project work in the Zurich ATC Centre meant that the controller was working with degraded equipment. Under pressure, he put two aircraft on the same flight level and failed to realise they were on a collision course until it was too late to effectively intervene. Independent systems designed to prevent the collision were ignored by the pilots in one aircraft. Middle management (operations and projects) were prosecuted.

Potential for experiential learning: This case works well to illustrate the importance of some of the defined capabilities. The video allows people to identify with the people and see parallels to their own work making it a good option for workshop-based learning designs. It is less suited to role play due to the different technology and the much shorter timescale for decision-making than the pipeline case. Could form the basis of a mock trial regarding poorly organised project work.

Materials available: Official investigation report (BFU) and several published papers including our previous work with this case. Cut down version of BBC documentary.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	•
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	• Importance of transition risk assessments • Safety critical risk controls not defined and so impact not identified
	• Making ethical choices	•
3. Think systematically and understand interconnectedness	• Understanding context	• Failing to understand the impact of the project work on the operating system

	• Prioritising actions in complex situations	•
	• Applying risk concepts	• No testing of backups
	• Taking enough time	• No time to reflect—all happened very quickly
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	• No checking as the second controller was on a break.
	• Knowing your limitations	• Controller did not call a second controller back from break when things got busy
	• Building a good relationship with field people	• Poor links between project and operations
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	• Operational impact of project work
	• Learning from small failures	•
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	• ATC let the project work go ahead, even though he was not happy • Russian pilot did not stand up to his senior in the cockpit

Accident Case 2: Quebec Bridge

Description: Iconic Canadian engineering failure. This 1907 bridge collapse during construction killed 75 workers. The standard design was inadequate in this bespoke application. There were many signs of trouble before the bridge collapsed during construction including major buckling of members.

Potential for experiential learning: This case works well to illustrate the importance of some of the defined capabilities. Could be used as the basis for role plays about standing up for safety / speaking up. Some aspects translate, but the different era of the accident means we don't have the voices of the people involved and it might be difficult for role players to see themselves in the shoes of those involved.

Materials available: Brady Heywood podcast https://bradyheywood.libsyn.com/episode-18-quebec-bridge-collapse, Krankis article.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Failed to see potential for collapse, even when structure started to buckle
	• Choosing with the long term in mind	• Expediency in design and construction overtook consideration of the practicality of the installed bridge
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	• Using standard specs for novel design
	• Understanding risk processes and concepts	•
	• Making ethical choices	• Overarching requirement was for a cheap project, despite novelty. Failed to prioritise worker safety.
3. Think systematically and understand interconnectedness	• Understanding context	• The required span tested engineering limits at the time, and yet a standard design was used
	• Prioritising actions in complex situations	• Edits to the standard specs to try to take the novel design requirements into account actually made things worse
	• Applying risk concepts	•

	• Taking enough time	• Spec changes done in a hurry so implications not realised. The whole project was a rush job with no time to reflect.
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	• Expert overseer had to do parts of the work because the base team was not competent
	• Knowing your limitations	• Standard bridge design not suitable for this bespoke application • Site engineer had a railway background and expert (Cooper) not paid for site supervision
	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	• Using a standard design in non-standard conditions
	• Learning from small failures	• Didn't see buckling as a sign of impending failure
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	•

Accident Case 3: Florida International University footbridge

Description: In 2018, a pedestrian bridge under construction at Florida International University in Miami collapsed during the middle of the day killing one construction worker and five motorists. Analysis following the collapse showed that formal checking of the design did not include checking for structural integrity at each construction stage and so failed to identify a lack of redundancy in the design in this partially constructed state. Despite extensive cracking over several days, no-one realised the bridge was about to collapse.

Potential for experiential learning: This case works well to illustrate the importance of some of the defined capabilities. Could be used as the basis for a fairly simple workshop or role plays, especially the response to cracks being found or the peer review scope not including intermediate states.

Materials available: US Department of Labor. (2019). *Investigation of March 15, 2018 Pedestrian Bridge Collapse at Florida International University, Miami, FL*. Retrieved from Washington, DC: https://www.osha.gov/doc/engineering/pdf/2019_r_03.pdf

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Various engineers failed to link cracks to potential for failure
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	• Could not explain why cracks were occurring and yet did not act conservatively e.g. close the road
2. Understand norms and values that inform actions	• Using standards	• Did not follow standard requirements for checks at intermediate states
	• Understanding risk processes and concepts	•
	• Making ethical choices	• Did not consider impact on road users
3. Think systematically and understand interconnectedness	• Understanding context	• Neither the design nor the peer review considered the strength of the bridge in a partially constructed state
	• Prioritising actions in complex situations	•
	• Applying risk concepts	• Failed to consider transition i.e. partly constructed states in consideration of risk. Traffic allowed to continue under construction activity.

	• Taking enough time	•
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	•
	• Knowing your limitations	•
	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	•
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	• Design and build contractor deferred to client engineer regarding action on cracks (not clear what they thought about the cracks)
	• Standing up for public safety	• Not clear if any individuals wanted to take action once cracks started

Accident Case 4: Enbridge Pipeline failure

Description: On 25 July 2010, during a routine shutdown, Enbridge's diluted bitumen (dilbit) pipeline failed near Marshall, Michigan. Alarms went off, but were not seen as an indication of leakage. The operations people failed to realise what was happening for many hours until they received complaints about the smell of the leaking oil.

Potential for experiential learning: Could be used as a workshop encouraging people to be in the shoes of the operators—would they have acted? Or mock trial trying to defend integrity management decision-making.

Materials available: NTSB Report, Hayes and Hopkins book.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Did not understand that the line had failed for some hours after it happened
	• Choosing with the long term in mind	• Short term focus in inspection responses to try to delay repairs
	• Dealing with uncertainty	• Uncertainty in inspection results interpreted optimistically
2. Understand norms and values that inform actions	• Using standards	• Over focus on compliance
	• Understanding risk processes and concepts	• Attitude of compliance, rather than assessment of risk
	• Making ethical choices	• No consideration of ethics
3. Think systematically and understand interconnectedness	• Understanding context	• Control room alarms not linked to real outcomes
	• Prioritising actions in complex situations	•
	• Applying risk concepts	•
	• Taking enough time	•
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	•
	• Knowing your limitations	•

	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	• Operational problems explained away
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	•

Accident Case 5: San Bruno Pipeline Failure

Description: In 2010 a gas transmission pipeline ruptured in San Bruno, a suburb of San Francisco. The result was an explosion and fire in which eight people died, many others were injured, and 38 homes were destroyed. The events were triggered by project work but the source of the problem was soon found to be a weld poorly made in 1956 when the pipeline was installed. IM activities in intervening years failed to find the problem.

Potential for experiential learning: This case works well to illustrate the importance of some of the defined capabilities. Could be used as the basis of workshops or for mock trial.

Materials available: NTSB Report, Hayes and Hopkins book.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• IM, Projects both failed to link actions and consequences
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	• Lots of fantasy planning going on
2. Understand norms and values that inform actions	• Using standards	• Grandfathering
	• Understanding risk processes and concepts	• Grandfathering
	• Making ethical choices	• Grandfathering
3. Think systematically and understand interconnectedness	• Understanding context	• Failed to identify the impact of project work on the operational system • Incorrect data in the IM system
	• Prioritising actions in complex situations	•
	• Applying risk concepts	• Failed to identify the impact of project work on the operational system • IM system errors—averaging risks
	• Taking enough time	•

4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	•
	• Knowing your limitations	•
	• Building a good relationship with field people	• Project work impacted operations in unexpected ways
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	• Evidence of problems ignored
	• Be sceptical of models and calculations	• Believed the IM model despite evidence of problems
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	•

Accident Case 6: Hurricane Katrina—design of flood protection system

Description: The design of the Louisiana hurricane protection system and its field operation during Hurricane Katrina was used in the Pipeline Engineers Practice Guide to illustrate the value of thinking in the long term.

Potential for experiential learning: The main source of detailed information is quite technical. It describes flaws in thinking but at an organisational level. Possibly not as useful as some other cases.

Materials available: US Army Corps of Engineers report.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Silo based design
	• Choosing with the long term in mind	• Ad hoc changes with little view of the long term
	• Dealing with uncertainty	• Design basis changed, but full design not revisited
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	• Design not well linked to risk concepts
	• Making ethical choices	• Didn't understand the consequences of failure
3. Think systematically and understand interconnectedness	• Understanding context	• Didn't see the system as having to operate as a whole
	• Prioritising actions in complex situations	•
	• Applying risk concepts	•
	• Taking enough time	•
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	•
	• Knowing your limitations	•
	• Building a good relationship with field people	•

	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	• Some system could not be accessed to operate
	• Learning from small failures	•
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	• Did anyone foresee problems?

Accident Case 7: Ford Pinto

Description: In the late 1960s, Ford Motor Company engineers were working on a new small car for release into the US domestic market. Design and production processes were accelerated due to market considerations regarding release of competing models from GM and overseas manufacturers. Crash testing of the new Ford Pinto revealed that the fuel system was likely to be punctured in even a low speed rear end collision. Engineers reported the problem to management but their concerns were ignored. The car was released onto the market. The resultant crash performance led to major reputational damage for Ford.

Potential for experiential learning: Input for role play regarding speaking up to management.

Materials available: Various books and articles.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Senior management did not seem to link decision with public deaths
	• Choosing with the long term in mind	• Chose to address the short term issue of getting a car on the market but did not address the longer term potential for reputational damage
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	•
	• Making ethical choices	• People died as a result of short term expedient decision
3. Think systematically and understand interconnectedness	• Understanding context	• Decision was driven by context factors
	• Prioritising actions in complex situations	•
	• Applying risk concepts	• Poor risk tradeoff
	• Taking enough time	• No time to fix the problem due to market competition
	• Build networks or seek others' opinions	•

4. Collaborate with and draw on the experience of others	• Knowing your limitations	•
	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	•
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	• Engineers' concerns were ignored
	• Standing up for public safety	•

Accident Case 8: Challenger

Description: NASA Space Shuttle Challenger was lost on liftoff in 1986, killing the crew of seven astronauts. The loss resulted from failure of o-ring seals in a joint on the solid rocket boosters that allowed hot gases to escape, impinging on the fuel tank and causing structural failure which then led to the shuttle breaking apart. The o-rings themselves failed due to the cold weather on the morning of the launch but the safety of the design of the joints that required these seals and the impact of weather on the o-ring performance had been the subject of discussion within the project team for some time. The contractor tried to get the launch delayed but their concerns were ignored.

Potential for experiential learning: Good case for a workshop. Can use as a role play / discussion about how to make a case.

Materials available: BBC documentary. New Netflix documentary? Lots of published materials.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• NASA did not think loss of shuttle was possible
	• Choosing with the long term in mind	• Design option was chosen for political reasons
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	•
	• Making ethical choices	• People died as a result of short term expedient decision to launch
3. Think systematically and understand interconnectedness	• Understanding context	• Decision was driven by context factors—political need to launch
	• Prioritising actions in complex situations	•
	• Applying risk concepts	• Poor risk tradeoff
	• Taking enough time	• Pressure to launch
4. Collaborate with and draw on the experience of others	• Build networks or seek others’ opinions	• System in place to seek views of others, but they were coerced into agreement

	• Knowing your limitations	•
	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	• Evidence of problems was dismissed
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	• Engineers concerns were ignored
	• Standing up for public safety	• Engineers tried to stand up but were ignored in the end

Accident Case 9: Texas City Refinery Fire

Description: On 23 March 2005, plant operators at the Texas City Refinery were restarting a distillation column after a routine maintenance shutdown. A series of operating errors meant that the column was overfilled with hydrocarbon liquids. The pressure relief system activated, and the excess fluids were released into the blowdown system. The blowdown system was also overwhelmed by the material being released from the distillation column. A massive vapour cloud originating from the blowdown stack was ignited by a nearby vehicle. The resultant vapour cloud explosion was heard several miles away. The blast wave damaged surrounding buildings causing 15 deaths and 180 injuries.

Potential for experiential learning: Some of this is operator error (rather than engineers'). Could run as a workshop and do some role play regarding grandfathering of vent system and trailer siting.

Materials available: Baker report, CSB animations, Hopkins books, other published reports etc.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Operators did not understand the consequences of overfilling the column
	• Choosing with the long term in mind	• Grandfathering of vent system
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	• Grandfathering of vent system
	• Understanding risk processes and concepts	• Grandfathering of vent system
	• Making ethical choices	• Grandfathering of vent system
3. Think systematically and understand interconnectedness	• Understanding context	• Restart, temporary trailer in poor location
	• Prioritising actions in complex situations	•
	• Applying risk concepts	• Trailer sited near operating unit
	• Taking enough time	•
	• Build networks or seek others' opinions	•

4. Collaborate with and draw on the experience of others	• Knowing your limitations	•
	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	•
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	• Did anyone argue internally for new flare system, different location for trailer?

Accident Case 10: Flixborough

Description: An explosion at the Flixborough chemical plant in the UK in 1974 killed 28 people. The plant produced an intermediary chemical used to make nylon. The process involved large volumes of cyclohexane circulating through a series of reactor vessels. Two months before the accident, one of the reactors was found to be cracked. The reactor was taken out of service and it was decided that a temporary bypass should be installed so that the plant could continue to run while a repair was made. The temporary bypass was not designed to standards and it failed in service.

Potential for experiential learning: May be useful for Capability 4.

Materials available: Many articles but not much electronic media due to the age of the event.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Did not link design to potential for disaster
	• Choosing with the long term in mind	• Manufacturing process itself was not inherently safe
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	• Did not know what appropriate standards to use
	• Understanding risk processes and concepts	• Did not understand the need for change control
	• Making ethical choices	• Did not link to potential for disaster
3. Think systematically and understand interconnectedness	• Understanding context	•
	• Prioritising actions in complex situations	•
	• Applying risk concepts	•
	• Taking enough time	•
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	• Unqualified people did not seek advice even though it was available
	• Knowing your limitations	• Bypass designed by unqualified people

	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	• Modification was not fit for purpose
	• Learning from small failures	•
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	•

Accident Case 11: Piper Alpha

Description: An operational error led to a leak and fire on the Piper Alpha platform in the UK North Sea in July 1988. The fire escalated through the facility ultimately causing its complete collapse and 167 people died.

Potential for experiential learning: Quite operationally focused, rather than engineering. The main engineering issues are in design. Could be used in a workshop to illustrate Capability 3.

Materials available: Cullen report and lots of other analysis. Many photos and videos, BBC re-enactment video. 2013 film.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Design done in silos
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	• Risk scenarios not commonly considered then
	• Making ethical choices	•
3. Think systematically and understand interconnectedness	• Understanding context	• Surrounding platforms did not shut down but continued to feed the fire • Confusion over work on pumps that caused initial leak
	• Prioritising actions in complex situations	• No effective leadership on the facility
	• Applying risk concepts	•
	• Taking enough time	•
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	•
	• Knowing your limitations	•

	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	• Potential for escalation not considered in design
	• Learning from small failures	•
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	• Surrounding platforms waited for approval to shut down

Accident Case 12: Deepwater Horizon

Description: A blowout occurred on the Deepwater Horizon drilling rig in the Gulf of Mexico during a well test. Eleven people died and a massive oil spill resulted.

Potential for experiential learning: The decision-making around the test is an interesting case study regarding interpreting data. Could be a useful role play regarding making the case to stop linking Capability 3 and Capability 6.

Materials available: Multiple investigation reports, Hopkins book, film.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Failed to link test feedback to potential for failure
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	• Focus on personal safety rather than system safety
	• Making ethical choices	•
3. Think systematically and understand interconnectedness	• Understanding context	• Driven by cost to cut corners
	• Prioritising actions in complex situations	• Failed to understand the data coming from the test
	• Applying risk concepts	•
	• Taking enough time	•
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	•
	• Knowing your limitations	•
	• Building a good relationship with field people	•

	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	• Didn't see it
	• Be sceptical of models and calculations	• Made up theoretical excuses for the data seen
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	• No-one said stop

Accident Case 13: Longford

Description: An explosion at the Longford gas plant in 1987 killed two people and caused major disruption to Melbourne's gas supply for several weeks. The leak that ignited as the result of a major operational problem that developed over hours. Despite major signs of trouble, the plant was not shut down.

Potential for experiential learning: Particularly good for Capability 3. Could be a good discussion case but a bit too process plant related?

Materials available: Royal Commission report, Hopkins book.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Didn't understand how serious the operating problems were
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	•
	• Making ethical choices	•
3. Think systematically and understand interconnectedness	• Understanding context	• Did not understand the impact of low temperature on the old plant
	• Prioritising actions in complex situations	• HAZOP identified 100s of action items but not prioritised and closed out
	• Applying risk concepts	• HAZOP identified 100s of action items but not prioritised and closed out
	• Taking enough time	•
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	•
	• Knowing your limitations	•

	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	•
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	• No-one said stop

Accident Case 14: Dreamworld

Description: A fatal accident at Australia's largest theme park, Dreamworld. In 2016, a raft carrying six people in the white-water rafting ride *Thunder River Rapids* collided with an empty raft causing it to flip. Four adults died. The Coroner's Report found that the design and construction of the ride along with 'multiple significant modifications' between 1987 and 2016 that were made without consideration of hazard consequences, posed significant safety risks for patrons. Required audits not done, staff not trained. Overall, an inadequate risk assessment and safety management system was in place, and engineering and technical staff were unqualified to undertake such tasks. Senior management failed to adequately assess and manage risks in compliance with regulations, heed consultant recommendations and ensure adequately trained engineers.

Potential for experiential learning: This type of scenario would be suitable for a discussion case, or role play based activity with participants taking on different roles within this scenario to identify opportunities for reaching better safety outcomes.

Materials available: Coroners Court report, an ABC 7:30 Report presentation (with an animated demonstration of the accident) along with other news reports, a peer-reviewed journal article (*Taming the wild river rapids: How process safety can apply outside the process industries* by Trish Kerin, 2020).

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• This case shows how worst-case outcomes were not considered by management, design or maintenance engineers
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	• Not following the Australian standard was noted as a key reason the ride could continue operating
	• Understanding risk processes and concepts	• Staff were not fully aware of risks and consequences
	• Making ethical choices	• There appeared to be a lack of consideration of the risk and responsibility to human life in the decisions made regarding the ride
3. Think systematically and understand interconnectedness	• Understanding context	•
	• Prioritising actions in complex situations	•

	• Applying risk concepts	•
	• Taking enough time	•
4. Collaborate with and draw on the experience of others	• Build networks or seek others’ opinions	•
	• Knowing your limitations	• The engineering team were not qualified to ensure compliance with Australian Standards or undertake risk assessments
	• Building a good relationship with field people	•
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	• Small failures of the ride were not learned from
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	• Staff expressed concerns however this was not heeded by management
	• Standing up for public safety	• Despite safety concerns from some staff and consultants, this message was only communicated with Dreamworld management rather than external regulators

Accident Case 15: Beaconsfield

Description: Beaconsfield Gold Mine (BGM) collapse in Tasmania, Australia resulting in the death of one miner, and the rescue of two miners after being trapped for 14 days. On 25 April 2006 a local seismic event due to mining activity caused three falls of ground. Increased seismic activity had been reported by operations staff to management and assessed by five different engineering consultants who made a range of recommendations including increasing ground supports. A State Coroner's inquiry in 2009 found that better risk assessment processes at BGM would have resulted in a reduced likelihood of Mr Knight's death.

Potential for experiential learning: This is a good case to explore advocating for action and taking responsibility because, although engineers were not deemed at fault, they identified issues that were not adequality acted upon by the mining company. Taking enough time to assess and manage risk identified is also a key learning from this case, along with imagining worst case scenarios and understanding context. This would be useful for a role play regarding how to better communicate upwards.

Materials available: Coroner Chandler's 2009 inquest report, Special Investigator Melick's 2007 Investigation report, a tele-movie available in full length on YouTube, media articles and news broadcasts.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Worst case scenarios were not acted upon by the mining company
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	• Inadequate risk assessment processes were present
	• Making ethical choices	•
3. Think systematically and understand interconnectedness	• Understanding context	• Lack of critical oversight regarding increasing pattern of seismic activity
	• Prioritising actions in complex situations	• Prioritising adequate ground support and risk assessment processes was needed
	• Applying risk concepts	•

	• Taking enough time	• Waiting for modelling and full risk assessment to take place could have prevented the death
4. Collaborate with and draw on the experience of others	• Build networks or seek others' opinions	•
	• Knowing your limitations	•
	• Building a good relationship with field people	• Engineers and management did not consult with personnel
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	• Rockfalls prior to the fatal incident were responded to by hiring consultants however full safety measures were not implemented
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	• Personnel and engineering consultants presented concerns and recommendations to senior management however these were largely unaddressed by the time the incident occurred
	• Standing up for public safety	•

Accident Case 16: Massachusetts gas system overpressuring

Description: In September 2018, a series of fires and explosions occurred in north eastern Massachusetts when high pressure natural gas was released into a low pressure system. A hundred and thirty one structures were damaged, one person was killed and 29 people were injured. A cast iron gas main was being replaced with polyethylene by a contract pipeline service firm (Feeney Brothers). The mechanical work was completed but the pressure sensing lines from an upstream pressure regulator remained connected to the old main, meaning that the pressure regulation system opened, exposing the new system and downstream piping to upstream pressure.

Potential for experiential learning: This is mostly an illustration of organisational problems (poor records, high staff turnover, no system for engineering checking). Could be used as a workshop case with distribution people including role play aspects regarding taking responsibility or mock trial.

Materials available: NTSB report.

Capability	Interview themes	Links to case
1. Use long term, foresighted reasoning, especially in the face of uncertainty	• Imagining worst case outcomes	• Did not connect work to potential for public safety issues
	• Choosing with the long term in mind	•
	• Dealing with uncertainty	•
2. Understand norms and values that inform actions	• Using standards	•
	• Understanding risk processes and concepts	• Poor change control
	• Making ethical choices	•
3. Think systematically and understand interconnectedness	• Understanding context	• Impact of mechanical work on the instrumentation was not foreseen
	• Prioritising actions in complex situations	•
	• Applying risk concepts	•
	• Taking enough time	•
	• Build networks or seek others' opinions	• Doesn't seem to have been any proper checking

4. Collaborate with and draw on the experience of others	• Knowing your limitations	• Junior engineer working beyond his experience (but expected to do so)
	• Building a good relationship with field people	• Poor links between engineering and M&R
	• Building external stakeholder relationships	•
5. Ground decisions in reality	• Making practical choices	•
	• Learning from small failures	• Multiple similar accidents have occurred in the past in the US
	• Be sceptical of models and calculations	•
	• Imagine being there	•
6. Advocate for action and take responsibility	• Influencing senior management and clients	•
	• Standing up for public safety	•

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