2.4

Risk Analysis and Risk Management Skills

Claire Lucas[a] *and Diana Martin*[b]

[a] Aston University, United Kingdom, ORCID: 0000-0003-2284-272X;
[b] University College London, United Kingdom, ORCID: 0000-0002-9368-4100.

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Risk analysis and risk management are foundational skills for engineers, traditionally taught using structured industrial methodologies such as Failure Modes and Effects Analysis (FMEA) and risk registers. However, the integration of software systems, global supply chains, and artificial intelligence has introduced new categories of risk — technical, ethical, environmental, systemic, and security related, that existing tools only partially address. In this chapter, you will be introduced to a framework that integrates established risk approaches with systems thinking, ethical reasoning, and professional judgement. The chapter moves beyond failure-focused models to explore questions of who benefits, who bears risk, and who holds decision-making power. It provides guidance on curriculum design, learning activities and assessment approaches, including scenario-based learning, project-based learning, ethical risk analysis, and behavioural marker systems for observing skills such as judgement, communication, and responsibility. Strategies are suggested for embedding risk education across programmes. Overall, the chapter supports you in preparing students for a complex and evolving risk landscape where uncertainty and moral considerations are as central as technical assessment

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1 Definition

At its simplest, *risk* is the possibility of an adverse outcome. It is typically expressed as a combination of the consequences of an event, and the associated likelihood and severity of occurrence. The term itself derives from the Italian *risco*, meaning danger. In engineering, risk analysis refers to the systematic identification, evaluation, and mitigation of factors that could negatively impact outcomes.

In engineering education, it is important to distinguish between the processes of risk analysis and risk management, and the skills which articulate the ability to carry out these processes. In this context, risk should be understood more widely as '*anticipation of adverse outcomes before failure occurs*'. These outcomes are not constrained to technical domains or immediate users or operators; rather they extend across social, environmental and ethical domains. In education, the priority must therefore be cultivating a mindset that equips students to recognise, question, and evaluate uncertainty systemically.

Risk analysis refers to this systematic process of identifying potential adverse events, evaluating their causes, estimating likelihood and severity, and analysing possible consequences. Risk management refers to the broader decision-making process through which risks are prioritised and addressed, encompassing actions such as mitigation, monitoring, and acceptance of residual risk.

Risk analysis and risk management skills describe the *capability of the engineer* to enact these processes effectively in practice. These skills extend beyond the application of tools and methods to include judgement under uncertainty, the ability to balance competing values, and responsibility for decisions that affect different stakeholders. In contrast to domain-specific processes such as project management, which focus on planning and delivery, risk-related skills are primarily concerned with navigating uncertainty, anticipating unintended consequences, and making defensible decisions in situations where outcomes are incomplete, contested, or unknown.

Graduates who can anticipate risk, communicate uncertainty, and balance competing values are therefore better prepared for roles that demand professional judgement rather than routine technical execution.

1.1 ISO 3100: key concepts and steps

The International Organization for Standardization (ISO) 31000 standard (ISO, 2018) defines risk as the "*effect of uncertainty on objectives*" and sets out principles of integration, structure, and continual improvement. The standard defines eight key terms, as shown in Fig. 2.4.1:

- *Risk:* the effect of uncertainty on objectives;
- *Risk source:* the element which alone or in combination has the potential to give rise to risk;
- *Event:* an occurrence or change of circumstance;
- *Consequence:* of an outcome or event;
- *Likelihood:* the chance of something happening;

- *Risk identification:* the process of finding and recognising risks;
- *Risk analysis:* the process of understanding the nature of risks and its characteristics;
- *Risk evaluation:* the process of comparing results of analysis with criteria to determine significance.

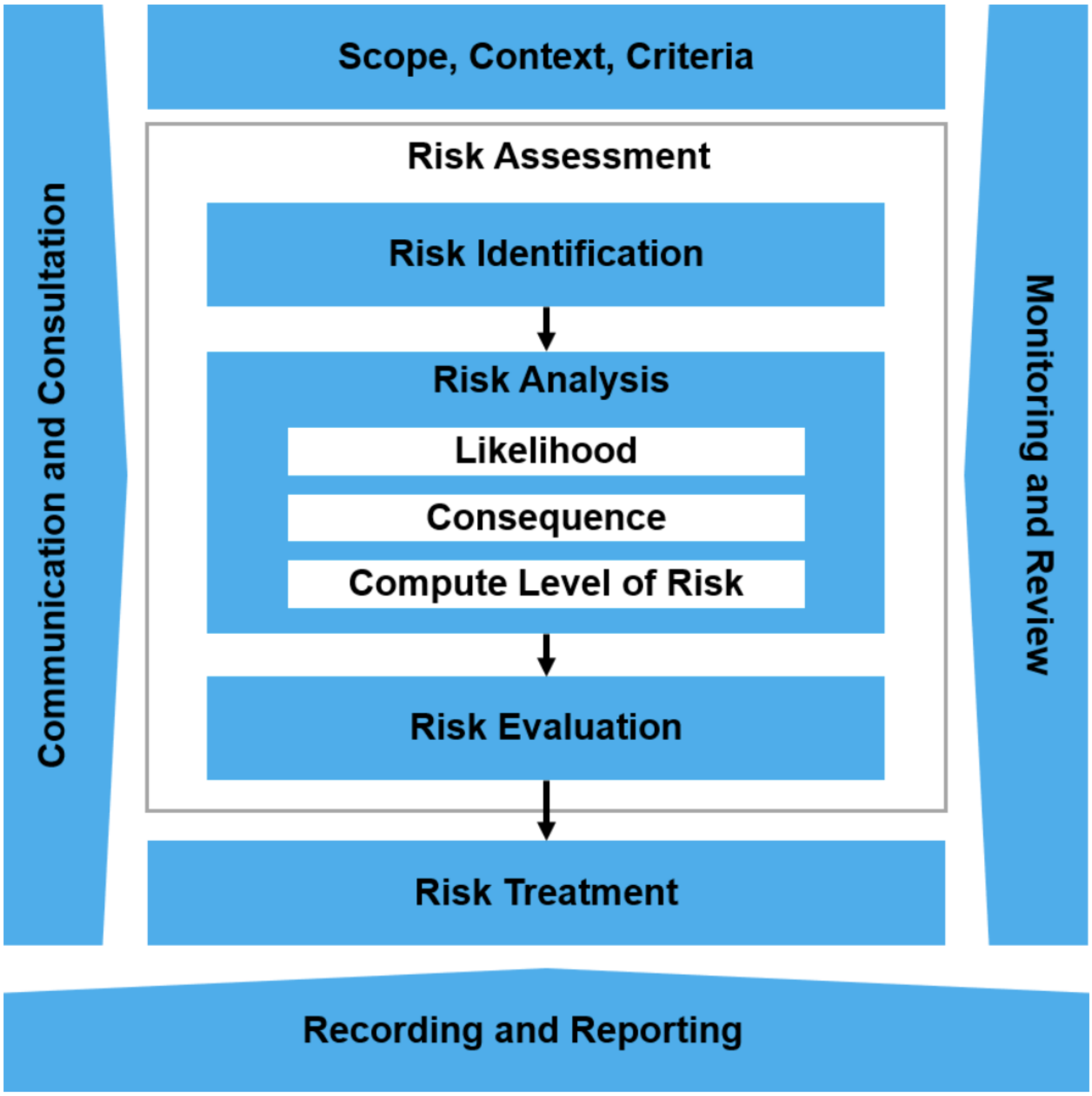

Figure 2.4.1: ISO 3100:2018 Risk management process, by ISO, 2018. Copyright 2018 by International Organization for Standardization.

The framework is operationalised through seven iterative steps (summarised by Marlin et al., 2019) including context establishment, identification, analysis, evaluation, treatment, communication, and monitoring.

ISO 31000 emphasises embedding risk management into organisational culture, focussing less on prescribing processes and more on integrating risk thinking into decision making.

1.2 Related frameworks

The NASA Systems Engineering Handbook reinforces similar principles: identifying technical risks, analysing likelihood and consequences, developing handling strategies (avoid, accept, monitor, mitigate), documenting and communicating, and integrating into engineering decisions.

- *Avoid* means redesigning systems or decisions to remove the risk entirely (e.g., eliminating hazardous materials, removing unsafe processes, or preventing exposure).
- *Accept* means recognising that some risks cannot be eliminated (at least cost-effectively) and therefore making an explicitly decision to tolerate them. This may be based on proportionality, benefit, and ethical defensibility.
- *Monitor* means monitoring risk indicators over time, using early-warning signals, inspections, and other control loops to detect emerging problems before harm occurs.
- *Mitigate* means reducing the severity of the outcome through safeguards, design, or protective measures.

Risk analysis relates closely to systems thinking, decision making and professional ethics, and includes safety, health, environmental, security, and (as we urge you to incorporate) ethical dimensions.

1.3 Safety, health, and environmental (SHE) risks

Many engineering risks are systemic, arising not from a single technical failure but from interactions between technical design, regulation, organisational practice and societal values. The Institution of Engineering and Technology (IET)'s (2012) framework for incorporating safety, health, and environmental (SHE) risk into curricula stresses that graduates must engage with SHE risks within their regulatory, ethical, and governance contexts. Embedding SHE across the curriculum rather than within specialist safety modules ensures all engineers engage with long-term environmental and health consequences of their work. Case examples which illustrate such systemic risks include Grenfell Tower (London, United Kingdom), which combined safety and environmental risks with governance breakdown, and the VW Diesel emissions scandal, which highlights the risks of regulatory evasion in engineering practice.

Security risks introduce qualitatively different challenges. Unlike safety risks, security threats arise from deliberate intent: the attacks on the Ukrainian power grid illustrate the weaponisation of risk. Cyberattacks, sabotage, insider threats, social engineering, and terrorism all expose vulnerabilities. Students must understand not only failure probabilities but also adversarial behaviours. Defences must be layered and adaptive. Exercises such as red team-blue team simulations illustrate how attackers might probe weakness across multiple layers of defence by assigning students to either attacker or defender roles.

1.4 Balancing prudence and innovation

Excessive risk avoidance can stifle innovation, while reckless risk-taking can undermine safety and public trust. Engineers must learn to balance prudence with creativity, resilience with responsibility. The challenge might be summarised as: *what do we do when we don't know what to do?* Students must be taught to become habitual in their responses to such dilemmas.

2 Conceptual foundations of risk

2.1 Traditional framing

Risk is inherent in all engineering activities. Traditionally, engineers treat risk as a subset of failure analysis, focussing on how things might break, and the consequences of these failures. Students should therefore be introduced to fault-based approaches such as fault tree analysis or Failure Mode and Effects Analysis), which are widely used in industrial contexts to identify, analyse and mitigate failure.

2.2 Where to look for risks

While traditional approaches provide structured process for analysing failure, a key limitation is that they do not explicitly guide students on where to look for risk or how to identify it in complex systems. What students identify as risk will depend on the context, their experience, and what you encourage them to notice. For this reason, students benefit from heuristic tools that help them to actively scan for potential problems and vulnerabilities with a systematic and categorised approach. Several established tools can support this type of structured analysis:

The 5M model (Ishikawa, 1968) directs attention systematically towards specific aspects of the system — man, machine, material, method, measurement, and environment — as potential risk domains. You can utilise this model to help students to examine each potential category of risk across the whole system. For example, students could consider how measurement errors in design, manufacturing, and any embedded control systems might lead to failure of the system.

Fault tree analysis means systematic mapping of causal chains from root causes to outcomes. Teaching students to construct these chains helps them to understand how risk propagates across technical and organisational systems. This approach can be combined with statistical failure analysis to estimate probability of failure through *'chain reaction'* as well as identifying the minimum cut set — the smallest combination or sequence of events which will cause failure. Students may find this approach satisfying since it incorporates probability analysis giving numerical outputs. You might utilise this method to analyse a case study which sets out a particularly unfortunate series of events.

Noise analysis, as part of parameter diagrams originating from Taguchi's robust design methodology (Taguchi, 1986), helps students to develop an understanding of noise factors — the uncontrollable external influences on system performance. Students may not naturally consider noise because it is outside of the design space, but resilient and robust systems must be able to maintain performance within a noisy operating environment. By understanding how noise influences the performance of a system, students can design robust and resilient systems which continue to work regardless of environmental effects such as temperature or moisture, degradation effects over time and misuse by operators.

The *Swiss Cheese Model* (Reason, 1990) frames complex systems as multiple layers of organisational, technical, and human defences with weaknesses in each that arise from design and human errors. Reason visualises each of these weaknesses as a hole in a specific layer; when weaknesses (holes) in multiple layers align, hazards and attacks are able to propagate through the layers of defence. This model is often taught in introductory security modules and can help students to develop holistic awareness of security risks.

When you teach risk, the tools mentioned will help students to go beyond failure analysis. They can be incorporated into exercises and workshops. Your students will learn to anticipate and prevent problems by systematically examining potential vulnerabilities and weak points as part of design and considering the likely effect and outcome. However, we must also teach students what to do in response to this risk.

While these tools support structured analysis and broaden students' ability to scan for risk across systems, they also have limitations. Many remain rooted in failure-based reasoning focussing on known pathways and defined boundaries. As a result, they may not support the identification of emergent or systemic risks. This is particularly significant where students lack the experiential knowledge of prior failures that often underpins their effective use in industry. Developing risk competence therefore requires you to cultivate the ability to anticipate uncertainty and engage with risk across technical, organisational and societal domains.

2.3 Risk, uncertainty, and deep uncertainty

A common metaphor for grappling with complexity in engineering education comes from distinctions in decision theory between perfect knowledge, risk, and uncertainty (Knight, 1921). Under conditions of *perfect knowledge* all possible outcomes and their probabilities are fully specified. Under *risk*, outcomes and probabilities are in principle knowable, even if not yet determined. Under *uncertainty,* however, some outcomes or their probabilities remain fundamentally indeterminate. Finally, *deep uncertainty* describes situations where there is no agreement on, or clear knowledge of possible outcomes themselves, the models that link them, or the probabilities that may be assigned. These epistemic decision-making contexts are summarized in Table 2.4.1.

Table 2.4.1: Epistemic decision-making contexts

Decision context	*Definition*
Perfect Knowledge	All outcomes and probabilities are fully understood and known
Risk	Recognised gaps where outcomes are known and probabilities can be estimated
Uncertainty	Emerging or unconsidered issues; outcomes known but probabilities unknown
Deep uncertainty	No agreement on possible outcomes, models or probabilities

This tripartite framing has been popularised as known knowns (established), known unknowns (not yet considered), known unknows, and unknown unknowns, as shown in Table 2.4.2. As a heuristic, it underscores the epistemic boundaries of engineering knowledge.

Table 2.4.2: Risk, uncertainty, and unknowns

Knowledge of outcome	*Knowledge of probability*	*Category*	*Example*
Known	Can be estimated	Risk	Steel bridge design, with well-established material data
Known	Unknown	Uncertainty	New material with untested fatigue properties
Unknown	Unknown	Deep uncertainty	Long-term mobility options, changes to vehicle weights or modalities of transport

Engineering education has historically focussed on *perfect knowledge*: risks with calculable probabilities and clear solutions (Martin et al, 2023). Yet practicing engineers increasingly face *unknown unknowns* (Dalal et al., 2021). This highlights the importance of preparing students not only to solve well-defined problems, but also to navigate ambiguity and unexpected situations. Therefore, you need to equip students to work confidently even when analytical methods no longer apply.

2.4 Normative uncertainty and ethical dimensions

Beyond epistemic challenges, engineering decisions are value-laden. *Normative uncertainty* arises when there is no clearly 'right' option. In that case there are multiple defensible but incompatible courses of action, or alternatively no defensible option is available (Nickel, 2020). This often occurs when disruptive innovations undermine established moral norms without clearly leading to new ones, thus leaving individuals uncertain of their obligations (Hofbauer, 2023; Taebi et al., 2020).

Understanding this landscape requires attention to four interconnected dimensions. First, *evolutionary uncertainty* addresses how societal values, technologies, and environments will change over time. Engineers designing infrastructure intended to last decades must anticipate not only technical requirements but also shifting societal priorities that may alter how their work is evaluated by the public. Second, *theoretical uncertainty* concerns which ethical frameworks should guide decisions when different frameworks point to different actions and desired outcomes; for instance, whether engineers should prioritize utilitarian calculations that maximise overall benefit or deontological principles that focus on the rights and duties of each individual. Third, *conceptual uncertainty* focuses on which values matter in context and how to operationalise them. Even when engineers agree on general principles like safety, sustainability, or equity, translating these concepts into specific design criteria implies navigating competing interpretations and priorities. Finally, *epistemic uncertainty* extends beyond technical performance to include what can be reliably predicted about impacts across sociotechnical and ecological systems whose behaviour cannot be fully anticipated.

Risk in engineering is never value-neutral. Every risk decision involves ethical judgement about whose safety matters, whose interests are prioritised and whose voices are heard. Teaching risk therefore necessarily involves teaching ethics. These four dimensions highlight that engineering decisions involve more than probabilities or likely outcomes. They are, at their core, about values, duties, and the kinds of futures we choose to create through engineering work.

3 Forms of implementation

The following examples illustrate different ways in which these concepts can be translated into teaching practice, each with specific strengths and limitations.

3.1 From technical risk to ethical risk analysis

Traditional risk analysis asks what the probability of harm is and how severe might it be. In the Integrated Engineering Programme at University College London (UCL), UK, we introduce students to ethical risk analysis (Hansson, 2018, 2022). This approach asks different questions: who bears risk, who benefits, and who decides, and are these decisions morally defensible?

The UCL framework identifies three key roles that people occupy in relation to any engineering activity. The risk-exposed are those who may potentially suffer harm, whether workers subjected to occupational hazards, communities living near industrial facilities, or future generations inheriting the environmental consequences of present decisions. Beneficiaries are those who gain from risk-taking, such as consumers enjoying products, investors earning returns, or societies accessing new capabilities. Decision makers are those whose choices determine the exposure to potential harm, including engineers designing systems, managers authorizing operations, regulators setting acceptable risk thresholds, and stakeholders who are consulted and can veto or approve projects.

Each role raises ethical challenges. If beneficiaries do not share risks, this raises questions of distributive justice. This is the case with shareholders profiting from industrial operations while workers face daily exposure to hazardous conditions. Decision makers who also benefit face conflicts of interest, as their personal or organizational stakes may bias judgement toward risk acceptance, regardless of the impacts on the risk-exposed. The presence of risk-exposed groups with no benefit and no voice illustrate the most ethically problematic scenario (Hansson, 2017; Okereke, 2018). This is a pattern disturbingly common in environmental justice contexts, where low-income communities and communities of colour bear disproportionate pollution burdens from facilities serving more affluent populations. Ethical risk analysis thus prompts one to take a stance on whether benefits to one group ever fully justify imposing risks on another, and if so, under what conditions.

In practice, students engage with this framework through structured case-based activities (for an example set in a challenge-based learning pedagogical context, see Martin et al., 2024). At UCL, they are presented with engineering scenarios and asked to identify risk-exposed groups, beneficiaries and decision makers, before analysing how risks and benefits are distributed. Students then evaluate whether these distributions are ethically justifiable using tools such as stakeholder mapping, distributional analysis and rights-based reasoning. This is typically done through facilitated discussion, group work or written reflection.

Complementary analytical tools extend this analysis beyond stakeholder identification. Stakeholder mapping visualizes relationships among actors positioned differently and power asymmetries that may distort decision making. Distributional analysis examines whether risk-benefit arrangements are fair given pre-existing inequalities, recognizing that formally equal treatment may be substantively unjust when applied to unequally situated groups. Rights analysis asks whether risk impositions violate fundamental entitlements, beginning from the premise that each person possesses a defensible right not to have risks imposed by others. Power analysis investigates whether decision-making structures give meaningful voice to the most affected and vulnerable populations or instead concentrate authority among those insulated from consequences of their choices. Together, these frameworks extend risk analysis from a technical calculation to a moral practice of balancing fairness, responsibility, and precaution (Martin, 2026).

The approach implemented in the Integrated Engineering Programme offered by UCL enables teachers to move beyond technical risk calculations by making the distribution of risks and benefits explicit and open to judgement. It is particularly effective in helping students to recognise the impact of stakeholder conflict and justice, which are not accounted for within the traditional risk process. A potential limitation is that students may initially struggle with the lack of a clear correct answer, which requires careful facilitation and support to ensure discussions are structured and reasoned rather than grounded in opinion. This approach is best suited to learning environments where ambiguity and competing priorities can be explored under supervision and in depth.

3.2 Curriculum integration

You can embed risk education across your programme using a developmental approach. Technical risk analysis can be introduced into first-year design projects, with complexity, conflicting perspectives, and ethical reflections progressively built in through upper-level modules. SHE and security considerations can be tied into capstone projects linking compliance with broader questions of accountability to the public and professional judgement.

Example 1. King's College London

King's College London scaffolds student development by embedding risk analysis throughout undergraduate study. It utilises a project-based learning framework to introduce, deepen, and synthesise risk competencies year by year. Students encounter evolving tools matched to their stage of development and to the increasing complexity of projects. In parallel, they are introduced to the risks of engineering practice itself, such as health and safety in laboratories, project management, and research ethics, so that students experience both the technical and organisational dimensions of risk.

In the foundational stage, students are introduced to risk through user-centred design focusing on satisfaction risks. They explore how poor alignment with user needs can create dissatisfaction and failure to adopt. Tools such as the Kano model (Kano, 1984) are used to analyse potential causes of user dissatisfaction, allowing students to distinguish between basic expectations which must be met, performance factors where satisfaction is linearly related to success, and excitement features which are worth the risk because of their reward. At this stage, framing risk in human-centred terms helps students to appreciate that engineering risk is not limited to physical hazards but also includes user and stakeholder trust. At the same time, students complete health and safety inductions for laboratories and makerspaces, and complete simple project risk charters to manage work.

Students then progress onto integration risks, particularly the challenge of hardware-software interactions. Here, model-based systems engineering is introduced to provide a structured framework for managing complexity. By modelling subsystems and their interactions, with a deep focus on simulation, students learn to anticipate and test for integration problems early. In parallel, students appreciate the risks posed by team dynamics and decision-making structures in negotiating design decisions without complete data.

In the intermediate stage (Year 2), students apply more formal failure analysis, sustainability, and commercial risk approaches. They employ tools such as finite-element analysis to evaluate designs as well as utilising forward failure mode and effects analysis to anticipate and prioritise technical failures. At the end of Year 2, students utilise lifecycle analysis to consider environmental risks as well as mapping potential positive and negative outcomes against the UN Sustainable Development

Goals (SDGs). Commercial exposure introduces business and financial risks; here, students use business risk frameworks to explore issues such as market volatility, supply chains, and intellectual property.

Throughout the advanced stage (Year 3), students undertake an individual project in which they are assessed on their ability to plan for and mitigate risks, maintaining active risk registers which are updated dynamically. Professional risks — such as ethical decision making, leadership accountability and compliance with standards and regulations — are explicitly assessed through the individual dissertation. Alongside this, they can take optional modules focussing on manufacturing and deployed operational risks, incorporating learning from statistical quality control and design of experiment.

The developmental approach employed by Kings College London enables a coherent progression of risk competence scaffolding learning from creation of awareness to complex, integrated judgement across technical, organisational, and ethical domains. The strength of a continuous approach is that competence becomes a continual development process rather than an isolated topic and is embedded into other technical contexts. However, it requires strong programme-level oversight and alignment, which can be challenging to implement in some organisational structures. The model is therefore most effective when there is already a programme-level approach to curriculum design.

3.3 Scenario- and case-based learning

Case-based learning offers the opportunity for immersive decision making in which learners imagine themselves in specific scenarios and reflect on the strengths and weaknesses of their own practice (Rae, 2016).

Student perspectives on risk education reveal a persistent challenge: risk is often abstract, procedural, or boring. Students identify strongly with dramatic case studies but cannot situate themselves within those scenarios. Examples include designing resilient infrastructure under climate uncertainty, evaluating AI deployment with unknown social consequences, managing cyberattacks on energy systems, and balancing economic and environmental trade-offs in supply chains.

Here, the uncertainty matrix (Kermisch & Depaus, 2024) provides a valuable pedagogic tool. Students can classify case studies into domains of risk, uncertainty, and deep uncertainty, deciding which analytical and ethical approaches are appropriate. This reinforces the insight that not all engineering problems are reducible to probabilistic calculation.

Case-based learning enables you to situate students within realistic, high-stakes scenarios, helping them to connect the concepts to decision-making experiences. It is useful for developing judgement, reflection, and awareness of uncertainty. A limitation is that without structured guidance, students focus on narrative rather than reasoning and so tools that scaffold the process are essential. When supporting this type of learning, you must facilitate reflection and ensure students explicitly link back to the conceptual frameworks.

3.4 Ethical and security risk mapping tools

Ethical risk mapping encourages students to classify stakeholders as risk bearers, beneficiaries, or decision makers. Security risk exercises can similarly map potential adversaries, assets, and vulnerabilities, highlighting the intentionality that distinguishes security from other risks.

Building on this, students can be introduced to *normative uncertainty* (Taebi et al., 2020). Exercises can ask them to recognise value conflicts (conceptual uncertainty), debate which ethical theory to apply (theoretical uncertainty), anticipate how values may evolve over time (evolutionary uncertainty), and confront the limits of knowledge (epistemic uncertainty). Embedding these categories into mapping activities helps students see that risk is never only technical, but always entangled with values, norms, and contested futures.

These mapping approaches help your students to visualise the relationships between stakeholders, power, values, and threats — extending risk analysis into social or organisational domains. They are especially useful to help students to understand that risks are shaped not only be systems but also by human decisions and interests. However, these can become conceptually complex and overwhelming, so you should carefully consider the appropriate sequencing in teaching and introduce it progressively, perhaps within case-study contexts.

3.5 Agile and adaptive risk management

Teaching agile methods exposes students to iterative, adaptive risk handling. These complement traditional (linear) risk frameworks, preparing students for diverse industrial contexts. Examples include incremental risks associated with each sprint, red team-blue team simulations, and adaptive sustainability assessments.

Adaptive approaches can also be tied to the precautionary principle (Raffensperger & Tickner, 1999), which holds that the absence of certainty is not a justification for inaction when serious harms are plausible. Paired with participatory mapping — where students consult or simulate the perspectives of affected communities — ensures students see adaptive risk management as both technical and social practice.

Agile and adaptive approaches enable you to expose students to dynamic and evolving risk environments which replicate more realistic ways of working (especially in software or other complex systems contexts). This emphasises iteration, feedback, and adaption over static risk analysis. Students may struggle to reconcile these approaches with more traditional, linear, or waterfall (sequential and stage-gated) risk frameworks and so making the difference explicit can be helpful. Students should already be familiar with the foundational concepts, so that they can reflect on the difference between linear and agile approaches.

3.6 Behavioural marker systems (BMS)

Beyond technical definitions and use of tools, risk competence in engineering can be further defined by breaking the concept into cognitive and behavioural sub-elements. These capture not only what an engineer knows about risk, but how they act under conditions of uncertainty. One way to articulate this is through the use of behavioural marker systems (BMS) adapted from aviation and healthcare (for an overview, see Dietz 2014). These describe the observable behaviours that engineers should demonstrate in practice, and which have been linked empirically to underlying competence and skills. Such frameworks provide structured indicators of good and poor performance across domains such as risk identification, scenario building, interdependency awareness, communication, and compliance.

One such system has been developed at King’s College London, UK, as part of the General Engineering Non-Technical Skills (GENTS) Project (Jaberi et al., 2023). An extract from this, as relates to risk, is shown in Table 2.4.3. This summary table defines the sub-competencies of risk management in conceptual terms. A more detailed version with performance descriptors, verbal cues and contextual scenarios is provided as part of the full behaviour marker system (see Lucas and Ciriello (2026) for additional materials, including example videos and assessment frameworks).

Example 2. BMS at King’s College London

The BMS developed by King’s College London involved literature review, expert workshops, interviews with senior engineers, and validation with video-based scenarios. Its design principles emphasise clarity, observability, and direct links to engineering practice. You can utilise Likert scales to assess performance within project-based learning based on the example behaviours given in the BMS. By defining positive and behavioural markers associated with risk, BMS allows educators to provide structured observation and feedback to students and design role-play and simulation exercises.

The General Engineering Non-Technical Skills (GENTS-NTS) taxonomy extends this approach linking risk and security with broader non-technical competencies such as teamwork, resilience, and ethical reasoning. Within the wider category of “ethical and contextual awareness”, the following competencies and behaviours are relevant:

Understanding project context assesses students for proactively scanning regulations, technologies, organisational dynamics, and sustainability factors to frame feasible, compliant, and future-aware engineering work. Positive behavioural markers include inquiring about upcoming or potential legislation relevant to engineering work and discussing how future legislation might constrain or influence potential solutions. Negative markers include ignoring or downplaying non-technical constraints like licensing or geopolitical considerations in technical discussions and passively waiting for explicit instructions regarding sustainability.

Assessing wider societal and environmental impact assesses the systematic examination of who benefits or is harmed, dual-use risks, missing voices, and *broader consequences beyond immediate technical results. Positive behavioural markers include investigating the broader consequences of cost-driven decisions, raising questions about potential negative impacts or unintended consequences, inquiring about who benefits and who might be negatively affected by a project's social or environmental aspects, and probing designs persistently by posing challenging or devil's advocate questions to identify hidden risks or weaknesses. Negative markers include overlooking or ignoring the perspectives of certain individuals or groups, not identifying key elements or factors that are absent from a situation or discussion, and focusing only on implementation details.*

Acting reliably and responsibly assesses whether students demonstrate integrity under pressure. Positive behavioural markers include identifying short-term pressures that might conflict with long-term compliance and safety requirements, applying and, where appropriate, exceeding codes and standards, identifying potential conflicts between different obligations, reasoning transparently about risks, applying the "Swiss cheese model" to analyse how multiple small vulnerabilities can create significant failures, and speaking up to protect safety, integrity, and the public good. Negative behaviours include framing ethics as an obstacle, operating at the lowest common denominator defined by codified standards, and compromising safety or compliance due to specific pressures.

Table 2.4.3 Extract of behavioural marker system for risk competence.

Element	Good performance (summary)	Poor performance summary)
Understanding and identifying	Uses structured frameworks, remains adaptable, considers wider context, acknowledges uncertainty	Neglects emerging risks, relies on single sources, assumes risks are fixed
Building scenarios	Develops what-if cases, considers multiple approaches, seeks diverse perspectives	Avoids scenario exploration, disregards conflicting evidence
Awareness of interdependencies	Identifies small risks, applies Swiss cheese model, takes proactive action	Treats risks in isolation, overlooks systemic interactions
Evaluating and mitigating	Stays calm, prioritises severity, follows protocols, analyses holistically	Responds reactively, ignores urgency, blames single causes
Communicating	Informs relevant parties, promotes learning culture, supports trust	Withholds information, discourages reporting, undermines trust

Complying with codes	Ensures compliance, demonstrates integrity, supports no-blame culture	Disregards regulations, misrepresents compliance
Acting reliably and responsibly	Applies and exceeds standards, reasons transparently, speaks up to protect safety and public good	Frames ethics and safety as an obstacle, compromises under pressure
Responding to change	Balances stability with adaptability, maintains awareness, adapts to protocols	Resists adaptation, clings to outdated routines

Behavioural marker systems enable you to assess risk competence through observable actions rather than written outputs, making tacit aspects of professional judgement both visible and assessable. They are particularly valuable when providing structured feedback on behaviours. However, there is a need for trained assessors and calibration exercises to prevent subjectivity between markers.

Taken together, these examples demonstrate that there is no single way to teach risk effectively but rather a set of complementary strategies that can be adapted to different educational contexts. The following recommendations synthesise these into practical guidance for curriculum design and teaching delivery.

4 Recommendations for implementation and learning

Drawing on the conceptual foundations and examples of implementation, the following recommendations provide actionable guidance for embedding risk competencies and skills within engineering programmes.

Adopt a developmental approach. Build risk learning across the curriculum, increasing complexity and integration as students progress. Begin with qualitative tools, then move to system-level analysis and integrative capstone projects.

Embed uncertainty as a learning outcome. Go beyond calculable probability — teach resilience in uncertainty and deep uncertainty. Use the uncertainty matrix to distinguish between risk types, and ethical case debates to highlight value conflicts. Encourage students to be comfortable with incomplete knowledge and reflect on their responses to ambiguity.

Integrate ethics and justice into risk analysis. Risk education should include moral responsibility. Use Hansson's ethical risk analysis framework to identify risk-exposed, beneficiaries, and decision makers. Embed justice concerns in case studies and use participatory approaches to ensure those affected have a voice.

Leverage active and scenario-based learning. Use real-world cases, simulations, and role-play to connect risk concepts to practice. Encourage explicit mapping of uncertainty and reflection on decision making under ambiguity. Highlight voices of those most affected.

Use behavioural marker systems to assess non-technical skills. Observational assessment is more effective than written exams for risk judgement and communication. Behavioural marker systems provide structured feedback on observable behaviours. Use Likert scales and peer assessment in project-based learning to support metacognitive awareness and long-term skill development.

Principles for effective teaching of risk skills

When teaching risk, prioritise approaches that foster deep engagement and authentic learning. Use real cases and simulations to encourage reflection and embed risk into professional practice through activities such as lab inductions, project work, and safety walk-arounds. Integrate risk education across the curriculum, ensuring students encounter it in varied contexts and at different stages of their development. Above all, give students a voice — allow them to build and articulate their own stakeholder perspectives.

Avoid treating risk as a mere compliance exercise or relying solely on mathematical tools, as these can obscure the true nature of uncertainty. Do not separate safety from security or ethics, and refrain from assessing risk competence exclusively through written exams. Remember, genuine risk competence is behavioural and situational, best observed in practice rather than on paper.

References

Bonjean Stanton, M. C., & Roelich, K. (2021). Decision making under deep uncertainties: A review of the applicability of methods in practice. Technological Forecasting and Social Change, 171, 120939. https://doi.org/10.1016/j.techfore.2021.120939

Dalal, M., Carberry, A., & Archambault, L. (2021). Developing a ways of thinking framework for engineering education research. Studies in Engineering Education, 1(2), 108–125. https://doi.org/10.21061/see.38

Dietz, A. S., Pronovost, P. J., Benson, K. N., Mendez-Tellez, P. A., Dwyer, C., Wyskiel, R., & Rosen, M. A. (2014). A systematic review of behavioural marker systems in healthcare: what do we know about their attributes, validity and application? BMJ Quality & Safety, 23(12), 1031–1039. https://doi.org/10.1136/bmjqs-2013-002457

Engineering Council. (2018). Guidance on risk for the engineering profession. https://www.engc.org.uk/media/ye2lwps1/guidance-on-risk.pdf

Faber, M. H. (2012). Statistics and probability theory. In pursuit of engineering decision support. Springer. https://doi.org/10.1007/978-94-007-4056-3_1

Fjelland, R. (2016). When laypeople are right and experts are wrong: Lessons from Love Canal. HYLE: International Journal for Philosophy of Chemistry, 22(1), 105–125.

IET & Engineering Council. (2012). Incorporating safety, health and environmental risk issues in undergraduate engineering courses [PDF]. IET. https://www.theiet.org/media/9432/incorporating-safety-health-and-environmental-risk-issues-in-undergraduate-engineering-courses.pdf

Klimsza, L. (2021). Sven Ove Hansson: The ethics of risk. Ethical analysis in an uncertain world. Basingstoke: Palgrave Macmillan, 2013, 172 pp. [Book review]. Ecumeny and Law, 9(1), 149–150. https://doi.org/10.31261/eal.2021.09.1.08

Hansson, S. O. (2017). Technology and distributive justice. In S. O. Hansson (Ed.), The ethics of technology: Methods and approaches (pp. 51–66). Rowman & Littlefield.

Hansson, S. O. (2018), How to perform an ethical risk analysis (eRA). Risk Analysis, 38, 1820–1829. https://doi.org/10.1111/risa.12978

Hansson, S. O. (2022). Risk assessment. In B. Hale, A. Light, & A. Zimmermann (Eds.), The Routledge companion to environmental ethics (pp. 696–706). Routledge. https://doi.org/10.4324/9781315768090-68

Helmrich, A. M., & Chester, M. V. (2020). Reconciling complexity and deep uncertainty in infrastructure design for climate adaptation. Sustainable and Resilient Infrastructure, 7(2), 83–99. https://doi.org/10.1080/23789689.2019.1708179

Hofbauer, B. (2023). Normative uncertainty in solar climate engineering research governance. Ethics, Policy & Environment, 27(3), 451–470. https://doi.org/10.1080/21550085.2023.2216148

Holton, R. (2023). Artificial intelligence and the problem of radical uncertainty. In S. Lindgren (Ed.), Handbook of critical studies of artificial intelligence (pp. 56–66). Edward Elgar Publishing. https://doi.org/10.4337/9781803928562.00010

International Organization for Standardization. (2018). ISO 31000:2018 — Risk management: Guidelines. https://www.iso.org/standard/65694.html

Ishikawa, K. (1968). Guide to quality control. JUSE.

Jaberi, A., Ciriello, F., & Lucas, C. (2024). Towards skillful engineers: A competence framework for engineering education. Warwick Journal of Education — Transforming Teaching. https://doi.org/10.31273/10.31273/9781911675167/1650

Joint Institution Group on Safety Risk. (2012). Incorporating safety, health and environmental risk issues in undergraduate engineering courses. The Institution of Engineering and Technology. https://www.theiet.org/media/9432/incorporating-safety-health-and-environmental-risk-issues-in-undergraduate-engineering-courses.pdf

Kano, N., Seraku, N., Takahashi, F., & Tsuji, S. (1984). Attractive quality and must-be quality. Journal of the Japanese Society for Quality Control, 14(2), 39–48.

Kermisch, C., & Depaus, C. (2023). Accounting for future generations in energy ethics: The case for temporalized ethical matrices. Ethics, Policy & Environment, 27(1), 30–47. https://doi.org/10.1080/21550085.2023.2170156

Knight, F. H. (1921). Risk, uncertainty, and profit. Houghton Mifflin.

Kumar, M. (2022). Making decisions under uncertainty: The Prudent Judgement Approach. European Journal of International Security, 8(1), 109–129. https://doi.org/10.1017/eis.2022.17

Love, P. E. D., Matthews, J., Ika, L. A., & Fang, W. (2024). Rumsfeld's heuristic: A metaphor for understanding the knowns and unknowns of rework in construction. IEEE Engineering Management Review, 52(1), 43–59. https://doi.org/10.1109/EMR.2023.3322626

Lucas, C., & Ciriello, F. (2026). GENTS-BMS Website. https://gentsbms.notion.site/

Marling, G., Horberry, T., & Harris, J. (2019). Development and validation of plain English interpretations of the seven elements of the risk management process. Safety, 5(4), 75. https://doi.org/10.3390/safety5040075

Marchau, V. A. W. J., Walker, W. E., Bloemen, P. J. T. M., & Popper, S. W. (Eds.). (2019). Decision making under deep uncertainty: From theory to practice. Springer. https://doi.org/10.1007/978-3-030-05252-2

Martin, D. A., Bombaerts, G., & Horst, M. (2023). Pedagogical orientations and evolving responsibilities of technological universities: A literature review of the history of engineering education. Science and Engineering Ethics, 29, Article 40. https://doi.org/10.1007/s11948-023-00460-2

Martin, D. A., Clancy, R. F., Zhu, Q., & Bombaerts, G. (2023). Why do we need norm sensitive design? A WEIRD critique of value sensitive approaches to design. Global Philosophy, 33(4), Article 40. https://doi.org/10.1007/s10516-023-09689-9

Martin, D. A., Audu, S., & Mantingh, J. (2024). Case study: From plastic waste to infrastructure: Understanding circular business models in context. Engineering Professors Council. https://epc.ac.uk/toolkit/case-study-from-plastic-waste-to-infrastructure-understanding-circular-business-models-in-context/

Martin, D. A. (2026). Defining the responsibilities of engineers: A conceptual framework for engineering ethics education, policy, and practice. Engineering Studies, 1–26. https://doi.org/10.1080/19378629.2025.2609063

NASA. (2016). NASA systems engineering handbook (2nd ed.). https://www.nasa.gov/sites/default/files/atoms/files/nasa_systems_engineering_handbook_0.pdf

Nickel, P. J. (2020). Disruptive innovation and moral uncertainty. NanoEthics, 14(3), 259–269. https://doi.org/10.1007/s11569-020-00375-3

Nolt, J. (2017). Future generations in environmental ethics. In S. M. Gardiner & A. Thompson (Eds.), The Oxford handbook of environmental ethics. Oxford University Press https://doi.org/0.1093/oxfordhb/9780199941339.013.28

Okereke, C. (2018). Equity and justice in polycentric climate governance. In A. Jordan, D. Huitema, H. van Asselt, & J. Forster (Eds.), Governing climate change: Polycentricity in action? (pp. 320–337). Cambridge University Press.

Open Risk. (n.d.). Open Risk Manual. Retrieved September 1, 2025, from https://www.openriskmanagement.com/open-risk-manual/

Ottinger, G. (2013). Refining expertise: How responsible engineers subvert environmental injustice. NYU Press.

Raffensperger, C., & Tickner, J. (Eds.). (1999). Protecting public health and the environment: Implementing the precautionary principle. Island Press.

Reason, J. (1990). Human Error. Cambridge University Press.

Schlosberg, D. (2007). Defining environmental justice: Theories, movements, and nature. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199286294.001.0001

Taebi, B., Kwakkel, J. H., & Kermisch, C. (2020). Governing climate risks in the face of normative uncertainties. Wiley Interdisciplinary Reviews: Climate Change, 11(6), Article e666. https://doi.org/10.1002/wcc.666

Taguchi, G. (1986). Introduction to quality engineering: Designing quality into products and processes. Asian Productivity Organization.

Verbeek, P. P. (2006). Materializing morality: Design ethics and technological mediation. Science, Technology and Human Values, 31(3), 361–380. https://doi.org/10.1177/0162243905285847

Verbeek, P. P. (2008). Morality in design: Design ethics and the morality of technological artifacts. In P. E. Vermaas, P. Kroes, A. Light & S. A. Moore (Eds.), Philosophy and design: from engineering to architecture (pp. 91–103). Springer.

AI statement

During the preparation of this work, Claire Lucas used ChatGPT in order to help her work through reviewers' comments and make direct suggestions for improvements such as keywords to highlight, how to emphasise the first person, and where to include additional information. After using this tool, the author reviewed, edited, and made the content their own as needed. The authors take full responsibility for the content of the publication

Contributor statement

Conceptualisation	Claire Lucas, Diana Martin
Writing - original draft	Claire Lucas, Diana Martin
Writing - reviewing and editing	Claire Lucas, Diana Martin